WASHINGTON STATE DEPARTMENT OF
Natural Resources

PETER GOLDMARK
Commissioner of Public Lands

MEMORANDUM

DATE: February 3, 2016

TO: Forest Practices Board

FROM: Marc Engel
Assistant Division Manager, Policy and Services

SUBJECT: Proposal Initiation for unstable slopes

On November 10, 2015 the Board directed staff to address those items not near resolution needing either more science or rule making to be brought back to the Board at the February 2016 Board meeting as a proposal initiation with a recommendation to the Adaptive Management Program Administrator. Attached is the Proposal Initiation with staff recommendations regarding these items for your consideration. This process is outlined in Board Manual Section 22, part 3.1, *Initiation and Screening of Proposals*.

Should you have any questions in advance of the February 10th meeting I can be reached at 360.902.1390, or marc.engel@dnr.wa.gov.

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WASHINGTON STATE DEPARTMENT OF
Natural Resources

PETER GOLDMARK
Washington State Commissioner of Public Lands

MEMORANDUM

DATE: February 2, 2016

TO: Stephen Bernath, Chair,
Forest Practices Board

FROM: Marc Engel, Forest Practices Assistant Division Manager,
Policy and Services

SUBJECT: Board Motion request Proposal Initiation to address those Conservation Caucus issues not near resolution through the board manual stakeholder group and those needing either more science or rule making

Please accept this Proposal Initiation (PI) request from Department of Natural Resources (DNR) acting as board staff to initiate Adaptive Management Program review, per Board motion, of the Conservation Caucus issues raised in their November 9, 2015 letter to the Board that are not near resolution through the board manual Qualified Expert stakeholder group and those needing either more science or rule making. With Board approval the Adaptive Management Program Administrator (AMPA) is asked to review this Proposal Initiation request per direction in the Adaptive Management Program (AMP) section in the Forest Practices Board Manual. With this request, the AMPA will make recommendations for Policy's consideration on how to accomplish each task and develop recommendations addressing unstable slopes for inclusion in the Policy recommendations to be presented to the Forest Practices Board (Board).

This proposal requests the AMPA to propose for Policy approval the:

- Development track(s) and timeline(s) for completion of the review of the unstable slopes elements for review listed in #2 below;
- When developed, these products will be included in the Policy recommendations to the Board for
  - Unstable slopes rule making and associated board manual guidance, and
  - Potential identification of additional research.

The following information is presented based on the requirements for a complete request for proposal initiation beginning on page M22-7 in Board Manual Section 22.

1. The affected forest practices rule, guidance, or DNR product.
WAC 222-10-030, *"SEPA policies for potentially unstable slopes and landforms"*
WAC 222-16-010, "*General Definitions*"
WAC 222-16-050, *"*Classes of forest practices"*
WAC 222-20-010, *"Applications and notifications – Policy"*
WAC 222-12-090 (16) "*Guidelines for Evaluating Potentially Unstable Slopes and Landforms"*

Attachment B:
Potentially Unstable Slopes within Watershed Analysis Units (flow chart 1)
Potentially Unstable Slopes (flow chart 2)

2. The urgency based on scientific uncertainty and resource risk.
The Board, at their 10th November, 2015 regular meeting moved that those items within the Conservation Caucuses list of seven issues, as outlined in their 9th November letter and associated attachments to the Board, that are not near resolution through the board manual Qualified Expert group and may need either more science or rule making will be brought back to the Board at their February 2016 Board meeting as a proposal initiation for Adaptive Management Program review, **see Attachment A**. The proposal initiation with Board approval will be sent to the Adaptive Management Program Administrator to review and make recommendations to Policy for the appropriate AMP review and subsequent recommendations back to the Board.

The Conservation Caucus presented seven bullet points on page 3 of their November 9, 2015 letter to the Board outlining why they assert the guidance in Board Manual Section 16 "falls far short of what should be required for a board manual to implement the forest practices rules", see Attachment A. They based their assertions on the opinions of three professional geologists who collectively "contend the guidance in Board Manual Section 16 will not accurately identify landslides and will not require the type of geologic review necessary to protect public safety."

This proposal requests Board approval to initiate AMP review of the concerns in six of the seven items brought forward by the Conservation Caucus. The concerns raised in the first item, *Use of Heavily-Qualified, Weak Language*, are not included because they are inappropriate for an AMP review. The expressed concern in item (1) is the guidance in the November 2016 Board Manual Section 16 was weakened from the language originally provided by the expert panel in the November 2014 manual section with vague terms such as "could" instead of "should." The Board accepted the edits based on DNR staff recommendations when they approved the current version of Board Manual Section 16 at their November 2015 meeting, acknowledging the changes provided greater clarity, ensured the language did not imply a requirement where a rule requirement did not exist, and that they provided more effective transitions from one content area to another.

The elements of the proposal:
Policy requests the Adaptive Management Program Administrator (AMPA) to review this PI and make recommendations to Policy on how to conduct the review and make recommendations for each task based on the review steps for the AMPA to follow in Board manual Section 22, *Guidelines for Adaptive Management Program,* Stage 1: Initiation and Screening of Proposals (beginning on page M22-8). Following the steps in Stage 1, the AMPA will assemble and present a proposal review packet for Policy's review and approval (page M22-10). The packet shall include a summary of the proposals, recommendations of proposed tracks for adaptive management program development and proposed timelines for completion.

This proposal initiates Adaptive Management Program review in the form of six tasks containing questions for AMP review based on the concerns presented in items (2) – (7) as listed in the Conservation Caucus letter. The AMP is tasked with review and development of recommendations to bring back to the Board for consideration of potential changes to forest practices rules, board manual guidance, or DNR products.

(2) Non-glacial deep-seated landslides, concerns are contained in Attachment 4, memo authored by David Montgomery, dated November 9, 2015, to the Board outlining requested "Revisions to Guidelines for Evaluating Potentially Unstable Slopes"
Conservation Caucus concern
The Board Manual requires less geologic review and protection for deep-seated landslides on non-glacial soils.

Concerns expressed by David Montgomery
- All deep-seated landslides including "dormant" landslides and any associated groundwater for all deep-seated landslides should become rule identified landforms or be covered under the definition of Category E, thus triggering Class IV-special status (Montgomery letter, pages 3 and 5).
- Need guidance in manual for how to evaluate and assess reactivation potential for all dormant or relict deep-seated landslides and any associated groundwater as the result of forest practices (Montgomery letter, pages 3 and 5).
- The board manual should require estimating the potential increase or alteration in groundwater recharge from timber harvest and assessment of how this will potentially affect the stability of dormant landslides, especially sites that could pose a potential threat to public safety if reactivated (Montgomery letter, pages 5 and 6).

Concern expressed by Dan McShane
Part 6.2 should apply to all deep-seated landslides, not just glacial deep-seated landslides. (McShane letter, comments 2 and 6)

Where the BM16 addresses the identification and assessment of both glacial and non-glacial deep-seated landslides

- Sub-part 4.5 explains that active bedrock deep-seated landslides are an example of a category (E) landform and lists topographic, hydrologic, and vegetative indicators of potential slope instability.
- Part 5, Identifying Potential Unstable Slopes and Landforms, provides guidance on office and field assessments for all landforms, except sub-part 5.3 specifically addresses delineating groundwater recharge areas for glacial deep-seated landslides.
- As expressed in the first paragraph of Part 6, it provides guidance for analyses that qualified experts can consider for both glacial and non-glacial landslide assessments such as:
    - Landslide activity assessments;
    - Groundwater recharge assessments related to glacial and non-glacial deep-seated landslides; and
    - Runout assessments for rule-identified landforms in general.

  In the case of runout assessments, introductory language specifies that “predictive methods for calculating deep-seated landslide runout are not discussed because they are still under development by the scientific community.”

Task 1 - Board Recommendations for AMP review

The Board directs the Adaptive Management Program to develop answers to the following questions and bring recommendations back to the Board:

1. Should all deep-seated landslides be added as rule identified landforms (RIL)? To determine, the Board requests existing Technical Writing and Implementation Group (TWIG) include deep-seated landslides for inclusion in the development of a CMER study to determine if there should be additional landforms added to the list of RILs found in WAC 222-16-050(1)(d)(A) – (E), Class IV-special.
2. Is further guidance is needed for evaluating and assessing reactivation potential for all dormant or relict deep-seated landslides and any associated groundwater? If yes, should an assessment be required?
3. Do non-glacial deep- seated landslides have associated groundwater recharge areas? If yes, should an assessment for influence on the deep- seated landslide from the groundwater recharge area be required?

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(3) Deep-seated Landslide Reactivation (Reactivation), letter Attachment 4, memo authored by David Montgomery, dated November 9, 2015, to the Board outlining requested “Revisions to Guidelines for Evaluating Potentially Unstable Slopes”

Conservation Caucus concern

The Board Manual fails to adequately address the principle of landslide reactivation, that additional water generated by forest practices may have the potential to reactivate “relict distinct” or “relict indistinct” landslides that have lain dormant for decades or even centuries.

Background
The landslide activity assessment was part of the Phase I expert group's work in response to the Board's direction to review and amend guidance specific to identifying and delineating groundwater recharge areas. The Board approved Phase 1 on November 12, 2014.

Concerns expressed in the Conservation Caucus November 5, 2015 letter to the Board
In their letter Kara Whittaker and Chris Mendoza recommended: *Where the threat to public safety is moderate, high, or uncertain for a glacial deep-seated landslide of any "activity level", the landowner should quantitatively assess whether a potential increase in groundwater recharge from timber harvest will affect the stability of the landslide (Board Manual Parts 6.3-6.5). Because predictive models of deep-seated landslide runout are not yet readily available, it will also be necessary to describe qualitative methods for deep-seated landslide runout assessment in the Board Manual.*

Concern expressed by David Montgomery
The manual has inadequate consideration of the potential for forest practices to reactivate dormant landslides. It needs language to the effect that lack of evidence of active movement is not adequate evidence for dismissing the potential for reactivation. (Montgomery letter, page 3)

Where the BM16 addresses reactivation
Sub-parts 6.1 and 6.2 provide basic information to qualitatively assess landslide activity potential (from active to relict) in relation to risk to public safety and public resources. This is one of several "additional analyses" mentioned in Part 6 that qualified experts may consider when analyzing effects of forest practices in or around a deep-seated landslide and its associated groundwater recharge area.

Sub-part 6.2 lays out a decision process to assess potential reactivation as follows:

- If landslide is *relict* or *dormant/distinct* and reactivation potential is highly unlikely, additional analysis may not be needed.
- If landslide is *active/recent* or *dormant/distinct* and reactivation potential is low, a qualitative analysis of contributing factors is needed.
- If landslide is *active/recent* or *dormant/distinct* and reactivation potential is moderate or high, a qualitative assessment is needed, plus additional analyses such as assessing whether a potential increase in groundwater recharge from timber harvest will affect landslide stability.

Task 2 - Board Recommendations for AMP review
The Board directs the Adaptive Management Program to develop answers to the following questions and bring recommendations back to the Board:

1. Should a method to assess the degree of risk to public safety for glacial deep-seated landslides (low, moderate, high or uncertain) be developed? If yes, should the assessment be required in rule? Or provided as guidance in the manual?

2. Is there existing science available to assess the reactivation potential for dormant bedrock and glacial deep- seated landslides? If yes, should an assessment to determine the potential for further movement of dormant bedrock and glacial deep- seated landslides be developed and required?

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(4) (Ann) Weekes Landslide Screening Tool, title of document proposed for inclusion Complex or composite rotational deep-seated landslide assessment

Conservation Caucus concern

The Board Manual does not provide a precautionary screening technique which would enable forest stakeholders to accurately identify landslides and other potentially unstable landforms that may not appear on contemporary landslide maps.

Background

On June 10, 2015, Anne Weekes presented information to the stakeholder group on her work as an Environmental Scientist III, Landslide Hazard Mapping Project, King County Department Natural Resources that was related to applying a landslide screen for mapping complex deep-seated landslides in King County. Group members agreed that some of the material could be considered for inclusion in guidance in Board Manual 16.

The Conservation Caucus delivered draft material prepared by Ms. Weekes to be considered for inclusion by the stakeholder group via email on September 18, 2015. The late date of receipt by the group of this material entitled "Complex or composite rotational deep-seated landslides" did not allow time for the stakeholder group to fully discuss this material and therefore DNR did not include this material in the Board's draft for consideration at the November 10, 2015 meeting.

Complex or composite rotational deep-seated landslide assessment document

The concerns and recommendations in this document:

- "Further research and analysis is necessary in order to identify those characteristics of large landslides that may predispose them to failure modes that include long rapid runout. Dormant slump features that exhibit no evidence of recent or ongoing movement are assumed to be less likely to become unstable again, but given the limited historical record (e.g. 100 years or less) and problems with assuming that past climate patterns will continue into the future, predictions of dormancy are difficult to make with confidence. Furthermore, evidence of rotational deep- seated slide movement alone does not provide information on the potential for composite instabilities. It is not documented how frequently single rotational slump failures become composite slides when unconsolidated deposits are reactivated by external factors such as precipitation, snowmelt, and earthquake."

- "In Western Washington, the likelihood of composite failures in rotational deep-seated slides may increase in the future due to projections of a rise in the magnitude and duration of precipitation caused by atmospheric rivers and diminished mid-elevation

> snow falling as rain during the winter months. In addition to atmospheric precipitation and overland flow, stream capture and interrupted groundwater flowpaths may also elevate pore pressures in the unconsolidated hummocky topography characteristic of large rotational slides. For this reason we need methods that will improve our abilityto predict if the topographical signature of a rotational slide indicates a landform that is likely to fail as a composite slide, especially where multiple or secondary movements might evolve into rapid flows."

Expected results
The Complex or composite rotational deep-seated landslides document is being reviewed by the board manual Qualified Expert stakeholder group. Some of the guidance in the document needs to be vetted by the Adaptive Management Program.

Task 3 - Board Recommendations for AMP review
The Board directs the Adaptive Management Program to develop answers to the following questions and bring recommendations back to the Board:

1. What is the likelihood of an increase in the future of composite failures in rotational deep-seated slides due to projections of a rise in the magnitude and duration of precipitation caused by atmospheric rivers and diminished mid-elevation snow falling as rain during the winter months?
2. What effect would an increase in atmospheric precipitation have on overland flow, stream capture and groundwater? What would this increased water have on the unconsolidated hummocky topography characteristics of large rotational slides?
3. Should a TWIG be formed to develop a study to identify those characteristics of large landslides that may predispose them to failure modes that include long rapid runout? And to develop methods to improve the ability to predict if the topographical signature of a rotational slide indicates a landform that is likely to fail as a composite slide?
4. Is there a need for a precautionary screening technique to identify landslides and other potentially unstable landforms that may not appear on contemporary landslide maps?

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(5) Coarse Screen, title of document proposed for inclusion Shallow-rapid landslide coarse screen

Conservation Caucus concerns
The Board Manual does not include a screening analysis (the "Coarse Screen" developed by Paul Kennard) that would enable foresters and geologists to more accurately measure and evaluate potentially dangerous shallow-rapid landslides that may be destabilized by forest practices.

Background
March 18, 2015 marked the first group brainstorming session for developing guidance on how to identify slopes susceptible to shallow-rapid land sliding and estimate runout distances. In this and several subsequent meetings (April 1, April 15, August 19, and October 2) the group discussed the possibility of providing a simple "coarse" screening tool to help a general practitioner determine if there may be a landslide hazard, based on slope characteristics, in the area of a forest

practices proposal and make a rough calculation of whether a slope could initiate a landslide that could deliver to a public resource or threaten public safety. If so, the practitioner would be guided to seek a qualified expert's thorough analysis.

The group discussed that the Tolt Watershed Analysis provided such a tool for the Tolt River Basin (in the western slopes of the mid-Cascade Range), complete with a flow chart and accompanying text. Several hours-long discussions were devoted to how this type of screen could be fashioned appropriately for statewide guidance, and considered how to draw from other methods (i.e., methods from the Oregon Department of Forestry [ODF] and the University of British Columbia [UBCDFLOW]) to make it useful for a variety of geographic areas.

This was an attractive concept to DNR and the stakeholder group members, given that graphic flow charts can be a helpful in clarifying a technical document, especially if they are easy to follow and accompanied by a simply-stated description. The group worked diligently to create a product for statewide use that would not be perceived as a prescription for all sites. Ultimately, however, group members did not reach agreement on the specific runout distances to use, and how it could be structured for maximum readability.

What the Board manual contains

The new sub-part 6.6, as approved by the Board on November 10, 2015, contains general information about the influences of runout distances (slope gradients, confinement, volume, roughness, etc.) and lists a variety of scientifically-derived methods for analysts to consider when assessing a site. The Tolt, ODF, and UBC methods are 3 of the 11 methods included. **The appropriate method is left to the analyst who can best match it with the site under consideration.**

DNR reservations for including a coarse screen flow chart

The intent of developing a standardized coarse screening tool was to include a consistent system to help a general practitioner determine whether a qualified expert should investigate a site. The model under consideration is the screen in the Tolt Watershed Analysis which is specific to the soil types and precipitation regimes in the western slopes of the mid-Cascade Range.

Because the flow chart would contain specific parameters, DNR believes this screening method requires AMP review to assure it could be used for statewide application and questions:

- What runout distances should be used in the flow chart? (The higher the number, the more likely the general practitioner will tend to have a qualified expert analysis.)
- Could the coarse screen be perceived as prescriptive?
- If yes, could it potentially result in over- or underestimations resulting in inappropriately over- or underutilizing expert analysis?

Also, DNR is not convinced the flow chart is necessary and may confuse practitioners rather than help. The forest practices rules protect public resources via the riparian buffer rules upslope of public safety hazards. The rules also hold that if a landslide or resulting debris flow has the potential to reach a public resource (i.e., stream), then the proposed forest practices activities in and around must be evaluated by a QE and either becomes a Class III if the landowner submits an FPA with a completed potentially unstable slopes form and a QE report or a Class IV-Special and requiring full QE assessment and geotechnical report regardless of downstream resources/public safety.

Concerns expressed by Paul Kennard (See Declaration of Paul Kennard, pages 5-11)
This is one of the tools (along with the Landslide Decision Pathway) that is "essential to carrying out the requirements of WAC 222-16-050(1)(d), and omitting (them) makes the Board Manual an incomplete technical advisory supplement to the steep and unstable slopes forest practices rules." (Paul Kennard Declaration, page 3)

"Such a tool is highly necessary because it provides a consistent means by which individuals with a wide range of experience and education can accurately assess runout risk." (Paul Kennard Declaration, page 6)

Note: Compare the above statement with D. Montgomery's concern that the manual, "…assigns geologic screening and assessment tasks to personnel who may not have requisite training to practices geology in the State of Washington." (Montgomery letter, pages 1 and 7-9)

Existing Forest Practices rules regulating forest practices activities in and around potentially unstable slopes
The forest practices rules outline how FPAs with potentially unstable slopes "in and around" the proposed forest practices activities are to be classed, what geologic information is required with these applications, and the extent to which a qualified expert's analysis must address the impacts to and mitigation measures to avoid influence from forest practices activities on potentially unstable slopes (complete rules are listed in issue 7 below):

- WAC 222-16-050
    - Necessitates requirement for additional information or a detailed environmental statement before approval of forest practices involving timber harvest, or construction of roads, landings, gravel pits, rock quarries, or spoil disposal areas, on potentially unstable slopes or landforms that have the potential to deliver sediment or debris to a public resource or that has the potential to threaten public safety, and which has been field verified by DNR.
    - Establishes rule identified potentially unstable slopes or landforms as:
        - (A) Inner gorges, convergent headwalls, or bedrock hollows with slopes steeper than thirty-five degrees (seventy percent);
        - (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;
        - (D) Outer edges of meander bends along valley walls or high terraces of an unconfined meandering stream; or

    - (E) Any areas containing features indicating the presence of potential slope instability which cumulatively indicate the presence of unstable slopes.
  - The department will base its classification of the application or notification on professional knowledge of the area, information such as soils, geologic or hazard zonation maps and reports, review of approved watershed analysis mass wasting prescriptions, or other information provided by the applicant.
- WAC 222-20-010 **Where potentially unstable slopes or landforms are in or around the area of an application,**
  - DNR may require the landowner to provide additional information in order to classify the application appropriately;
  - DNR may require additional geologic information prepared by a qualified expert;
  - DNR may request that the qualified expert explain the methods the qualified expert used to evaluate the proposed harvest or construction activities with respect to the potentially unstable slopes or landforms.
- WAC 222-08-030 *SEPA policies for potentially unstable slopes and landforms.
  - FPAs with road construction activities or timber harvest on potentially unstable slopes or landforms must include the following additional information, prepared by a qualified expert:
    - A description of potentially unstable landforms in and around the application site and an analysis of
    - The likelihood that the proposed forest practices will cause movement on the potentially unstable slopes or landforms, or contribute to further movement of a potentially unstable slope or landform;
    - The likelihood of delivery of sediment or debris to any public resources, or in a manner that would threaten public safety; and
    - Any possible mitigation for the identified hazards and risks.
  - DNR must evaluate of whether the proposed forest practices activities
    - Are likely to increase the probability of a mass movement on or near the site;
    - Would deliver sediment or debris to a public resource or would deliver sediment or debris in a manner that would threaten public safety; and
    - If such movement and delivery are likely to cause significant adverse impacts.
  - DNR will evaluate the proposal, using appropriate expertise and in consultation with other affected agencies and Indian tribes.
  - Specific mitigation measures or conditions must be designed to avoid accelerating rates and magnitudes of mass wasting that could deliver sediment or debris to a public resource or could deliver sediment or debris in a manner that would threaten public safety.

Task 4 - Board Recommendations for AMP review

The Board directs the Adaptive Management Program to develop answers to the following questions and bring recommendations back to the Board:

1. Is there a need to include a shallow- rapid landslide coarse screen for general practitioners or Qualified Experts?
2. If yes, how prescriptive is the proposed shallow- rapid coarse screen based on the Tolt Watershed? Is it appropriate for guidance? For rule?
3. Should a TWIG be formed to develop a study to determine what runout distances should be used in a shallow- rapid landslide coarse screen flow chart designed for application in all geographic and geomorphic areas to be used statewide?
4. If a shallow- rapid landslide coarse screen is developed, should the Board consider establishing an acceptable level of risk? If yes, could it potentially result in over- or underestimations resulting in inappropriately over- or underutilizing expert analysis? On the latter point, Paul Kennard has scoped a possible study design, a “runout-risk evaluation tool” that may be suitable for Adaptive Management Program study. See Paul Kennard Declaration, pages 9-11.

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(6) Run-Out Path Analysis, title of document proposed for inclusion Methods for Deep-seated Landslide Runout Assessment

Conservation Caucus concerns

The Board Manual does not include a runout assessment method specifically for deep-seated landslides.

Concerns expressed in the proposed Methods for Deep-seated Landslide Runout Assessment

The document recommends:

- “To better understand the potential for future failure and rapid movement, analyses of past landslide mechanics, stratigraphy, and chronology, and forecasts of climate change and river channel migration may be essential”; and
- “Where public safety may be impacted, it is most appropriate to apply a precautionary principle, and a more conservative (further) runout distance should be assumed.”

Concerns expressed by David Montgomery

“While physically-based predictive models for runout of deep-seated landslides are still under development, qualitative and empirical methods are available for estimating deep-seated landslide runout, yet these are not mentioned in the proposed Board Manual. Field practitioners should at least be directed to examine the extent of past landslide deposits in comparable geologic materials in the vicinity as an indicator of potential future runout distances.” (Montgomery letter, page 7)

Background

Throughout the discussions the Qualified Expert board manual group recognized that there are no scientifically-derived predictive methods for deep- seated landslide runout (timing, triggering factors, distance). Therefore, with lack of such methods, the Board Manual did not provide one.

Conservation Caucus member Kara Whittaker presented a draft deep-seated landslide runout assessment tool in August and early September 2015. Some discussion was devoted to this product at the August 19 and September 2 meetings, but no specific group editing or agreement took place in those meetings. The latest version the group saw (Sept. 9, 2015 version) included a "D-Claw" numeric model for deep-seated landslide runout. The group did not have enough time to discuss its content or the appropriateness of including it in the manual by the final (Oct. 2) group meeting.

What the Board Manual contains

The manual covers identifying past deep-seated landslide features, including historic deposits using LiDAR and other screening tools (Parts 2.3, 4.5, 5 and 5.1.4). This provides a general practitioner with the information needed to determine whether a qualified expert's investigation is needed. The qualified expert determines risk on a site-by-site basis and is required to assess the likelihood of future movement in the analysis.

Task 5 - Board Recommendations for AMP review

The Adaptive Management Program must develop answers to the following questions and bring recommendations back to the Board:

1. Do scientifically-derived methods exist for predicting the potential for deep-seated landslide failure?
    a. If yes, is it appropriate to incorporate additional guidance in the manual? What guidance and for whom – the general practitioner, the qualified expert, or both?
    b. If no, is it appropriate to incorporate any additional guidance in the manual? What guidance and for whom; the general practitioner, the qualified expert, or both?
2. Given the level of review and the required analyses and protection criteria listed in the rules, where public safety may be impacted is there a need to develop an additional precautionary runout principle, including a more conservative (further) runout distance, for deep-seated landslides?

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(7) Landslide Risk Flow Chart, title of document proposed for inclusion Landslide Risk Decision Pathway

Conservation Caucus concern

The Board Manual does not provide guidance on a repeatable, defensible decision making process for landslide assessment and FPA review.

Background

In comments to the Forest Practices Board on November 12, 2014 regarding Board Manual 16, Chris Mendoza suggested that a risk matrix "…be developed to ensure the best available science is used in assessing the potential risk of unstable landforms to public resources and public safety." (Forest Practices Board November 12, 2014 meeting minutes)

During the board manual Phase 2 work, in June, July, and August 2015, the Conservation Caucus drafted several versions of this product for the stakeholder group to review and discuss. The Conservation Caucus believed it could be used for field practitioners, qualified experts, and DNR to determine the appropriate methods for assessing the presence of rule-identified landforms, and regulatory requirements for forest practices proposed on or near potentially unstable slopes or landforms. It contains a description, flow chart, methodologies and their limitations, and how levels of certainty impact FPA classifications. At the September 2, 2015 group meeting, DNR suggested the Conservation and Landowner caucuses work together to amend the risk matrix and provide the stakeholder group their draft. Consensus could not be reached.

Concerns expressed in the proposed Landslide Risk Decision Pathway

The document expressed concerns and recommends:

- Development of the decision pathway to provide a framework to help field practitioners, QE and DNR determine the appropriate methods for assessing the presence of RILs.
- "Is it appropriate to apply the precautionary principle to landslide hazard assessment because in the face of scientific uncertainty, land management decisions that err on the side of caution will best protect the environment and public well- being." "The overarching purpose of the decision pathway is to enable more effective and precautionary risk management."
- "Because scientific certainty is not defined by rule, DNR is ultimately responsible for determining whether or not the information submitted with a FPA provides sufficient certainty that a RIL is either present or absent."
- "Delivery/threat assessment may be limited to coarse methods if they result in high certainty, otherwise more technical methods should also be utilized. If delivery/threat is unlikely (low likelihood with high certainty), then the feature is not considered a RIL and the FPA may be classified as a Class III. If there is high or moderate delivery/threat potential or uncertainty is high or moderate, then the feature is treated as a RIL."
- "If forest practices are avoided or adequate mitigation measures are applied such that movement due to forest practices is unlikely then the FPA may be classified as a Class III."

Concerns expressed by David Montgomery

The board manual assigns geologic screening and assessment tasks to personnel who may not have requisite training to practice geology in the State of Washington (Montgomery letter, page 1).

Concerns expressed by P. Kennard

There is no repeatable, defensible decision making process consistent with a precautionary approach to the landslide assessment.

- Objective and repeatable decision-making tools are essential to consistent and accurate application of forest practices rules.
- Frequently, decisions are justified solely as "professional judgment" without additional justification.

(Paul Kennard Declaration, (pages 4 and 5)

DNR's opinion
Even though the Conservation Caucus brought forward revisions, this product never arrived at something appropriate for guidance. DNR and other group members felt it was too prescriptive and rule-like, i.e., what are the levels of certainty and where would the cut-off point be between Class III and Class IV-special applications?

The qualified expert determines risk on a site-by-site basis. The forest practices rules call for an analysis by a qualified expert where a forest practice on a potentially rule-identified landform has the potential to deliver to a public resource or threaten public safety. The qualified expert determines the likelihood of delivery (WAC 222-10-030). It is at the discretion of the qualified expert to determine the appropriate methods of investigation and the potential for delivery.

Also, DNR is not convinced Landslide Assessment Decision Pathway is necessary and may confuse practitioners rather than help. The forest practices rules definition of a Rule Identified Landform does not depend on a certainty rating based on the likelihood that the failure of an unstable landform would threaten public safety. The rules in WAC 222-16-050(1)(d)(i)(A) – (E) define Rule Identified Landforms with certainty, they do not make certain features a RIL under some circumstances and not a RIL under other circumstances. The rules require, with no uncertainty, that when road construction activities or timber harvest are proposed on any of the RILs then a QE assessment and geotechnical report is required. Each landform is unique and the methods used for the analysis and the assessment conclusion is left to the qualified expert. DNR's decision is based on the qualified expert's conclusion and case-by-case evaluation of submitted materials and therefore cannot be a 'repeatable' process. A decision pathway, if not consistent with current rule, may provide faulty assurances to field practitioners and misrepresents the scrutiny required for qualified expert's assessment.

The forest practices rules outline the decision pathway for FPAs with potentially unstable slopes "in and around" the proposed forest practices activities to determine the classification of the application, what geologic information is required with these applications, and the extent to which a qualified expert's analysis must address the impacts to and mitigation measures to avoid influence from forest practices activities on potentially unstable slopes, the complete unstable slopes rules are listed below:

Existing Forest Practices rules regulating forest practices activities in and around potentially unstable slopes
WAC 222-16-050 (1)"Class IV-special." Except as provided in WAC 222-16-051, application to conduct forest practices involving the following circumstances requires an environmental checklist in compliance with the State Environmental Policy Act (SEPA), and SEPA guidelines, as they have been determined to have potential for a substantial impact on the environment. It may be determined that additional information or a detailed environmental statement is required before these forest practices may be approved.

*(d) Timber harvest, or construction of roads, landings, gravel pits, rock quarries, or spoil disposal areas, on potentially unstable slopes or landforms described in (d)(i) of this subsection that has the potential to deliver sediment or debris to a public resource or that has the potential to

threaten public safety, and which has been field verified by the department (see WAC 222-10-030 SEPA policies for potentially unstable slopes and landforms).

(i) For the purpose of this rule, potentially unstable slopes or landforms are one of the following: (See board manual section 16 for more descriptive definitions.)

(A) Inner gorges, convergent headwalls, or bedrock hollows with slopes steeper than thirty-five degrees (seventy percent);

(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;

(D) Outer edges of meander bends along valley walls or high terraces of an unconfined meandering stream; or

(E) Any areas containing features indicating the presence of potential slope instability which cumulatively indicate the presence of unstable slopes.

(ii) The department will base its classification of the application or notification on professional knowledge of the area, information such as soils, geologic or hazard zonation maps and reports, review of approved watershed analysis mass wasting prescriptions according to WAC 222-22-090(6) or other information provided by the applicant.

WAC 222-20-010 (9) **Where potentially unstable slopes or landforms are in or around the area of an application,** the department may require the landowner to provide additional information in order to classify the application appropriately. If necessary, the department may require additional geologic information prepared by a qualified expert. The department may request that the qualified expert explain the methods the qualified expert used to evaluate the proposed harvest or construction activities with respect to the potentially unstable slopes or landforms. Nothing in this subsection is intended to require a geotechnical report if the geologic information provided is sufficient to appropriately classify the application.

WAC 222-08-030 *SEPA policies for potentially unstable slopes and landforms.
In addition to SEPA policies established elsewhere in this chapter, the following policies apply to forest practices described in WAC 222-16-050 (1)(d) relating to construction or harvest on potentially unstable slopes or landforms.

(1) In order to determine whether such forest practices are likely to have a probable significant adverse impact, and therefore require an environmental impact statement, the applicant must submit the following additional information, prepared by a qualified expert as defined in subsection (5) of this section. The qualified expert must describe the potentially unstable landforms in and around the application site and analyze:

(a) The likelihood that the proposed forest practices will cause movement on the potentially unstable slopes or landforms, or contribute to further movement of a potentially unstable slope or landform;

(b) The likelihood of delivery of sediment or debris to any public resources, or in a manner that would threaten public safety; and

(c) Any possible mitigation for the identified hazards and risks.

(2) The department's threshold determination will include an evaluation of whether the proposed forest practices:

(a) Are likely to increase the probability of a mass movement on or near the site;
(b) Would deliver sediment or debris to a public resource or would deliver sediment or debris in a manner that would threaten public safety; and
(c) Such movement and delivery are likely to cause significant adverse impacts.
If the department determines that (a), (b) and (c) of this subsection are likely to occur, then the forest practice is likely to have a probable significant adverse impact.

(3) The department will evaluate the proposal, using appropriate expertise and in consultation with other affected agencies and Indian tribes.

(4) Specific mitigation measures or conditions must be designed to avoid accelerating rates and magnitudes of mass wasting that could deliver sediment or debris to a public resource or could deliver sediment or debris in a manner that would threaten public safety.

(5) Qualified expert for the purposes of this section, reanalysis of watershed analysis mass wasting prescriptions under WAC 222-22-030, and preparation of required geologic information under WAC 222-20-010(9), means a person licensed under chapter 18.220 RCW as either an engineering geologist or as a hydrogeologist (if the site warrants hydrologist expertise), with at least three years of field experience in the evaluation of relevant problems in forested lands.
(a) "Qualified expert" is defined in WAC 222-10-030.
(b) "Potentially unstable slopes or landforms" are those listed in WAC 222-16-050 (1)(d)(i)(A) through (E).

Task 6 - Board Recommendations for AMP review
The Adaptive Management Program must develop answers to the following questions and bring recommendations back to the Board:

1. Do the existing forest practices rules, forest practices application review process flow charts (Attachment B), and Board Manual Section 16 provide a landslide hazard risk decision pathway? Based on the previous review, is there a need for a landslide hazard risk decision pathway? If the decision is to develop a landslide hazard risk decision pathway should a precautionary risk management principle be added to the decision pathway?
2. Should the definition of Rule Identified Landforms be amended to include a certainty rating based on the likelihood that a failure of the feature would threaten public safety? Or a certainty rating based on threats to public resources or public safety? If yes, how would the threat potential and the levels of certainty be defined?

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3. *Any outstanding TFW, FFR, or Policy agreements supporting the proposal.*

Forests & Fish Report and Statute
The Washington State Legislature found that the 1999 Salmon Recovery Act and the resulting Forests and Fish Rules "…taken as a whole, constitute a comprehensive and coordinated program to provide substantial and sufficient contributions to salmon recovery and water quality enhancement in areas impacted by forest practices…" (RCW 77.85.180(2)). It also recognized that federal and state agencies, tribes, county representatives, and private timberland owners have spent considerable effort and time to develop the Forests and Fish Report (RCW 76.09.055), and authorized the development of forest practices rules based on the analyses and conclusions of the Forests and Fish Report. The rules include the development of an adaptive management program

to: . . . *make adjustments as quickly as possible to forest practices that are not achieving the resources objectives . . . (and) shall incorporate the best available science and information, include protocols and standards, regular monitoring, a scientific and peer review process, and provide recommendations to the board on proposed changes to forest practices rules to meet timber industry viability and salmon recovery. (RCW 76.09.370(7)).*

The Forests and Fish Report called for a forest practices Adaptive Management Program in Appendix L. The AMP is designed to meet the goals and objectives for water quality and fish habitat within the jurisdiction of the Forest Practices Program.

Board Manual Section 22, *Guidelines for Adaptive Management Program*
This manual fulfills the objectives outlined in Appendix L of the Forests and Fish Report. It provides a technical advisory supplement to the Forest Practices act and rules and provides guidance to the AMP. The process to request an AMP review and subsequent preparation of recommendations to present to the Board for potential rules changes is found in Part 3.1 Stage 1: Initiation and Screening of Proposals.

4. *How the results of the proposal could address Adaptive Management Program key questions and resource objectives or other rule, guidance, or DNR product.*

This proposal follows the Adaptive Management Program goals expressed in FFR Appendix L, *Adaptive Management*, and embraces the Policy and science based process to develop recommendations for rule change to present to the Board. FFR called for the establishment of:

- A science-based adaptive management program to monitor the relationships and evaluate the effectiveness of rules and guidance toward achieving the target forest conditions and processes;
- Forest Practices Board adopted rules and guidance designating the required elements of an adaptive management process;
- Forest Practices Board set priorities for action as guided by information developed through the adaptive management process; and
- TFW (Policy) recommendations to the (Board) are to be accompanied by formal petitions for rulemaking and guidance.

5. Available literature, data and other information supporting the proposal.

The Board adopted forest practices rules protecting aquatic resources consistent with the recommendations contained in the forests and fish report. The following information lists the intent and direction from the Legislature to the Forest Practices Board through the Forest Practices Act (Chapter 76.09 RCW).

Forest Practices Act, Chapter 76.09 RCW

RCW 76.09.010 Legislative Finding and Declaration

(1) The legislature hereby finds and declares that the forest land resources are among the most valuable of all resources in the state; that a viable forest products industry is of prime importance to the state's economy; that it is in the public interest for public and private commercial forest lands to be managed consistent with sound policies of natural resource protection; that coincident with maintenance of a viable forest products industry, it is important to afford protection to forest soils, fisheries, wildlife, water quantity and quality, air quality, recreation, and scenic beauty.
(2) The legislature further finds and declares it to be in the public interest of this state to create and maintain through the adoption of this chapter a comprehensive statewide system of laws and forest practices rules which will achieve the following purposes and policies:
(a) Afford protection to, promote, foster and encourage timber growth, and require such minimum reforestation of commercial tree species on forest lands as will reasonably utilize the timber growing capacity of the soil following current timber harvest;
(b) Afford protection to forest soils and public resources by utilizing all reasonable methods of technology in conducting forest practices;
(c) Recognize both the public and private interest in the profitable growing and harvesting of timber;
(d) Promote efficiency by permitting maximum operating freedom consistent with the other purposes and policies stated herein;
(e) Provide for regulation of forest practices so as to avoid unnecessary duplication in such rules;
(f) Provide for interagency input and intergovernmental and tribal coordination and cooperation;
(g) Achieve compliance with all applicable requirements of federal and state law with respect to nonpoint sources of water pollution from forest practices;
(h) To consider reasonable land use planning goals and concepts contained in local comprehensive plans and zoning regulations;
(i) Foster cooperation among managers of public resources, forest landowners, Indian tribes and the citizens of the state;
(j) Develop a watershed analysis system that addresses the cumulative effect of forest practices on, at a minimum, the public resources of fish, water, and public capital improvements of the state and its political subdivisions; and
(k) Assist forest landowners in accessing market capital and financing for the ecosystem services provided to the public as a result of the protection of public resources.
(3) The legislature further finds and declares that it is also in the public interest of the state to encourage forest landowners to undertake corrective and remedial action to reduce the impact of mass earth movements and fluvial processes.
(4) The legislature further finds and declares that it is in the public interest that the applicants for state forest practices permits should assist in paying for the cost of review and permitting necessary for the environmental protection of these resources.

RCW 76.09.370 Findings – Forests and Fish Report

(1) The legislature finds that the process that produced the forests and fish report was instigated by the forest practices board, the report is the product of considerable negotiations between several diverse interest groups, and the report has the support of key federal agencies. When adopting permanent rules under this section, the forest practices board is strongly encouraged to follow the recommendations of the forests and fish report, but may include other alternatives for protection of aquatic resources. If the forest practices board chooses to adopt rules under this section that are not consistent with the recommendations contained in the forests and fish report, the board must notify the appropriate legislative committees of the proposed deviations, the reasons for the proposed deviations, and whether the parties to the forests and fish report still support the agreement. The board shall defer final adoption of such rules for sixty days of the legislative session to allow for the opportunity for additional public involvement and legislative oversight.

(2) The forest practices board shall follow the regular rules adoption process contained in the administrative procedure act, chapter 34.05 RCW, when adopting permanent rules pertaining to forest practices and the protection of aquatic resources except as limited by subsection (1) of this section. The permanent rules must accomplish the policies stated in RCW 76.09.010 without jeopardizing the economic viability of the forest products industry.

(3) The rules adopted under this section should be as specific as reasonably possible while also allowing an applicant to propose alternate plans in response to site-specific physical features. Alternate plans should provide protection to public resources at least equal in overall effectiveness by alternate means.

(4) Rule making under subsection (2) of this section shall be completed by June 30, 2001.

(5) The board should consider coordinating any environmental review process under chapter 43.21C RCW relating to the adoption of rules under subsection (2) of this section with any review of a related proposal under the national environmental policy act (42 U.S.C. Sec. 4321, et seq.).

(6) After the board has adopted permanent rules under subsection (2) of this section, changes to those rules and any new rules covering aquatic resources may be adopted by the board but only if the changes or new rules are consistent with recommendations resulting from the scientifically based adaptive management process established by a rule of the board. Any new rules or changes under this subsection need not be based upon the recommendations of the adaptive management process if: (a) The board is required to adopt or modify rules by the final order of any court having jurisdiction thereof; or (b) future state legislation directs the board to adopt or modify the rules.

(7) In adopting permanent rules, the board shall incorporate the scientific-based adaptive management process described in the forests and fish report which will be used to determine the effectiveness of the new forest practices rules in aiding the state's salmon recovery effort. The purpose of an adaptive management process is to make adjustments as quickly as possible to forest practices that are not achieving the resource objectives. The adaptive management process shall incorporate the best available science and information, include protocols and standards, regular monitoring, a scientific and peer review process, and provide recommendations to the board on proposed changes to forest practices rules to meet timber industry viability and salmon recovery.

WAC 222-10-030 *SEPA policies for potentially unstable slopes and landforms.
In addition to SEPA policies established elsewhere in this chapter, the following policies apply to forest practices described in WAC 222-16-050 (1)(d) relating to construction or harvest on potentially unstable slopes or landforms.

(1) In order to determine whether such forest practices are likely to have a probable significant adverse impact, and therefore require an environmental impact statement, the applicant must submit the following additional information, prepared by a qualified expert as defined in subsection (5) of this section. The qualified expert must describe the potentially unstable landforms in and around the application site and analyze:

(a) The likelihood that the proposed forest practices will cause movement on the potentially unstable slopes or landforms, or contribute to further movement of a potentially unstable slope or landform;

(b) The likelihood of delivery of sediment or debris to any public resources, or in a manner that would threaten public safety; and

(c) Any possible mitigation for the identified hazards and risks.

(2) The department's threshold determination will include an evaluation of whether the proposed forest practices:

(a) Are likely to increase the probability of a mass movement on or near the site;

(b) Would deliver sediment or debris to a public resource or would deliver sediment or debris in a manner that would threaten public safety; and

(c) Such movement and delivery are likely to cause significant adverse impacts.

If the department determines that (a), (b) and (c) of this subsection are likely to occur, then the forest practice is likely to have a probable significant adverse impact.

(3) The department will evaluate the proposal, using appropriate expertise and in consultation with other affected agencies and Indian tribes.

(4) Specific mitigation measures or conditions must be designed to avoid accelerating rates and magnitudes of mass wasting that could deliver sediment or debris to a public resource or could deliver sediment or debris in a manner that would threaten public safety.

(5) Qualified expert for the purposes of this section, reanalysis of watershed analysis mass wasting prescriptions under WAC 222-22-030, and preparation of required geologic information under WAC 222-20-010(9), means a person licensed under chapter 18.220 RCW as either an engineering geologist or as a hydrogeologist (if the site warrants hydrologist expertise), with at least three years of field experience in the evaluation of relevant problems in forested lands.

WAC 222-16-010 *General definitions.
Unless otherwise required by context, as used in these rules:

"Bedrock hollows" (colluvium-filled bedrock hollows, or hollows; also referred to as zero-order basins, swales, or bedrock depressions) means landforms that are commonly spoon-shaped areas of convergent topography within unchanneled valleys on hillslopes. (See board manual section 16 for identification criteria.)

"Debris" means woody vegetative residue less than 3 cubic feet in size resulting from forest practices activities which would reasonably be expected to cause significant damage to a public resource.

"Deep-seated landslides" means landslides in which most of the area of the slide plane or zone lies below the maximum rooting depth of forest trees, to depths of tens to hundreds of feet. (See board manual section 16 for identification criteria.)

"Inner gorges" means canyons created by a combination of the downcutting action of a stream and mass movement on the slope walls; they commonly show evidence of recent movement, such as obvious landslides, vertical tracks of disturbance vegetation, or areas that are concave in contour and/or profile. (See board manual section 16 for identification criteria.)

"Threaten public safety" means to increase the risk to the public at large from snow avalanches, identified in consultation with the department of transportation or a local government, or landslides or debris torrents caused or triggered by forest practices.

WAC 222-16-050 *Classes of forest practices.

There are four classes of forest practices created by the act. All forest practices (including those in Classes I and II) on nonfederal forest lands must be conducted in accordance with the forest practices rules. The department determines the classification of each forest practices proposal.

(1) **"Class IV-special."** Except as provided in WAC 222-16-051, application to conduct forest practices involving the following circumstances requires an environmental checklist in compliance with the State Environmental Policy Act (SEPA), and SEPA guidelines, as they have been determined to have potential for a substantial impact on the environment. It may be determined that additional information or a detailed environmental statement is required before these forest practices may be approved.

*(a) Aerial application of pesticides in a manner identified as having the potential for a substantial impact on the environment under WAC 222-16-070 or ground application of a pesticide within a Type A or B wetland.

(b) Specific forest practices listed in WAC 222-16-080 on lands designated as critical habitat (state) of threatened or endangered species.

(c) Harvesting, road construction, aerial application of pesticides and site preparation on all lands within the boundaries of any national park, state park, or any park of a local governmental entity, except harvest of less than five thousand board feet within any developed park recreation area and park managed salvage of merchantable forest products.

*(d) Timber harvest, or construction of roads, landings, gravel pits, rock quarries, or spoil disposal areas, on potentially unstable slopes or landforms described in (d)(i) of this subsection that has the potential to deliver sediment or debris to a public resource or that has the potential to threaten public safety, and which has been field verified by the department (see WAC 222-10-030 SEPA policies for potentially unstable slopes and landforms).

(i) For the purpose of this rule, potentially unstable slopes or landforms are one of the following: (See board manual section 16 for more descriptive definitions.)

(A) Inner gorges, convergent headwalls, or bedrock hollows with slopes steeper than thirty-five degrees (seventy percent);

(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;

(D) Outer edges of meander bends along valley walls or high terraces of an unconfined meandering stream; or

(E) Any areas containing features indicating the presence of potential slope instability which cumulatively indicate the presence of unstable slopes.

(ii) The department will base its classification of the application or notification on professional knowledge of the area, information such as soils, geologic or hazard zonation maps and reports, review of approved watershed analysis mass wasting prescriptions according to WAC 222-22-090(6) or other information provided by the applicant.

(iii) An application would not be classified as Class IV-special for potentially unstable slopes or landforms under this subsection if:

(A) The proposed forest practice is located within a watershed administrative unit (WAU) that is subject to an approved watershed analysis;

(B) The forest practices are to be conducted in accordance with approved prescriptions from the watershed analysis; and

(C) The applicable prescriptions are specific to the site or situation, as opposed to a prescription that calls for additional analysis. The need for an expert to determine whether the site contains specific landforms will not be considered "additional analysis," as long as specific prescriptions are established for such landforms.

*(e) Timber harvest, in a WAU not subject to an approved watershed analysis under chapter 222-22 WAC, construction of roads, landings, rock quarries, gravel pits, borrow pits, and spoil disposal areas on snow avalanche slopes within those areas designated by the department, in consultation with department of transportation and local government, as high avalanche hazard where there is the potential to deliver sediment or debris to a public resource, or the potential to threaten public safety.

(f) Timber harvest or construction of roads, landings, rock quarries, gravel pits, borrow pits, and spoil disposal areas on the following except in (f)(iv) of this subsection:

(i) Archaeological sites or historic archaeological resources as defined in RCW 27.53.030; or

(ii) Historic sites eligible for listing on the National Register of Historic Places or the Washington Heritage Register as determined by the Washington state department of archaeology and historic preservation; or

(iii) Sites containing evidence of Native American cairns, graves, or glyptic records as provided for in chapters 27.44 and 27.53 RCW. The department of archaeology and historic preservation shall consult with affected Indian tribes in identifying such sites.

(iv) A forest practice would not be classified as Class IV-special under this subsection if:

(A) Cultural resources management strategies from an approved watershed analysis conducted under chapter 222-22 WAC are part of the proposed forest practices, and the landowner states this in the application; or

(B) A management plan agreed to by the landowner, the affected Indian tribe, and the department of archaeology and historic preservation is part of the proposed application, and the landowner states this in the application.

*(g) Forest practices subject to an approved watershed analysis conducted under chapter 222-22 WAC in an area of resource sensitivity identified in that analysis which deviates from the prescriptions (which may include an alternate plan).

*(h) Filling or draining of more than 0.5 acre of a wetland.

(2) **"Class IV-general."** Applications involving the following circumstances are Class IV-general forest practices unless they are listed in Class IV-special. Forest practices applications

classified Class IV-general are subject to the SEPA review process described in subsection (1) of this section.

*(a) Forest practices (other than those in Class I) on lands that are being converted to another use;

(b) Forest practices that would otherwise be Class III, but are taking place on lands that are not to be reforested because of likelihood of future conversion to urban development (see WAC 222-16-060 and 222-34-050); or

(c) Where the regulatory authority for forest practices has not been transferred from the department to the local governmental entity pursuant to RCW 76.09.240(1), forest practices involving timber harvesting or road construction on lands that are contained within urban growth areas, designated pursuant to chapter 36.70A RCW, except where the forest landowner provides one of the following:

(i) A written statement of intent signed by the forest landowner not to convert to a use other than commercial timber operations for ten years. This statement must be accompanied by either a written forest management plan acceptable to the department or documentation that the land is enrolled under the provisions of chapter 84.33 or 84.34 RCW; or

(ii) A conversion option harvest plan approved by the local governmental entity and submitted to the department as part of the application.

Upon receipt of an application, the department will determine the lead agency for purposes of compliance with SEPA pursuant to WAC 197-11-924 and 197-11-938(4) and RCW 43.21C.037(2). Such applications are subject to a thirty-day period for approval unless the lead agency determines a detailed statement under RCW 43.21C.030 (2)(c) is required. Upon receipt, if the department determines the application is for a proposal that will require a permit from a local governmental entity acting under the powers enumerated in RCW 76.09.240, the department shall notify the applicable local governmental entity under WAC 197-11-924 that the department has determined according to WAC 197-11-938(4) that the local governmental entity is the lead agency for purposes of compliance with the SEPA.

(3) **"Class I."** Operations that have been determined to have no direct potential for damaging a public resource are Class I forest practices. When the conditions listed in Class IV-special are not present, these operations may be commenced without notification or application.

(a) Culture and harvest of Christmas trees and seedlings.

*(b) Road maintenance except: Replacement of bridges and culverts across Type S, F or flowing Type Np Waters; or movement of material that has a direct potential for entering Type S, F or flowing Type Np Waters or Type A or B Wetlands.

*(c) Construction of landings less than one acre in size, if not within a shoreline area of a Type S Water, the riparian management zone of a Type F Water, the bankfull width of a Type Np Water, a wetland management zone, a wetland, or the CRGNSA special management area.

*(d) Construction of less than six hundred feet of road on a sideslope of forty percent or less if the limits of construction are not within the shoreline area of a Type S Water, the riparian management zone of a Type F Water, the bankfull width of a Type Np Water, a wetland management zone, a wetland, or the CRGNSA special management area.

*(e) Installation or removal of a portable water crossing structure where such installation does not take place within the shoreline area of a Type S Water and does not involve disturbance of the beds or banks of any waters.

*(f) Initial installation and replacement of relief culverts and other drainage control facilities not requiring an application.

(g) Rocking an existing road.

(h) Loading and hauling timber from landings or decks.

(i) Precommercial thinning and pruning, if not within the CRGNSA special management area.

(j) Tree planting and seeding.

(k) Cutting and/or removal of less than five thousand board feet of timber (including live, dead and down material) for personal use (i.e., firewood, fence posts, etc.) in any twelve-month period, if not within the CRGNSA special management area.

(l) Emergency fire control and suppression.

(m) Slash burning pursuant to a burning permit (RCW 76.04.205).

*(n) Other slash control and site preparation not involving either off-road use of tractors on slopes exceeding forty percent or off-road use of tractors within the shorelines of a Type S Water, the riparian management zone of any Type F Water, or the bankfull width of a Type Np Water, a wetland management zone, a wetland, or the CRGNSA special management area.

*(o) Ground application of chemicals, if not within the CRGNSA special management area. See WAC 222-38-020 and 222-38-030.

*(p) Aerial application of chemicals (except insecticides), outside of the CRGNSA special management area when applied to not more than forty contiguous acres if the application is part of a combined or cooperative project with another landowner and where the application does not take place within one hundred feet of lands used for farming, or within two hundred feet of a residence, unless such farmland or residence is owned by the forest landowner. Provisions of chapter 222-38 WAC shall apply.

(q) Forestry research studies and evaluation tests by an established research organization.

*(r) Any of the following if none of the operation or limits of construction takes place within the shoreline area of a Type S Water or the riparian management zone of a Type F Water, the bankfull width of a Type Np Water or flowing Type Ns Water, or within the CRGNSA special management area and the operation does not involve off-road use of tractor or wheeled skidding systems on a sideslope of greater than forty percent:

(i) Any forest practices within the boundaries of existing golf courses.

(ii) Any forest practices within the boundaries of existing cemeteries which are approved by the cemetery board.

(iii) Any forest practices involving a single landowner where contiguous ownership is less than two acres in size.

(4) **"Class II."** Certain forest practices have been determined to have a less than ordinary potential to damage a public resource and may be conducted as Class II forest practices: Provided, that no forest practice enumerated below may be conducted as a Class II forest practice if the operation is within a "shorelines of the state," or involves owner of perpetual timber rights subject to RCW 76.09.067 (other than renewals). Such forest practices require an application. No forest practice enumerated below may be conducted as a Class II forest practice if it takes place on lands that are being converted to another use. Unless the conditions described in (f) or (g) of this subsection are met, no forest practice enumerated below involving timber harvest or road construction may be conducted as a Class II if it takes place within urban growth areas designated

pursuant to chapter 36.70A RCW. Such forest practices require a Class IV application. Class II forest practices are the following:

(a) Renewal of a prior Class II notification where no change in the nature and extent of the forest practices is required under rules effective at the time of renewal.

(b) Renewal of a previously approved Class III or IV forest practices application where:

(i) No modification of the uncompleted operation or of a forest practices hydraulic project design is proposed;

(ii) No notices to comply, stop work orders or other enforcement actions are outstanding with respect to the prior application;

(iii) No change in the nature and extent of the forest practice is required under rules effective at the time of renewal; and

(iv) The application is not a multiyear permit that is located within an area subject to reanalysis of a watershed analysis under WAC 222-22-090(6).

*(c) Any of the following if none of the operation or limits of construction takes place within the riparian management zone of a Type F Water, within the bankfull width of a Type Np Water, within a wetland management zone, within a wetland, or within the CRGNSA special management area:

(i) Construction of advance fire trails.

(ii) Opening a new pit of, or extending an existing pit by, less than one acre.

*(d) Salvage of logging residue if none of the operation or limits of construction takes place within the riparian management zone of a Type F Water, within the bankfull width of a Type Np Water, within a wetland management zone or within a wetland; and if none of the operations involve off-road use of tractor or wheeled skidding systems on a sideslope of greater than forty percent.

*(e) Any of the following if none of the operation or limits of construction takes place within the riparian management zone of a Type F Water, within the bankfull width of a Type Np Water, within a wetland management zone, within a wetland, or within the CRGNSA special management area, and if none of the operations involve off-road use of tractor or wheeled skidding systems on a sideslope of greater than forty percent, and if none of the operations are located on lands with a likelihood of future conversion (see WAC 222-16-060):

(i) West of the Cascade summit, partial cutting of forty percent or less of the live timber volume.

(ii) East of the Cascade summit, partial cutting of five thousand board feet per acre or less.

(iii) Salvage of dead, down, or dying timber if less than forty percent of the total timber volume is removed in any twelve-month period.

(iv) Any harvest on less than forty acres.

(v) Construction of six hundred or more feet of road, provided that the department shall be notified at least two business days before commencement of the construction.

*(f) Forest practices involving timber harvesting or road construction listed in (a) through (e) of this subsection within urban growth areas (UGAs) designated pursuant to chapter 36.70A RCW, if the landowner provides one of the following:

(i) A written statement of intent signed by the forest landowner not to convert to a use other than commercial timber operations for ten years. This statement must be accompanied by either a written forest management plan acceptable to the department, or documentation that the land is enrolled under the provisions of chapter 84.33 or 84.34 RCW; or

(ii) A conversion option harvest plan approved by the local governmental entity and submitted to the department as part of the application.

*(g) Forest practices listed in (a) through (e) of this subsection within UGAs, and where the regulatory authority for forest practices has been transferred to the local governmental entity pursuant to RCW 76.09.240(1), may nonetheless be Class II forest practices and regulated by the department if:

(i) The forest practice is on a landowner's ownership of contiguous forest land equal to or greater than twenty acres; and

(ii) The landowner provides documentation described in (f)(i) or (ii) of this subsection.

(5) **"Class III."** Forest practices not listed under Classes IV, I or II above are Class III forest practices. Among Class III forest practices are the following:

*(a) Forest practices hydraulic projects except where classed as Class I, II, and IV forest practices.

*(b) Those within the shorelines of the state other than those in a Class I forest practice.

*(c) Aerial application of insecticides, except where classified as a Class IV forest practice.

*(d) Aerial application of chemicals (except insecticides), except where classified as Class I or IV forest practices.

*(e) Harvest or salvage of timber except where classed as Class I, II or IV forest practices.

*(f) All road construction except as listed in Classes I, II and IV forest practices.

(g) Opening of new pits or extensions of existing pits over one acre.

*(h) Road maintenance involving:

(i) Replacement of bridges or culverts across Type S, F or flowing Type Np Waters; or

(ii) Movement of material that has a direct potential for entering Type S, F or flowing Type Np Waters or Type A or B Wetlands.

(i) Operations involving owner of perpetual timber rights subject to RCW 76.09.067.

(j) Site preparation or slash abatement not listed in Classes I or IV forest practices.

(k) Harvesting, road construction, site preparation or aerial application of pesticides on lands which contain cultural, historic or archaeological resources which, at the time the application or notification is filed, have been identified to the department as being of interest to an affected Indian tribe.

(l) Harvesting exceeding nineteen acres in a designated difficult regeneration area.

(m) Utilization of an alternate plan. See WAC 222-12-040.

*(n) Any filling of wetlands, except where classified as Class IV forest practices.

*(o) Multiyear permits.

*(p) Small forest landowner long-term applications that are not classified Class IV-special or Class IV-general, or renewals of previously approved Class III or IV long-term applications.

*(q) Forest practices involving timber harvest or road construction listed in (a) through (p) of this subsection within urban growth areas (UGAs) designated pursuant to chapter 36.70A RCW, if the landowner provides documentation described in subsection (4)(f)(i) or (ii) of this section.

*(r) Forest practices listed in (a) through (p) of this subsection within UGAs, and where the regulatory authority for forest practices has been transferred to the local governmental entity pursuant to RCW 76.09.240(1), may nonetheless be Class III forest practices and regulated by the department if:

(i) The forest practice is on a landowner's ownership of contiguous forest land equal to or greater than twenty acres; and

(ii) The landowner provides documentation described in subsection (4)(f)(i) or (ii) of this section.

(s) Removal of beaver structures from culverts on forest roads.

WAC 222-20-010 Applications and notifications—Policy.

(1) **No Class II, III or IV forest practices** shall be commenced or continued unless the department has received a notification for Class II forest practices, or approved an application for Class III or IV forest practices pursuant to the act. Where the time limit for the department to act on the application has expired, and none of the conditions in WAC 222-20-020(1) exist, the operation may commence. (NOTE: OTHER LAWS AND RULES AND/OR PERMIT REQUIREMENTS MAY APPLY. SEE CHAPTER 222-50 WAC.)

(2) **The department shall** prescribe the form and contents of notifications and applications. The department shall specify the information required for a notification, and the information required for the department to approve or disapprove an application.

(3) **Except as provided in subsection (4) of this section, applications and notifications** shall be signed by the landowner, the timber owner, and the operator if the operator is known at the time the application is submitted.

(4) In lieu of a landowner's signature, where the timber rights have been transferred by deed to a perpetual owner who is different from the forest landowner, the owner of perpetual timber rights may sign a forest practices application or notification for operations not converting to another use and the statement of intent not to convert for a set period of time. The holder of perpetual timber rights shall serve the signed forest practices application or notification and the signed statement of intent on the forest landowner. The forest practices application shall not be considered complete until the holder of perpetual timber rights has submitted evidence acceptable to the department that such service has occurred.

(5) **Where an application** for a conversion is not signed by the landowner, the department shall not approve the application. Applications and notifications for the development or maintenance of utility rights of way shall not be considered to be conversions.

(6) **Transfer of the** approved application or notification to a new landowner, timber owner or operator requires written notice by the former landowner or timber owner to the department and should include the original application or notification number. This written notice shall be in a form acceptable to the department and shall contain an affirmation signed by the new landowner, timber owner, or operator, as applicable, that he/she agrees to be bound by all conditions on the approved application or notification. In the case of a transfer of an application previously approved without the landowner's signature, the new timber owner or operator must submit a bond securing compliance with the requirements of the forest practices rules as determined necessary by the department. If an application or notification indicates that the landowner or timber owner is also the operator, or an operator signed the application, no notice need be given regarding any change in subcontractors or similar independent contractors working under the supervision of the operator of record.

(7) **The landowner or timber owner must provide notice of hiring or change of operator** to the department within forty-eight hours of the change. The department shall promptly notify

the landowner if the operator is subject to a notice of intent to disapprove under WAC 222-46-070. Once notified, the landowner will not permit the operator, who is subject to a notice of intent to disapprove, to conduct the forest practices specified in the application or notification, or any other forest practices until such notice of intent to disapprove is removed by the department.

(8) **Applications and notifications,** if complete, will be considered officially received on the date and time shown on any registered or certified mail receipt, or the written receipt given at the time of personal delivery, or at the time of receipt by general mail delivery. The department will immediately provide a dated receipt to the applicant. Applications or notifications that are not complete, or are inaccurate will not be considered officially received until the applicant furnishes the necessary information to complete the application.

(a) A review statement from the U.S. Forest Service that evaluates compliance of the forest practices with the Columbia River Gorge National Scenic Area Act (CRGNSA) special management area guidelines is necessary information for an application or notification within the CRGNSA special management area. The review statement requirement shall be waived if the applicant can demonstrate the U.S. Forest Service received a complete plan application and failed to act within forty-five days.

(b) A complete environmental checklist (WAC 197-11-315) is necessary information for all Class IV applications.

(c) A local governmental entity clearing and/or grading permit is necessary information for all Class IV applications on lands that will be converted to a use other than commercial timber operations if the local governmental entity has jurisdiction and has an ordinance requiring such permit.

(d) A checklist road maintenance and abandonment plan is necessary information for all small forest landowners' applications or notifications for timber harvest (including salvage), unless exempt under WAC 222-24-0511, or unless the application is a small forest landowner long-term application which requires a roads assessment.

(9) **Where potentially unstable slopes or landforms are in or around the area of an application,** the department may require the landowner to provide additional information in order to classify the application appropriately. If necessary, the department may require additional geologic information prepared by a qualified expert. The department may request that the qualified expert explain the methods the qualified expert used to evaluate the proposed harvest or construction activities with respect to the potentially unstable slopes or landforms. Nothing in this subsection is intended to require a geotechnical report if the geologic information provided is sufficient to appropriately classify the application.

(a) "Qualified expert" is defined in WAC 222-10-030.

(b) "Potentially unstable slopes or landforms" are those listed in WAC 222-16-050 (1)(d)(i)(A) through (E).

(10) **Financial assurances** may be required by the department prior to the approval of any future forest practices application or notification to an operator or landowner under the provisions of WAC 222-46-090.

Attachment A - Proposal Initiation for Unstable Slopes

FORESTS AND FISH CONSERVATION CAUCUS

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615 Second Avenue, Ste 360
Seattle, WA 98104

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November 9, 2015

Via electronic mail to forest.practicesboard@ dnr.wa.gov

Forest Practices Board
1111 Washington St. SE
PO Box 47012
Olympia, WA 98504-7012

Re: Revised Board Manual Guidelines for Evaluating Potentially Unstable Slopes and Landforms (Section 16)

Dear Chair Bernath and Boardmembers:

The Conservation Caucus thanks the Board and DNR staff in advance for its time spent on the development of Board Manual Section 16 (BM 16). This letter, and the materials appended to it, support the Conservation Caucus' opposition to adoption of BM 16.

The Conservation Caucus requests that the Board **not** adopt BM 16 (Vers. November 2015) at its November 10, 2015 meeting. We request the Board to postpone adoption of BM 16 for a short period of time and remand it to DNR with direction that DNR reconvene its technical committees to address the multiple inadequacies addressed herein and elsewhere. The Board should direct DNR, in collaboration with caucus-appointed qualified geologists only, to prepare a Manual that implements the forest practices rules according to best available science and the precautionary principle. The Board's policy objective must be a Manual that thoroughly and accurately specifies the screening and geologic analysis steps necessary to ensure that forest practices do not potentially contribute to **any** kind of landslide that has the potential to threaten public safety or resources.

At the outset, we briefly recap the history of BM 16. The Board last considered BM 16 at its August 2015 meeting. At that meeting, the Board adopted DNR's version of BM Phase I, identification and delineation, and gave DNR until its November 2015 meeting to complete BM Phase II, which estimate a landslide's run-out length and path. The Conservation Caucus agreed to the DNR-requested extension for Phase II but voiced its opposition to the Board's adoption of Phase I, which version included landowner-

Mary Scurlock, Policy Representative ▪ **Chris Mendoza**, Science Representative

Conservation Northwest ▪ Olympic Forest Coalition ▪ Pacific Rivers Council ▪ Washington Environmental Council
Washington State Chapter of the Sierra Club ▪ Washington Forest Law Center ▪ Wild Fish Conservancy

requested revisions to the "expert panel's" version. The Board adopted Phase I in August 2015, but directed DNR staff to reconsider the Conservation Caucus' concerns with DNR's Phase 1 revisions, the majority of which DNR did not accept. The first formal Board consideration of BM 16 Phase II is scheduled for the Board' its November 10, 2015 meeting.

I. For At Least Seven Reasons, Geology Experts Believe BM 16 Does Not Scientifically Implement The Forest Practice Regulations, Regulations For Which Implementation and Enforcement by DNR Depends Heavily on the Board Manual.

After the tragic Oso landslide in March 2014, elected officials, citizens, and geologists called for enforcement and, where necessary, revised regulations, policies, and other guidelines that protect the public from dangerous natural and human-contributed to landslides. The urgency underlying these calls was based in strong part on the reality that global climate change was ushering in storms of unprecedented magnitude and frequency, and the fact that many deep-seated landslides like the one that struck Oso have yet to be properly identified and mapped.

At the expense to the State of Washington,[1]which provides grants to forest stakeholders participating in board manual development, the Conservation Caucus and other Caucuses devoted over nine months in BM 16 working groups. Our Caucus' policy position has consistently been that, although only a "guidance-only" document, the BM functionally implements the rules and therefore must (1) specify technically-sound ways for DNR screening staff and forest stakeholders to identify up-front potential landslides of any kind; (2) specify the office and site-specific measurement and testing scientifically required to determine whether a proposed forest practices could contribute to a landslide; and (3) delineate the areas where these landslides could either threaten public safety or "deliver" to a public resource.

Unfortunately, however, on November 10, 2015 DNR is requesting the Board to adopt a BM that falls far short of these mandatory goals. DNR only shared its proposed new BM with the nine caucuses on Monday, October 26, 2015, allowing 15 days for comment preparation.

Below, are **seven** bullet points why BM 16 falls far short of what should be required for a board manual to implement the forest practices rules. These bullet points are based on the professional opinions of three highly-qualified and experienced professional geologists with experience in the forest sector, Dr. David Montgomery, Paul Kennard,

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[1] By way of example, the Conservation Caucus' lead geologist in the development of the BM, Paul Kennard, devoted 220 hours of time to the BM process. The Conservation Caucus' CMER representative, Chris Mendoza, similarly spent at least 200 hours of time in the DNR-lead BM process.

and Dan McShane.[2] Together, these experts contend that BM 16 will not accurately identify landslides and will not require the type of geologic review necessary to protect public safety.[3] (**Note**: in the interest of brevity, we do **not** repeat in this letter that which is said in the expert declarations and letters to the Board).

(1) **Use of Heavily-Qualified, Weak Language**. Over our Caucus' repeated objection, inconsistent with the recommendation of DNR's panel of Qualified Experts, and added by DNR, DNR permitted the BM to replace the procedures and recommendations of best available science with weak and vague terms such as "may" or "could;"[4]

(2) **Non-glacial deep-seated Landslides**. For no justifiable geologic reason(s) and despite the risk to public safety, the BM arbitrarily requires *less* geologic review and protection for deep-seated landslides on non-glacial soils;

(3) **Reactivation**. The BM fails to adequately address the principle of landslide *reactivation*, that the additional water generated by forest practices may have the potential to reactivate "relict distinct" or "relict indistinct" landslides that have lain dormant for decades or even centuries;

(4) **Weekes Landslide Screening Tool**. DNR rejected Ann Weekes' precautionary landslide screening technique which would enable forest stakeholders to accurately identify landslides and other potentially unstable landforms that may not appear on contemporary landslide maps;

(5) **Coarse Screen**. DNR rejected an office and field screening analysis (the "Coarse Screen" developed by Paul Kennard) that would enable foresters and geologists to more accurately measure and evaluate potentially dangerous shallow rapid landslides that may be destabilized by forest practices;

(6) **Run-Out Path Analysis**. DNR excluded well-established techniques to help measure the run-out path of both shallow rapid and deep-seated land-slides that could jeopardize public safety or public resources; and

(7) **Landslide Risk Flow Chart**. The BM omits a land-slide risk analysis flow-chart (authored by Dr. Kara Whittaker) that would enable DNR and forest stakeholders to determine whether a landslide could potentially threaten public safety.

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[2] We also understand the Department of Ecology geologist Craig Graeber, who participated in the Phase II process, will testify in support of some or all of these concerns.

[3] Appended to this letter are (1) the declaration of Paul Kennard; (2) letter to the Board written by geologist Dan McShane; and (3) letter to the Board written by Kara Whittaker and Chris Mendoza. We also rely on the views of University of Washington Professor of Geomorphology Dr. David Montgomery, who is submitting a completely separate and personal letter to the Board on November 9, 2015. Attachments 1, 2, 3, and 4.

[4] See footnote 3.

II. CONCLUSION

For the above reasons, the Conservation Caucus respectfully requests the Board not to adopt BM 16 at its November 10 meeting and to instead re-set it for reconsideration at its February meeting.

Very truly yours,

FORESTS AND FISH CONSERVATION CAUCUS

Dave Werntz

David Werntz
Science & Conservation Director
Conservation Northwest

Lisa Remlinger

Lisa Remlinger
Evergreen Forests Agenda Director
Washington Environmental Council

Peter Goldman
Director
Washington Forest Law Center

Toby Thaler

Toby Thaler
Olympic Forest Coalition

ATTACHMENT 1

FOREST PRACTICES BOARD

STATE OF WASHINGTON

)
) **DECLARATION OF PAUL**
) **KENNARD, Licensed Engineering**
) **Geologist and Hydrogeologist.**
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)
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)

I, Paul Kennard, hereby declare the following under penalty of perjury:

1. The Forests and Fish Conservation Caucus has commissioned me to participate in the revision of a section of the Forest Practices Board Manual, titled "Board Manual 16, Guidelines for Evaluating Potentially Unstable Slopes." I attended 11 stakeholder meetings and spent approximately 220 total hours in the Board Manual revision process.

2. I am a geologist with specialized expertise in hillslope geomorphology, forest hydrology, and stream condition characterization. I currently work for Mount Rainier National Park, as a fluvial geomorphologist. My work for the Conservation Caucus is not connected to my Park work. For the past 27 years, I have done extensive work assessing the influence of forest activities on landslides and the effects of landslides on stream channel morphology and fish habitat. My resume and list of publications are attached to this declaration.

3. From 1988 to 1999, I was employed as a geomorphologist in the Tulalip Tribes' Fisheries Department. In that capacity, I evaluated the effects of forest activities on fish habitat in the Stillaguamish and Snohomish River basins in Washington. I assessed direct and cumulative watershed effects of forest activities by mapping erosion hazard sites, analyzing slope stability, and surveying stream and fish habitat conditions. My particular emphases were the influence of forest activities and roads on landslides, and their effects on stream channel morphology and fish habitat. From 1999 to 2002, I was the Senior Staff Scientist for the Washington Forest Law Center (a public service non-profit providing legal services for forest cases of statewide significance), where I continued to conduct scientific research and provide technical analyses of forest landslides and aquatic resources.

4. I also have extensive experience with the watershed analysis process conducted in Washington State. This process is intended to identify, prevent, and/or mitigate cumulative watershed impacts of forestry activities. I am co-author of the watershed analysis mass wasting assessment module. I was also instrumental in developing the later Rule Identified Landform definitions, in the current rules.

5. My overall opinion is that the Board Manual as currently drafted omits information and tools that are critical to attaining repeatable and accurate assessments of slope stability and risk to public safety. I have grave concerns that the Board Manual as currently drafted fails to take the steps necessary to consistently prevent the impacts of landslides by forest practices.

6. As explained further in this declaration, the proposed Board Manual omits the crucial Landslide Assessment Decision Pathway, which sets forth a standardized flowchart which aids in determining whether a given Forest Practices Application likely merits classification as "Class IV Special." The proposed Board Manual further omits a Shallow Rapid Landslide Coarse

Screen, which provides a means of assessing whether a given slope would likely deliver to public resources or risk public safety.

7. As a regular participant in the process, it appeared to me that there was widespread agreement among the actual geology experts as to the need for these two tools. DNR also supported the development of these tools. However, DNR removed them without adequate basis or explanation at the culmination of the process.

8. My understanding is that the Forest Practices Rules require a landowner, regulator, or practitioner to identify whether a proposed harvest or road building operation on "potentially unstable slopes or landforms… has the potential to deliver sediment or debris to a public resource or that has the potential to threaten public safety." WAC 222-16-050(1)(d). The Landslide Assessment Decision Pathway helps to guide a user through that determination in a step-by-step process. The Coarse Screen also helps navigate that determination by assisting in the evaluation of whether a potential shallow rapid landslide would deliver to a public resource or threaten public safety. As a result, in my professional opinion, these two tools are essential to carrying out the requirements of WAC 222-16-050(1)(d), and omitting these tools makes the Board Manual an incomplete technical advisory supplement to the steep and unstable slopes forest practices rules.

9. Below I address the Landslide Assessment Decision Pathway, Shallow Rapid Landslide Coarse Screen, and Board Manual process in order.

Landslide Assessment Decision Pathway

10. The Forest Practices Rules require a landowner, regulator, or practitioner to make a series of judgments in assessing the ultimate question of whether logging or road building on a

given area has the potential to cause delivery of sediment and debris to public resources or threaten public safety.

11. The Landslide Assessment Decision Pathway is a repeatable, defensible decision making process, consistent with a precautionary approach to the landslide assessment. To this end, Dr. Kara Whittaker developed the Landslide Assessment Decision Pathway with the assistance of multiple qualified experts (as defined in WAC 222-10-030(5)). I reviewed the proposal.

12. In my nearly three decades of experience working in forestry in Washington State, I have learned that objective and repeatable decision-making tools are essential to consistent and accurate application of forest practices rules. I have worked on private and state forest practices in Washington State since 1988, and I have in-depth experience and insight into how the DNR makes regulatory determinations. Frequently, decisions regarding landslide hazards and runout potential are made by otherwise competent foresters (both regulatory and industry), with no meaningful training nor understanding of mass wasting science. Not having (or ignoring) data and science, these decisions are invariably justified solely as "professional judgment", without additional (or any) justification. I cannot over-emphasize how frequently this happens.

13. There may be a legitimate use of professional judgment by truly qualified professionals when balancing multiple societal interests in real world situations. However, in the forest practices arena, it has instead often become the go-to response to justify merely what a landowner wants to do, or is used by regulators to arbitrarily forestall objections without further discussion.

14. When I was involved fulltime in Timber Fish and Wildlife (the precursor to the adaptive management program), I learned that the false cover of uninformed professional

judgement was the biggest obstacle to advancing science-based management on the ground. It was for this exact reason I was directly involved in developing Watershed Analysis (and developing the mass wasting assessment, in particular), and the later Rule Identified Landform definitions. I remain convinced that uninformed or misused professional judgment is still the major obstacle to advancing science-based management.

15. The Landslide Assessment Decision Pathway is a fully developed product, and the Conservation Caucus version (as attached to the Conservation Caucus letter to this Board) can be readily incorporated into the Board Manual, as is. All of the other stakeholder groups had an opportunity to comment and help develop the Pathway.

16. I was provided no rationale for why DNR chose to omit the Landslide Assessment Decision Pathway from the Board Manual, and there is no replacement tool in the Board Manual. The Decision Pathway would aid considerably in guiding repeatable and transparent decision-making. Omitting the pathway risks public safety by leaving critical decisions to opaque and subjective judgment determinations. I cannot think of, nor was I provided, a scientific basis for omission of this vital tool.

Shallow Rapid Landslide Coarse Screen

17. If a landowner, regulator, or practitioner determines that a given slope has potential for slope instability, that individual must then determine whether the landslide that may occur has the potential to deliver sediment or debris to public resources or threaten public safety. The Shallow Rapid Landslide Coarse Screen tool assists in making the delivery determinations for potential shallow rapid landslides.

18. The Shallow Rapid Landslide Coarse Screen tool consists of a flowchart with a short text description that allows practicing foresters to estimate potential runout distances that start as shallow rapid landslides, to determine their potential to impact public resources or public safety.

19. In my opinion, such a tool is highly necessary because it provides a consistent means by which individuals with a wide range of experience and education can accurately assess landslide runout risk.

20. I prepared the Coarse Screen at the direction of DNR and the Board Manual stakeholder group. Throughout the process, I was led to believe that DNR would include the screen in the final Board Manual, and it was included in many rounds of drafts. The Coarse Screen is based on a Weyerhaeuser developed product and to my perception was not controversial, but rather had widespread support from qualified expert participants.

21. Inclusion of the Coarse Screen in the Board Manual would substantially enhance protection of public safety because it would provide a repeatable and relatively accurate means of assessing runout distance. If the Forest Practices Rules truly expect individuals other than licensed geologists to be making determinations of slope stability and runout, it is essential that there be a standardized framework to guide those decisions. Useful features, making the method integral to protecting public safety in a Board Manual context, include:

a. **Simplicity of use**. Most foresters would need a day of training at most to learn how to utilize the Coarse Screen. It is much less complex than the current riparian management zone rules, for example.

b. **Based on standard field measurements**. Most measurements involve either slope or distance, and can be done with routine forestry instruments, such as clinometers and laser rangefinders.

c. **Repeatable**. Because a standard methodology is used and the input variables are from field measurements of visible landscape characteristics, the method is repeatable. This eliminates "professional judgement" by field practitioners who are not slope stability experts, while not putting an undue burden on the Qualified Experts. If a potential problem area is identified by the Coarse Screen, a qualified expert can make a more refined determination of runout.

d. **Accurately identifies both on- and off-site runout impacts**. Upon entering a stream channel, shallow rapid landslides can become debris flows and/or landslide dam-break floods. These guidelines automatically accommodate these process transformations and account for the increased runout distances, including those delivering to areas distant from the original forest practice. Currently, even experienced foresters don't necessarily account for these potentially devastating events.

e. **Science-based**. The coarse screen method is based on a framework developed by the Tolt Watershed Analysis Prescription Team. The Tolt Watershed Analysis is a Weyerhaeuser-initiated, DNR "Approved Watershed Analysis" (with currently approved prescriptions – that is not rescinded by later Board action - https://fortress.wa.gov/dnr/protectionsa/ApprovedWatershedAnalyses). It, in turn, is based on published, peer-reviewed (Benda and Cundy 1990) and TFW CMER developed and accepted (Coho and Burges 1994) methodologies. Both methods have been used for decades in the Pacific Northwest by Qualified Experts with great accuracy and success. The coarse screen method we prepared for the revised

Board Manual has been updated to reflect newly published science (e.g., ODF 2003).

f. **Management decision oriented**. The coarse screen is developed to work seamlessly with a Landslide Assessment Decision Pathway (see discussion above). For a minimum effort, accurate, physically-based runout information is generated, that leads to unambiguous, repeatable, and rule compliant decision making.

22. Throughout the Board Manual development process, DNR encouraged the Conservation Caucus' technical experts to develop this tool. My meeting notes reflect that all of the stakeholders' technical group representatives agreed to the concept of the Coarse Screen tool in some form. At the end of the process, DNR simply eliminated it without explanation. I was provided no rationale for why DNR chose to omit the Shallow Rapid Landslide Coarse Screen tool from the Board Manual, and there is no adequate replacement tool in the Board Manual.

23. At a meeting shortly before completion of the Board Manual, DNR announced that the Shallow Rapid Landslide Coarse Screen was no longer part of the Manual, and that there was to be no further discussion on the content nor the decision to arbitrarily abandon the screen between meetings. This was surprising (the screen was the main agenda item of the meeting during which its demise was announced), and disturbing (the group had spent most of its effort on this component to date).

24. Most importantly, omission of the Coarse Screen greatly undermined the group's technical integrity, and subverted the Forest Practice Board's desire for a scientifically-based Manual. To that point, every technical member of the group ─ agency, industry, and Conservation Caucus ─ had supported a methodological coarse screen approach. The only

remaining discussion was in minor details (such as specific landslide runout distances once they reached flat terrain).

25. The Coarse Screen was nearly complete and ready for inclusion in the final Board Manual. The one outstanding question remaining for the Coarse Screen was the determination of runout distances for certain types of slides. To solve this question, I repeatedly proposed a Runout Risk Evaluation tool. Below I briefly describe: (1) what the tool is; and (2) why it would be so useful to the Board Manual revision process to protect public safety.

26. The tool. Even landslides that are similar (approximately the same slope, moisture content, composition, etc.) will still exhibit variations in runout distances. These can be plotted in a frequency distribution, which is the number of landslides plotted against the runout distance. This results in a curve showing the distribution of runout distances. A small number are on the short and long ends, and most are throughout the middle of a more or less bell-shaped curve.

27. Given these distributions of geomorphically similar landslide runout distances, it is straightforward to specify runout distance decision thresholds for the Shallow Rapid Landslide Coarse Screen. For example, if you want to account for 85% of the landslides, the corresponding value from the Runout Risk Evaluation Tool distribution is used. The same procedure applies if you want to identify 95% or 99% of the landslides (as is more consistent with a precautionary risk approach).

28. Development of the technical tool can proceed in the face of complete uncertainty about the ultimate target risk, were risk to be later defined by the Forest Practices Board. It also allows for easy modification of the Board Manual (or rules), if the threshold of acceptable risk is changed in the future. One merely changes the landslide runout factor in the Shallow Rapid

Landslide Coarse Screen, based on the distribution already developed for the Runout Risk Evaluation Tool.

29. Lastly, it would be a straightforward endeavor to fully develop the tool for Washington State. For example, data from existing shallow-rapid landslide surveys can be "mined" for maximum runout distances as a function of landslide type. When I refer to maximum runout distances, I mean we include only landslides that are reach their full runout potential (without hitting an obstruction or river). Readily available data sources include approved watershed analyses, the CMER post-mortem landslide studies, and numerous other regional landslide surveys.

30. In the Board Manual revision process, it is of particular use having a Runout Risk Evaluation Tool, because it allows development of technically justified landslide runout methods that that are both directive and repeatable, even when the target ─ the policy-set Level of Risk ─ is unspecified. It supports the justifiable development of the Shallow Rapid Landslide Coarse Screen, to better protect public safety from shallow rapid landslide hazards.

31. Additionally, it allows a straightforward mechanism to rationally set, and subsequently modify (if necessary), a policy directed risk level, with minimum effort. For example: (1) a desired level of risk for landslide runout avoidance is specified (say 95% are accounted for); (2) the corresponding runout distance from the Runout Risk Evaluation Tool distribution is identified; and (3) the distance is applied in the Shallow Rapid Landslide Coarse Screen. This also provides a measureable value to evaluate the effectiveness of the Board Manual (or rule mandated) risk threshold.

32. Despite my repeated attempts, DNR refused without explanation to entertain the development of the Runout Risk Evaluation Tool. There is no comparable replacement in the Board Manual.

33. In sum, the Board Manual as drafted is incomplete because it fails to provide a pragmatic and applicable tool for assessing runout and delivery by general practitioner foresters. Based on my extensive experience, I believe that this omission will result in landowners, regulators, and practitioners underestimating potential runout distances across the landscape. I cannot think of, nor was I provided, a scientific basis for omission of this vital tool.

Procedural Flaws

34. To the best of my understanding, the Forest Practices Board directed DNR to employ a team of geotechnical experts to create a science-based guidance document. Where this direction was followed, the experts generally were able to reach agreement and develop technically sound and useful guidance.

35. Unfortunately, in the second phase of Board Manual development, DNR allowed policy personnel with no technical credentials to participate. These individuals generally served only to advocate for the policy positions of their stakeholder groups. For example, an individual representing the timber industry repeatedly and extensively rewrote sections of the Board Manual to weaken existing language. I believe the inclusion of policy advocates diverged from the direction of the Forest Practices Board and severely weakened the ultimate product.

36. The other flaw in the Board Manual process is that DNR had insufficient technical staff support available to the group efforts (DNR had only two non-technical facilitators and administrative support). In the end, this led to an apparent time crunch and the omission of tools that are valuable for protecting public safety.

37. As mentioned earlier, there was a failure of communication from DNR to stakeholders. DNR simply omitted entire sections that the Conservation Caucus representatives devoted months to developing. If DNR had explained a rationale, it would have likely been possible to address those concerns and modify text to facilitate incorporation into the Board Manual.

38. In addition to my comments above, I wish to voice my support for inclusion in the Board Manual of deep seated landslide assessment tools and guidance. Indeed, this was the fundamental purpose of the development of the Board Manual in response to the 2014 Hazel slide. The Manual as proposed does not provide: (1) sufficient guidance in identifying the type of landslide that devastated Oso ─ a complex or composite rotational deep-seated landslide; nor (2) rudimentary runout assessment methods for deep-seated landslides. After review, I strongly recommend the inclusion of Complex or Composite Rotational Deep-Seated Landslides and Methods for Deep-Seated Landslide Runout Assessment (attachments 2 and 5, respectively, in the Conservation Caucus comments). This would go a long way toward rectifying current Manual omissions, and will provide much more assurance for public safety.

39. In sum, the Board Manual in its present form does not provide sufficiently useful guidance to working land managers to assess landslide risks, and it utterly fails to protect public safety. Particularly in the Runout and Delivery Assessment, the good faith work by the technical members of the committee was completely negated when DNR arbitrarily removed the core tools (the Landslide Assessment Decision Pathway and Shallow Rapid Landslide Coarse Screen components). These tools were the only meaningful methods to assess landslide delivery in the Manual, and DNR made no discernible effort to replace them with alternative, equivalent methods. The omitted tools are particularly important given the reality that the Board Manual

will often be applied by non-geologists, who require straight-forward, repeatable, easy to follow guidance on the identification and assessment of potentially unstable slopes.

40. If these components were included, the Manual provides a straightforward, user friendly decision process, and an easy-to-use landslide runout assessment tool that allows landowners to quickly and accurately assess potential landslide runout. With this information, a forester could modify the forest practice or have a Qualified Expert conduct further analysis. This is exactly what a guidance manual should do.

41. Instead, we are left with a hodge-podge of methods for estimating runout distance that may be of limited use to Qualified Experts, but will leave the average practicing forester confused.

42. I strongly recommend that the Board reinstate the omitted methods into the Manual. Additionally, I strongly recommend that if the technical process is revived, the group be allowed to work unimpeded from the policy interference that greatly impeded the last effort.

I declare under penalty of perjury under the laws of the State of Washington that the foregoing is true and correct to the best of my knowledge.

DATED this 9th day of November, 2015, at Ashford, Washington.

Paul M. Kennard

Paul Kennard

PAUL M. KENNARD

REGION GEOMORPHOLOGIST—Licensed Engineering Geologist and Hydrogeologist (Washington State)

Professional Services

Specialized analyses of wildland watersheds, particularly the effect of climate change on glacier sourced rivers. Interdisciplinary expertise in hillslope and fluvial geomorphology; glaciology; slope stability and landslides; wildland hydrology and 'rain-on-snow' flooding; riparian buffer assessment; and stream classification and survey techniques.

Education

M.S. Geophysics, University of Washington, Seattle, WA, 1983
B.S. Applied Physics, Tufts University, Medford, MA, 1975

Specialized Training

Hillslope and fluvial geomorphology.
Slope stability analysis, and debris flows and landslide dam-break floods.
Wildland hydrology and 'rain-on-snow'.

Honors and Awards

NPS Director's 2014 Professional Excellence in Natural Resources Award.
Adjunct Professor, Portland State University.

Select Publications and Presentations

A more complete list of publications, presentations, abstracts, and reports is attached.

Topographic and Hydrologic Insight for the Westside Road Problem, co-author Natural Resource Report NPS/MORA/NRR—2015/1057

The geomorphic impacts and historical precedence of debris flows within Tahoma Creek, Mount Rainier, WA, Journal of Geophysical Research.

Debris flow initiation in proglacial gullies on Mount Rainier, Washington, author, In Press, Geomorphology.

Extreme river response to climate-induced aggradation in a forested, montane basin, Carbon River, Mount Rainier National Park, Washington, United States, co-author, American Geophysical Union 46th Annual Fall Meeting 2013, December 9-13, 2013, San Francisco, CA.

Surficial Ice Velocities of the lower Nisqually glacier and their relationship to Outburst Flood Hazards at Mount Rainier National Park, Washington, United States, co-author, Geological Society of America 2013 Abstracts with Programs, Vol. 45, No. 7, p. 565.

Using repeat LiDAR to assess sediment transport conditions in a mountain stream, co-author, European Geophysical Union General Assembly 2013, Vienna, Austria, April 7–12, 2013.

Aggradation of glacially-sourced braided rivers at Mount Rainier National Park, Washington, in review, co-author, National Park Service Natural Resource Technical Report NPS/MORA/NRTR—2013/XXX, 100 p.

Landscape response to climate change and its role in infrastructure protection and management at Mount Rainier National Park, Park Science, co-author, 2011, Park Science, Vol. 28, No. 2, p. 31-35.

Surficial Velocities of the Nisqually Glacier, Mount Rainier National Park, 2011 and 2012, in prep., lead author, *Natural* Resource Data Series, National Park Service, Fort Collins, Colorado.

The role of riparian forests in river avulsion and floodplain disequilibrium in aggrading pro-glacial braided rivers: a newly recognized model in geomorphology, lead author, abstract for Geological Society of America, 2011.

Modeling rates and pathways for woody debris recruitment in northwestern stream, co-author, North American Journal of Fish Management 20 (2): 436-452, 2000.

Ice Volumes on Cascade Volcanoes: Mount Rainier, Mount Hood, Three Sisters, and Mount Shasta, 1986, co-author, U.S. Geological Survey Professional Paper 1365.

PAUL KENNARD
SELECT PUBLICATIONS, PRESENTATIONS, & REPORTS

I) **PEER-REVIEWED PUBLICATIONS**

Thomas, M.A. and **P. Kennard**, In press, Topographic and Hydrologic Insight for the Westside Road Problem, Natural Resource Report NPS/MORA/NRR—2015/1057

Anderson, S., and **P. Kennard**, In Press, *The geomorphic impacts and historical precedence of debris flows within Tahoma Creek, Mount Rainier, WA*, Journal of Geophysical Research.

Legg, N., M. Meigs, G. Grant, and **P. Kennard**, 2014, *Debris flow initiation in proglacial gullies on Mount Rainier, Washington*, Geomorphology.

Beason, S.R., L.C. Walkup and **P.M. Kennard**, In Review, Aggradation of glacially-sourced braided rivers at Mount Rainier National Park, Washington: National Park Service Natural Resource Technical Report NPS/MORA/NRTR—2013/XXX, 100 p.

Kennard, P., L. Walkup, J. Ohlschlager, and S. Beason, In Prep., *Surficial Velocities of the Nisqually Glacier, Mount Rainier National Park, 2011 and 2012*, Natural Resource Data Series NPS/XXXX/NRDS—20XX/XXX. National Park Service, Fort Collins, Colorado.

Beason, S., **P. Kennard**, T. Abbe and L. Walkup, 2011, *Landscape response to climate change and its role in infrastructure protection and management at Mount Rainier National Park*, Park Science, Vol. 28, No. 2, p. 31-35.

Abbe, T., S. Beason, **P. Kennard**, and J. Park, 2010, *Rivers gone wild: Mountain river response to a warming climate in the Pacific Northwest*, Freshwater, Vol. 2, No. 2, p. 10-13.

Beason, S., and **P. Kennard**, 2007, *Environmental and ecological implications of aggradation in braided rivers at Mount Rainier National Park*, p. 52-53 *in* J. Selleck, ed., Natural Resource Year in Review—2006, Publication D-1859, National Park Service, Denver, Colorado, 136 p.

Beechie, T.J., G. Pess, **P. Kennard**, R.E. Bilby, and S. Bolton, 2000, *Modeling rates and pathways for woody debris recruitment in northwestern streams*, North American Journal of Fish Management 20 (2): 436-452

Pollock, M.M., and **P. Kennard**, 1998, *A low-risk strategy for protecting salmonid habitat in forested watersheds of Washington state*, report to the Bullitt Foundation, by the 10000 Years Institute, Seattle, WA

Kennard, P., G. Pess, T. Beechie, B. Bilby, and D. Berg, 1996, *Riparian-in-a-Box: a Manager's Tool to Predict the Impacts of Riparian Management on Fish Habitat,* Proceedings to the Fish-Forest Conference, Trout Unlimited Canada, May 1-4, 1996, Calgary, Canada

Driedger, C.D., and **P. Kennard**, 1986, *Ice Volumes on Cascade Volcanoes: Mount Rainier, Mount Hood, Three Sisters, and Mount Shasta*, U.S. Geological Survey Professional Paper 1365

Kennard, P., and C.D. Driedger, 1986, *Glacier Volume Estimation*, Annals of Glaciology, volume 8

Driedger, C.D. and **P. Kennard**, 1984*, Ice Volumes on Cascade Volcanoes: Mount Rainier, Mount Hood, Three Sisters, and Mount Shasta*, U.S. Geological Survey Open File Report 84-581

II) **PRESENTATIONS AND PUBLISHED ABSTRACTS**

Beyeler, J., R. Rossi, **P. Kennard**, and S. Beason*, Extreme river response to climate-induced aggradation in a forested, montane basin, Carbon River, Mount Rainier National Park, Washington, United States*, American Geophysical Union 46th Annual Fall Meeting 2013, December 9-13, 2013, San Francisco, CA.

Walkup, L., Beason, S., **Kennard, P**., Ohlschlager, J., and A. Stifter, 2013, *Surficial Ice Velocities of the lower Nisqually glacier and their relationship to Outburst Flood Hazards at Mount Rainier National Park, Washington, United States,* Geological Society of America Abstracts with Programs, Vol. 45, No. 7, p. 565.

Kennard, P., 2013, *Goats to Geoducks: Landscape Response to Climate Change from the Summit of Mount Rainier to Puget Sound, Washington State*, Association of Engineering Geologist's 2013 Annual Meeting, Flooding and Coastal Hazards session, September 13, 2013, Seattle, WA.

Anderson, S., **P. Kennard**, and J. Pitlick, 2013, *Using repeat LiDAR to assess sediment transport conditions in a mountain stream*, European Geophysical Union General Assembly 2013, Vienna, Austria, April 7–12, 2013.

Kennard, P., 2013, *Introduction the Nisqually glacier*, Nisqually Glacier Research and Geohazards at Mount Rainier: NPS, USGS, University of Washington seminar, January 19, 2013, Ashford, WA.

L. Walkup, J. Ohlschlager, **P. Kennard**, and S. Beason, 2013, *Surficial ice velocities on the lower Nisqually Glacier, Mount Rainier National Park, 2011-2012*, Nisqually Glacier Research and Geohazards at Mount Rainier: NPS, USGS, University of Washington seminar, January 19, 2013, Ashford, WA.

German, L., and **P. Kennard**, 2013, *Measurement of Glacial Meltwater Outflow through Water Analysis, for geohazard recognition*, Nisqually Glacier Research and Geohazards at Mount Rainier: NPS, USGS, University of Washington seminar, January 19, 2013, Ashford, WA.

Stevens, M., and **P. Kennard**, 2013, *Glacier retreat, outburst floods, and kinematic waves -Nisqually glacier changes related to climate*, Nisqually Glacier Research and Geohazards at Mount Rainier: NPS, USGS, University of Washington seminar, January 19, 2013, Ashford, WA.

Magirl, C., and **P. Kennard**, 2013, *River sedimentation and the role of the Nisqually glacier rockfall*, Nisqually Glacier Research and Geohazards at Mount Rainier: NPS, USGS, University of Washington seminar, January 19, 2013, Ashford, WA.

Kennard, P., 2013, *Glacier Retreat, Kinematic Waves, and Outburst Floods: Glacier Response to Climate Change at Mount Rainier*; invited keynote presentation to Mount Rainier National Park All Tribal Meeting, June 12, 2013, Ashford, WA.

Anderson, S., **P. Kennard**, and J. Pitlick, 2012, *Geomorphic Response to Significant Sediment Loading in Tahoma Creek, Mt. Rainier, WA,* poster presentation at the American Geophysical Union Fall Meeting, December 3-7, 2012.

Legg, N., A. Meigs, G. Grant, and **P. Kennard**, 2012, *Controls on Debris Flow Bulking in Proglacial Gullies on Mount Rainier, Washington*, poster presentation at the American Geophysical Union Fall Meeting, December 3-7, 2012.

Magirl, C., **P. Kennard**, C. Curran, J. Czuba, and C. Czuba, 2012, *Sediment loads and sources affecting rivers draining Mount Rainier, Washington*, Seminar to the Washington Department of Natural Resources Geology and Earth Resources Division, Olympia, Washington, 5 November.

Magirl, C., **P. Kennard**, J. Czuba, C. Czuba, and C. Curran, 2012, *Rivers from Mount Rainier to Puget Sound*, Tacoma Science Café produced by Pacific Science Center and KTCS 9, Tacoma, Washington, 13 November; http://kcts9.org/events/rivers-mt-rainier-puget-sound-tacoma-science-cafe

Zechmann, J., S. Wilson, and **P. Kennard**, *Field mapping glacier extents and ice velocities at Mount Rainier*, Meeting of the Northwest Glaciologists, 2012, University of Washington, Seattle, WA.

Walkup, L., J. Ohlschlager, **P. Kennard**, S.R. Beason, 2012*, Surficial ice velocities on the lower Nisqually Glacier, Mount Rainier National Park, 2011-2012*, Meeting of the Northwest Glaciologists, 2012, University of Washington, Seattle, WA.

Kennard, P., C. Magirl, T. Abbe, and **S. Beason**, 2012, Goats to Geoducks: Landscape response to climate change from the summit of Mount Rainier to Puget Sound: Northwest Geological Society meeting, October 9, 2012, Seattle, WA.

Kennard, P., 2012, *Goats to Geoducks: 2012 geology research at Mount Rainier National Park,* invited presentation to Natural and Cultural Resources, 2-28-12, Mount Rainier National Park, Ashford, WA.

Kennard, P., 2012, *Climate change, exploding hillslopes, and rivers gone wild: Trying Times for Trails*?, invited presentation to Trails and Ranger Division, Mount Rainier National Park, Ashford, WA.

Kennard, P., 2012, *Thunder on the Mountain: Park Research on Angry Glaciers, Restless Rivers, and Climate Change at Mount Rainier,* invited presentation to the Nisqually River Council, Mount Rainier National Park, Ashford, WA.

Magirl, C., J. Czuba, C. Czuba, C. Curran, K. Johnson, **P. Kennard**, T. Olsen, H. Kimball, and C. Gish, 2012, *Goats to Geoducks: The journey of water and sediment from Mount Rainier to Puget Sound*, Invited presentation to Workshop on Managed Rivers in Western Washington, Tacoma, WA, 23 May, 2012.

Legg, N., Meigs, A., Grant, G., Lancaster, and **P. Kennard**, 2012, "*Headless" Debris Flow Initiation and Debris Flow Fans on Mount Rainier***,** Bretz Club 2012, Oregon State University.

Kennard, P., T. Abbe, M. Ericsson, J. Bjork and S. Beason, 2011, *The role of riparian forests in river avulsion and floodplain disequilibrium in aggrading pro-glacial rivers: A newly recognized model in fluvial geomorphology*, Geological Society of America Abstracts with Programs Vol. 43, No. 5, p. 164.

Beason, S., S. Anderson, L. Walkup, **P. Kennard**, C. Floyd, and A. Stifter, 2011, *Wave-like motion of coarse bed materials in high-gradient pro-glacial rivers at Mount Rainier Washington, USA*, Geological Society of America Abstracts with Programs Vol. 43, No. 5, p. 372.

Legg, N., M. Meigs, G. Grant, and **P. Kennard**, 2011, *LiDAR-based geomorphic mapping in forested landscapes: using trees to your advantage*, Geological Society of America Abstracts with Programs Vol. 43, No. 5.

Kennard, P., and S. Lofgren, 2011, *Goats to Geoducks: Landscape Response to Climate Change from the Summit of Mount Rainier to Puget Sound*, Invited presentation Climate Change at Mount Rainier, Mount Rainier National Park, Ashford, WA.

Kennard, P., T. Abbe, and S. Beason, 2011, *Climate change, water and landscape response*, Invited presentation to Climate Change Impacts on Water Resources in the Pacific Northwest, 5/12/11, Sustainable Seattle, Seattle, WA.

Kennard, P., T. Abbe, and S. Beason, 2011, *Goats to Geoducks: Landscape response to climate change from the summit of Mount Rainier to Puget Sound*, Invited presentation to North Cascadia Adaptation Partnership Climate Change Workshop, Seattle, WA.

Magirl, C., J. Czuba, C. Czuba, and **P. Kennard**, 2011. *Geomorphic response of rivers downstream from retreating glaciers on Mount Rainier, Washington*, Invited presentation to the Oregon State University Graduate Water Resources Program Seminar Series: Water Resources Research—At the Interface of Science and Policy, Corvallis, OR, October 12, 2011.

Magirl, C., J. Czuba, C. Czuba, and **P. Kennard**, 2011, *Geomorphic response of rivers downstream from retreating glaciers on Mount Rainier, Washington*, Invited presentation to the USGS Water Mission Area 2011 Lectureship Series, Helena, MT, October 19, 2011.

Magirl, C., J. Czuba, C. Czuba, and **P. Kennard**, 2011, *Geomorphic response of rivers downstream from retreating glaciers on Mount Rainier, Washington*, USGS Water Mission Area 2011 Lectureship Series, Minneapolis, MN, October 25, 2011. Invited presentation

Magirl, C., J. Czuba, C. Czuba, and **P. Kennard**, 2011, *Geomorphic response of rivers downstream from retreating glaciers on Mount Rainier, Washington*, Invited presentation USGS Water Mission Area 2011 Lectureship Series, Indianapolis, IN, October 26, 2011.

Magirl, C., J. Czuba, C. Czuba, and **P. Kennard**, 2011, *Geomorphic response of rivers downstream from retreating glaciers on Mount Rainier, Washington*, Invited presentation USGS Water Mission Area 2011 Lectureship Series, Richmond, VA, November 16, 2011.

Magirl, C., J. Czuba, C. Czuba, and **P. Kennard**, 2011, *Geomorphic response of rivers downstream from retreating glaciers on Mount Rainier, Washington*, Invited presentation USGS Water Mission Area 2011 Lectureship Series, Reston, VA, November 17, 2011.

Magirl, C., J. Czuba, C. Czuba, and **P. Kennard**, 2011, *Geomorphic response of rivers to glacial retreat and increasing peak flows downstream from Mount Rainier, Washington*, Invited presentation to the National Resources Program Seminar Series.

Magirl, C., J. Czuba, C. Czuba, and **P. Kennard**, 2011, *Geomorphic Response of the White River Downstream from Mud Mountain Dam: Living with river draining volcanoes*, Invited presentation to the Army Corps of Engineers, Seattle District, Seattle, WA.

Magirl, C., J. Czuba, C. Czuba, and **P. Kennard**, 2011, *Tools to assess geomorphic response of rivers subject to rapid change in sedimentation: A case study on rivers draining Mount Rainier, Washington*, Invited presentation to USGS Water Mission Area 2011 Lectureship Series, Raleigh, NC.

Magirl, C., J. Czuba, C. Czuba, and **P. Kennard**, 2011, *Tools to assess geomorphic response of rivers subject to rapid change in sedimentation: A case study on rivers draining Mount Rainier, Washington*, Invited presentation to USGS Water Mission Area 2011 Lectureship Series, Atlanta, GA.

Kennard, P., T. Abbe, M. Ericsson, S. Beason, and B. Copeland, 2010, *Rivers Gone Wild: Observations of increasing peak flows, greater sediment inputs and channel response in glacial rivers of Western Washington: Signs of what is to come?*, Invited presentation to USGS Washington Water Science Center Seminar Series, 10-6-10, Tacoma, WA.

Legg, N., and **P. Kennard**, 2010, *Geomorphic Effects of Debris Flows in Glacially Fed Drainages on Mount Rainier, Washington*, Poster presentation to 69th Annual Oregon Academy of Science Meeting, 2-27,2010, Concordia University, Portland, OR.

Kennard, P., 2010, *Hillslope Stability and Submerged Landslide Erosion*, Invited presentation, USGS, BOR, NPS Elwha River Research Field Trip, July 27-28, 2010, Port Angeles, WA.

Kennard, P., 2010, *Rivers Gone Wild! Climate Change, Rising Riverbeds, and the Future of Mount Rainier*, Invited presentation, Northwest Notes Speaker Series, Klondike Gold Rush National Historic Park, 5-22-2010, Seattle, WA.

Abbe, T, **P. Kennard**, 2010, J. Scholtz, and J. Park, *Possible Signals of River Response to Climate Change in Western Washington*, American Water Resources Association (AWRA) conference, 9-9-2010, Seattle, WA.

Kennard, P., 2010, *Alluvial Landscape Response to Climate Change in Glacial Rivers and the Implications to River Restoration*, Invited presentation, 2010 National Park service Aquatic Professionals Meeting, 2-9-10, Fort Collins, CO.

Kennard, P., 2010, *Wastage, Debris Flows, and Kinematic Waves—Nisqually Glacier Changes Related to Climate*, Invited presentation, 2010 National Park service Aquatic Professionals Meeting, 2-10-10, Fort Collins, CO.

Kennard, P., 2010, *Observations of increasing peak flows, greater sediment inputs and channel response in glacial rivers of Western Washington: Signs of what is to come?*, Invited presentation, PNW Climate Science Conference, June 15-16, 2010, Portland State University, Portland, OR.

Kennard, P., 2010, *Floods, fish, and roads — anticipating disasters to protect endangered fish and park infrastructure*, Invited presentation, Mount Rainier National Park Management Team Meeting, Ashford, WA.

Kennard, P., 2010, *Wastage, Debris Flows, and Kinematic Waves—Nisqually Glacier Changes Related to Climate*, Invited presentation, Mount Rainier National Park Management Team Meeting, Ashford, WA.

Kennard, P., 2010, *Carbon river Crisis—Decision 2010, 'Carbon Copy' or 'Grace in Retreat'?*, Invited presentation, Mount Rainier National Park Management Carbon River Interdisciplinary Team, 2-1-10, Ashford, WA.

Kennard, P., 2010, *Emerging Hazards at Mount Rainier*, Invited presentation, Mount Rainier National Park Interpretation Training, Ashford, WA.

Kennard, P., 2010, *Floods, fish, and roads — anticipating disasters to protect endangered fish and park infrastructure*, Invited presentation, Mount Rainier National Park Maintenance Division, Ashford, WA.

Kennard, P., 2010, *Rising Riverbeds and the Future of Mount Rainier*, Invited presentation, USGS-sponsored Congressional Staff Tour, Mount Rainier National Park, Ashford, WA.

Kennard, P., 2009, *Hydrology and Climate Change Issues*, Invited presentation, Mount Rainier National Park Interpretation Training, 6-3-2009, Ashford, WA.

Kennard, P., 2009, *Climate Change, Rising Riverbeds, and the Future of Mount Rainier*, Invited presentation, Mount Rainier Climbing Guide Training, 5-12-2009, Ashford, WA.

Kennard, P., 2009, *Rising Riverbeds and the Future SR 410 (and Mount Rainier….)*, Invited presentation, Federal Highways White River Field Trip, Mount Rainier National Park, Ashford, WA.

Kennard, P., T. Abbe, S. Beason, and B. Copeland, 2009, *Alluvial Landscape Response to Climate Change in Glacial Rivers and the Implications to Transportation Infrastructure*, 2009 Western Federal Lands Highway Division Winter Conference, Vancouver, WA.

Kennard, P., T. Abbe, S. Beason, and B. Copeland, 2009, *Climate Change, Rising Riverbeds, and the Future of the Carbon River Road at Mount Rainier*, Invited presentation, Puyallup River Watershed Council, 8-26-2009, Puyallup, WA.

Kennard, P., 2009, *Climate Change, Rising Riverbeds, and The Future of Mount Rainier*, Invited presentation, Army Center for Health Promotion and Preventive Medicine (CHPPM)-West Mount Rainier , 9-16-09, Ashford, WA.

Kennard, P., T. Abbe, S. Beason, and B. Copeland, 2009, *Rivers Gone Wild – Alluvial Landscape Response to Climate Change in Mount Rainier*, Invited presentation, Climate Impacts Group Seminar, 5/5/09, University of Washington, Seattle, WA.

Kennard, P., T. Abbe, S. Beason, and B. Copeland, 2009, *Rivers Gone Wild – Climate Change, Rising Riverbeds, and the Future of Mount Rainier*, Invited presentation, National Park Ecology Graduate Seminar, 2/9/09, University of Washington, Seattle, WA.

Abbe, T., **P. Kennard**, J. Scholz, J. Park and S. Beason, 2009, *Climate change response in the rivers of Western Washington*, 2009 American Water Resources Association Spring Speciality Conference, Anchorage, Alaska.

Abbe, T., **P. Kennard**, J. Park and S. Beason, 2008, *Alluvial landscape response to climate change in glacial rivers and the implications to transportation infrastructure*, 2008 National Hydraulic Engineering Conference, Portland, Maine.

Abbe, T., S. Beason, **P. Kennard** and J. Park, 2008, *Alluvial landscape response to climate change in glacial rivers and the implications to river restoration*, River Restoration Northwest Annual Symposium, Skamania, Washington.

Kennard, P., J. Ledenican, 2008, *Climate Change, Rising Riverbeds, and the Future of Mount Rainier*, Invited presentation, 2-23-08, Ecumenical Church Council, Ashford, WA.

Kennard, P., 2008, *Rising Riverbeds and the Future SR 410 (and Mount Rainier….)*, Federal Highways Working Group, 8-18-08, Mount Rainier National Park, Ashford, WA.

Kennard, P., 2008, *Rising Riverbeds and the Future of Mount Rainier*, Invited presentation, 2008 National Park service Aquatic Professionals Meeting, 211-08, Fort Collins, CO.

Kennard, P., 2008, *Climate change, rising river beds, and the future of Mount Rainier*, Invited presentation, Mount Rainier National Park Interpretation Training, Ashford, WA.

Kennard, P., 2007, *Rising Riverbeds and the Future of Mount Rainier*, Invited presentation, Mount Rainier Institute's 2007 Summer Speaker Series, Ashford, WA.

Beason, S., and **P. Kennard**, 2007, *Climate change and increasing aggradation rates in glacially-fed braided rivers at Mount Rainier National Park, Washington*, Geological Society of America Abstracts with Programs, Vol. 39, No. 6, p. 504

Beason, S., E. Beaulieu, S. Halmon, M. Iqbal, **P. Kennard**, and J. Walters, 2006, *The environmental implications of aggradation in major braided rivers at Mount Rainier National Park, Washington*, Geological Society of America Abstracts with Programs, Vol. 38, No. 7, p. 440.

Abbe, T., Bountry, J., Piety, L., Ward, G., McBride, M. and **P. Kennard**, 2003, *Forest influence on floodplain development and channel migration zones*, Geological Society of America Annual Meeting (abstract), November 2-5, 2003. Seattle, WA.

Kennard, P., *Riparian-in-a-Box: a Manager's Tool to Predict the Impacts of Riparian Management on Fish Habitat,* presentation to the Fish-Forest Conference, Trout Unlimited Canada, May 4, 1996, Calgary, Canada

P. Kennard, 1985, *Estimated Ice Volumes on Cascade Volcanoes: Mount Baker, Glacier Peak, Mount Adams, and Mount Jefferson,* Geological Society of America Annual Meeting (abstract), November14-17, 1985, Orlando, FL.

Not included are innumerable, undocumented presentations made in the course of my geomorphology employment in the last 25 years. I presented to the general public, the Tribes, state and federal agencies, timber industry groups, and conservation organizations.

III) **AGENCY AND CONSULTANT REPORTS** (not refereed)

Kennard, P., 2012, *Landslide survey surrounding Lakes Mills and Aldwell, Elwha River, Olympic National Park*, technical assistance report to Elwha Project Team Leader, Olympic National Park, Port Angeles, WA.

Numerous coauthors and **P. Kennard**, 2010, *Lake Mills Delta Observations, December 1, 2010*, technical assistance report to Elwha Project Team Leader, Olympic National Park, Port Angeles, WA.

Kennard, P., 2010, *Elwha Historic District Flood Response Plan, Elwha River, Olympic National Park*, technical assistance report to Cultural Resources Division Chief and Elwha Project Team Leader, Olympic National Park, Port Angeles, WA.

Randle, T., J. Bountry, G. Smillie, and **P. Kennard**, 2010, *Lake Mills Delta Erosion Plan*, report to the Olympic National Park, Port Angeles, WA.

Numerous coauthors and **P. Kennard**, 2009, *Trip Report for Mills Delta, Elwha River, Olympic National Park*, technical assistance report to Elwha Project Team Leader, Olympic National Park, Port Angeles, WA.

Kennard, P., 2009, *Trip Report for Finley Creek,* technical assistance report to Chiefs of Natural and Cultural Resources, and Maintenance, Port Angeles, WA.

Kennard, P., 2006, *Trip Report: San Juan National Historical Park (SAJH)—Technical Assistance Analyzing Road Options and Associated Hydrologic Conditions at English Camp, SAJH*, report to Superintendent, San Juan National Historical Park, Friday Harbor, WA.

Kennard, P., 2005, *Enchanted Valley Chalet─Conditions and Options*, technical assistance report to Cultural Resources Division Chief and Environmental Protection Specialist, Olympic National Park, Port Angeles, WA.

Johnson, K., and **P. Kennard**, 2005, *Trip Report for Travel to Devil's Postpile National Monument*, technical assistance report to Park Superintendent, Mammoth Lakes, CA.

Numerous coauthors and **P. Kennard**, 2004, *Evaluation of Flood Potential on Lower Redwood Creek at Muir Beach and Recommendations for Additional Actions*, technical assistance report to Golden Gate National Monument, San Francisco, CA.

Kennard, P., 2002, *Effects of Forest Practice Activities on Sedimentation and Flooding in Contractors Creek, Jefferson County, Washington*, consultant's report to Jefferson County, WA

Kennard, P., 2001, *Middle Hoh Washington State Watershed Analysis Stream Channel Assessment*, Washington Department of Natural Resources, Forks, WA

Kennard, P., 2001, *Supplemental Report regarding the Causes of the 1997 New Year's landslide Impacting the Hanson Property, Dabob Bay*, consultant's report

Kennard, P., 1998, *Nature and Causes of the November 1995 Landslide Impacting Slippery Creek Station, near Greenwater, WA*, consultant's report

Kennard, P., 1998, *Causes of the 1997 New Year's landslide Impacting the Hanson Property, Dabob Bay*, consultant's report

Kennard, P., 1997, *Causes and Consequences of the 1997 New Year's Landslides Impacting Olson's Oyster Company, Quilcene, WA*, consultant's report

Kennard, P., 1996, *Hazel Watershed Analysis Stream Channel Assessment*, Washington State Watershed Analysis Report, Washington Department of Natural Resources, Sedro Woolley, WA

Co-authors with **P. Kennard**, 1995, *Mass wasting assessment*, in "Standard Methodology for Conducting Watershed Analysis under Chapter 222-22 WAC", version 4.0, Washington Forest Practices Act Board Manual, Olympia, WA

Kennard, P., 1995, *Deer Creek Watershed Analysis Mass wasting Assessment*, Washington State Watershed Analysis Report, Washington Department of Natural Resources, Sedro Woolley, WA

Collins, B., co-authors with **P. Kennard**, 1994, *Salmon Habitat and Watershed Assessment and Restoration Plan for Deer Creek, North Cascades of Washington*, consultants' report to the Stillaguamish Tribe and the WDOE by the 10000 Years Institute

Kennard, P. and G. Pess, 1994, *Forest management and stream degradation in Montague Basin: A watershed assessment*, Report to the Tulalip Tribes' Environmental Department, Marysville, WA. 44 p

Kennard, P., 1994, *Road Assessment Procedure (RAP) - A Method to Assess and Rank Risks to Watershed Resources from Forest Road Landslides*, consultant's report to the Weyerhaeuser Company, Tacoma, WA

Co-authors with **P. Kennard**, 1992, *Upper Wishkah river Level I Prototype Watershed Analysis*, consultants report to Rayonier Inc.

Kennard, P., 1991, *Snowmelt,* in 'Geotechnical and hydrologic analysis of the debris flows and extreme flood in Ottawa Hill, B.C.', consultants report to the Slocan Valley Watershed Alliance, April, 1991

Kennard, P., 1991, *Sedimentation analysis,* in 'A technical approach to address cumulative effects on state and private forestlands in Washington—a report to the Administration Committee', March 1991, by the Cooperative Monitoring and Evaluation Committee, Cumulative Effects Task Force, Timber/Fish/Wildlife, Olympia, WA

Not included are dozens of legal declarations on highly technical aspects of geomorphology.

ATTACHMENT 2

STRATUM GROUP
P.O. Box 2546, Bellingham, WA 98227
Phone (360) 714-9409

Forest Practices Board
1111 Washington St. SE
PO Box 47012
Olympia, WA 98504-7012

Re: Perspective on Revised Board Manual Guidelines for Evaluating Potentially Unstable Slopes and Landforms (Section 16)

Dear Forest Practices Board Members,

It is my understanding that you will be asked at your November 10, 2015 meeting to approve revisions to the Board Manual Section 16. Section 16 provides guidance on identification of and evaluation of potentially unstable slopes and landforms. I recognize that the intent of the Board Manual is to be a guidance document and is not a rule that must be followed.

My comments will mostly focus on deep-seated landslides. Rule identified landforms (WAC 222-16-050) identifies 5 categories of unstable slopes A through E. With the exception of toe areas of deep-seated landslides (B) and groundwater recharge to glacial deep-seated landslides (C), deep-seated landslides will follow under the catch all category (E).

Comment 1:

Part 5 of the Manual is "Identifying Potentially Unstable Slopes and Landforms". At the top of Page 16-30 in Part 5 the use of the word "may" leaves open the option of deep-seated landslides not being assessed. I would suggest the sentence be changed as follows:

If desired by the landowner or required by rule, further geotechnical assessments ~~may~~ should include:

I would further add that the use of the word "may" or generally optional language within the proposed Board Manual should be reviewed carefully. While some flexibility and professional judgment by qualified experts will be appropriate, an expert can justify not following a specific manual recommendation using a rational backed up on expertise or available information.

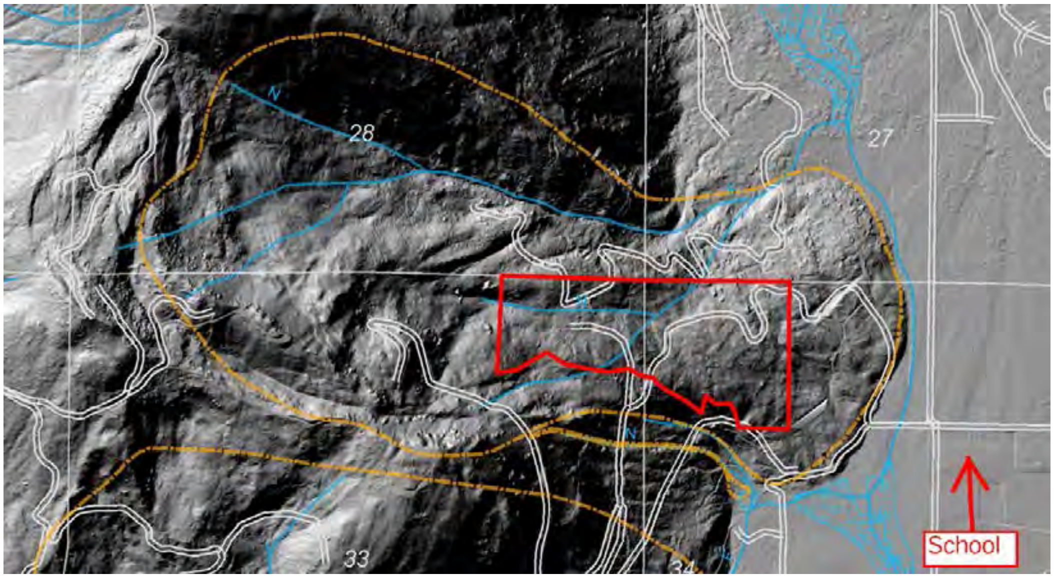
Comment 2:

Within Part 6, deep-seated landslides are only assessed in Part 6.1. Glacial deep-seated landslides are placed in another category, Part 6.2. Part 6.2 references back to Part 6.1 so that glacial deep-seated landslides are evaluated in both Part 6.1 and Part 6.2.

Part 6.2 should apply to all deep-seated landslides. Part 6.2 includes recommendations that should be applicable to all deep-seated landslides not just glacial deep-seated landslides. It is important that all deep-seated landslides be included in the evaluation procedures in Section 6.2.

It appears that the intent is to not include all deep-seated landslides in Section 6.2. The Board should ask if that is the intent and, if so, what is the justification of excluding deep-seated landslides from this level of review. Deep-seated non glacial landslides are very common and wide spread and are found in both non glaciated and glaciated areas throughout Washington State. Some of these landslides are potentially very dangerous and not considering the potential impacts from proposed forest practices would be a failure of the Board Manual.

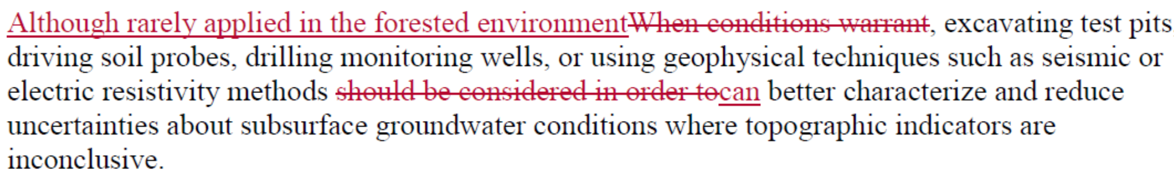
Presented below is an example of a deep-seated non glacial landslide location where a forest practice was proposed on Sumas Mountain in Whatcom County, the North Zender timber sale (#91633). This proposed timber harvest was clearly located on a deep-seated landslide per LiDAR as well as previous geologic mapping and expansion of the slide and further runout poses significant risk.



The proposed Board Manual would have the landslide assessed under Part 6.1 but not under Part 6.2. The criteria and assessment of Part 6.2 would not apply to this obvious deep-seated landslide simply because it is not a glacial deep-seated landslide. There no reasonable basis that Part 6.2 should not apply to this landslide.

Comment 3:

The very end of Part 5 includes the following paragraph:



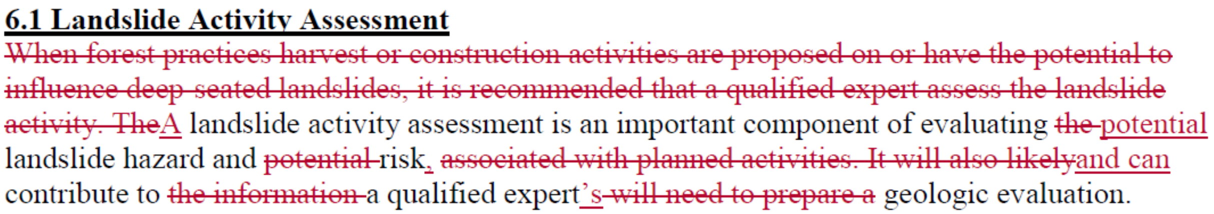
Although rarely applied in the forested environment~~When conditions warrant~~, excavating test pits, driving soil probes, drilling monitoring wells, or using geophysical techniques such as seismic or electric resistivity methods ~~should be considered in order to~~can better characterize and reduce uncertainties about subsurface groundwater conditions where topographic indicators are inconclusive.

I would say some of the methods listed in the paragraph for better characterizing a slope are rarely used in forest practice slope assessment, but to call them all out as rare is unnecessary - particularly test pits and to a lesser extent soil probes. I dig test pits all the time when assessing slope conditions, Yes, the pits I dig are always hand dug, but it is an important means of determining shallow subsurface conditions. I would be very surprised if other geologist do not do the same. I have justified timber harvests on steep slopes based on hand dug test pit results and have recommended avoidance of slopes based on test pits.

I suggest that then entire first phrase of the paragraph be dropped. I would further suggest that in the case of deep-seated landslides that may be impacted by forest practices, utilizing less common methods may be warranted given the potential risk (see additional comment below).

Comment 4:

The first paragraph at 6.1 has been significantly altered.



6.1 Landslide Activity Assessment

~~When forest practices harvest or construction activities are proposed on or have the potential to influence deep-seated landslides, it is recommended that a qualified expert assess the landslide activity. The~~A landslide activity assessment is an important component of evaluating ~~the~~ potential landslide hazard and ~~potential~~ risk, ~~associated with planned activities. It will also likely~~and can contribute to ~~the information~~ a qualified expert's ~~will need to prepare a~~ geologic evaluation.

I see no justification for removing the first sentence. The introductory paragraph should read as follows:

When forest practices harvest or construction activities are proposed on or have the potential to influence deep-seated landslides, it is recommended that a qualified expert assess the landslide activity. The landslide activity assessment is an important component of evaluating ~~the~~ potential landslide hazard and ~~potential~~ risk associated with planned activities. It will also likely contribute to the information a qualified expert will need to prepare a geologic evaluation.

Comment 5:

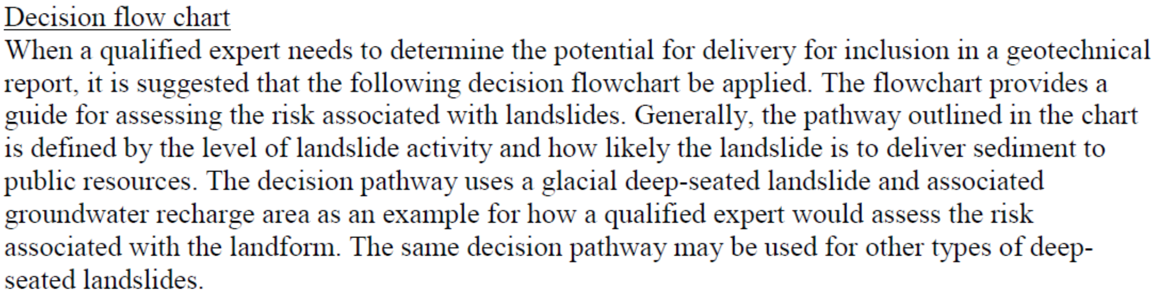
Table 2 is to be utilized for assessing the *state of activity* of a landslide. The use of the table is to determine if the slide is active, dormant distinct, dormant indistinct or relict. As noted in the Board Manual the table is a modified version of an approach version of an approach that had been used in Colorado and published in 1996.

Table 2 was developed prior to great expansion of LiDAR. While it may not be practical at this point in your process, this table should be replaced or substantially modified to incorporate LiDAR information.

Comment 6:

Part 6.2 should apply to all deep-seated landslides and hence should be titled Part 6.2 Deep-seated Landslides.

The interim Board Manual had a paragraph at the end of Part 7.1 (now Part 6.1), that showed clear intent to further assess deep-seated landslides via the referenced decision flow path (now removed) in the same manner as glacial-deep seated landslides.

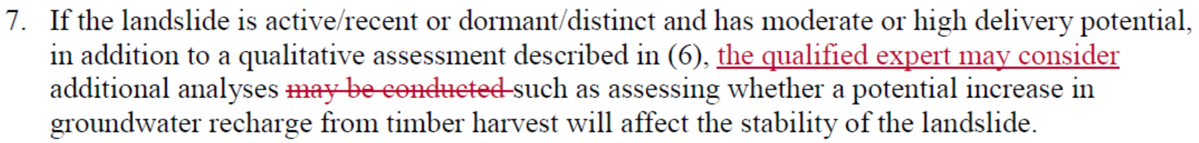


Decision flow chart

When a qualified expert needs to determine the potential for delivery for inclusion in a geotechnical report, it is suggested that the following decision flowchart be applied. The flowchart provides a guide for assessing the risk associated with landslides. Generally, the pathway outlined in the chart is defined by the level of landslide activity and how likely the landslide is to deliver sediment to public resources. The decision pathway uses a glacial deep-seated landslide and associated groundwater recharge area as an example for how a qualified expert would assess the risk associated with the landform. The same decision pathway may be used for other types of deep-seated landslides.

Comment 7:

The proposed Part 6.2 step 7.



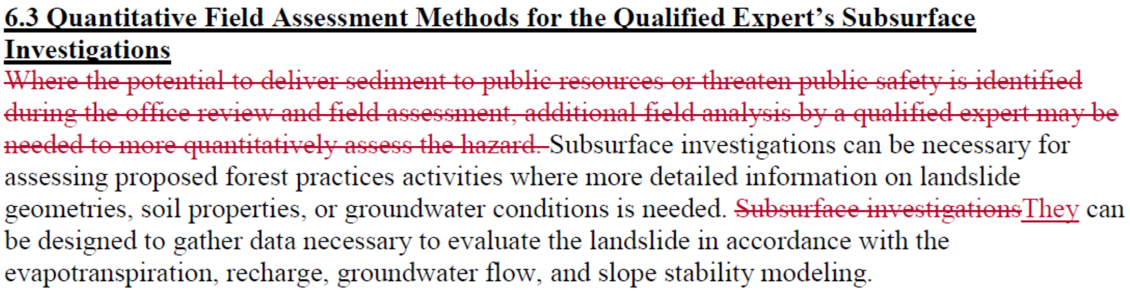
7. If the landslide is active/recent or dormant/distinct and has moderate or high delivery potential, in addition to a qualitative assessment described in (6), the qualified expert may consider additional analyses ~~may be conducted~~ such as assessing whether a potential increase in groundwater recharge from timber harvest will affect the stability of the landslide.

Step 7 should be modified to say that the qualified expert shall consider additional analyses......

Without that the Manual suggests it would be acceptable to not consider groundwater recharge impacts to the stability of a landslide. Is that really something that should be left open?

Comment 8:

Part 6.3 has been modified in a manner such that is not clear when quantitative field assessments are needed. The struck sentence provides guidance on when quantitative field work would be applicable.



6.3 Quantitative Field Assessment Methods for the Qualified Expert's Subsurface Investigations

~~Where the potential to deliver sediment to public resources or threaten public safety is identified during the office review and field assessment, additional field analysis by a qualified expert may be needed to more quantitatively assess the hazard.~~ Subsurface investigations can be necessary for assessing proposed forest practices activities where more detailed information on landslide geometries, soil properties, or groundwater conditions is needed. ~~Subsurface investigations~~They can be designed to gather data necessary to evaluate the landslide in accordance with the evapotranspiration, recharge, groundwater flow, and slope stability modeling.

Thank you for considering these comments.

Sincerely,

Dan McShane
Engineering Geologist
WA License # 1376
mcshanedan@gmail.com

ATTACHMENT 3

FORESTS AND FISH CONSERVATION CAUCUS

c/o Washington Forest Law Center
(Coordinating Organization)
615 Second Avenue, Ste 360
Seattle, WA 98104

Tel: (206) 223-4088
Fax: (206) 223-4280

November 5, 2015

Via electronic mail to forest.practicesboard@ dnr.wa.gov

Forest Practices Board
1111 Washington St. SE
PO Box 47012
Olympia, WA 98504-7012

Re: Fatal Flaws in the Revised Board Manual Guidelines for Evaluating Potentially Unstable Slopes and Landforms (Section 16)

Dear Forest Practices Board Members,

Long before the tragic landslide at Oso, the Forests and Fish Conservation Caucus has consistently advocated for more precautionary and effective risk management decision-making consistent with the intent of the Forest Practices Rules to "*avoid accelerating the rates and magnitudes of mass wasting that could deliver sediment or debris to a public resource or in a manner that would threaten public safety*" (WAC 222-10-030(4)). When it comes to avoiding potential risks that threaten public safety, it is both appropriate and responsible to apply the precautionary principle to landslide hazard assessment, because in the face of scientific uncertainty, land management decisions that err on the side of caution will best protect the environment and public well-being.[1]

During your November 10, 2015 meeting, DNR staff will request your approval of revisions to Board Manual Section 16. Our caucus has been engaged on the technical committee tasked with the revision process since your May 2014 motion directing DNR to review and amend this guidance in two phases: 1) identification, delineation, and additional analyses of Rule-Identified Landforms (RIL); and 2) estimating landslide runout and delivery potential. Phase 1 of Board Manual 16 revisions were developed by an "expert panel" comprised of qualified experts chosen by the DNR, without influence from Policy members. For reasons that have yet to be clarified by the DNR, for Phase 2 the revision process was changed to include both qualified experts and Policy representatives. In this regard, Policy member influence on screening qualified expert

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[1] Kriebel, D., J. Tickner, P. Epstein, J. Lemons, R. Levins, E.L. Loechler, M. Quinn, R. Rudel, T. Schettler, and M. Stoto. 2001. The Precautionary Principle in Environmental Science. Environmental Health Perspectives 109(9):871-876.

Mary Scurlock, Policy Representative ▪ **Chris Mendoza**, Science Representative

Conservation Northwest ▪ Olympic Forest Coalition ▪ Pacific Rivers Council ▪ Washington Environmental Council
Washington State Chapter of the Sierra Club ▪ Washington Forest Law Center ▪ Wild Fish Conservancy

work products essentially obstructed the ability of the technical committee members to revise the manual consistent with the best available science.

During the Board Manual revision process, the objective of our caucus was to develop methods supported by the best available science through a precautionary lens in order to minimize the risk to public safety consistent with existing Rule. Unfortunately, in many cases not all stakeholders agreed that a precautionary approach is consistent with existing Rule, even when it better protects public safety, and as a result of policy screening the proposed revision of the Board Manual falls short of this target. Despite many hours of discussion, revisions by the technical members, and policy negotiation, the stakeholder group was unable to reach agreement on a number of key sections that directly address minimizing potential risks to public safety. Each of these items is summarized below. More detailed scientific critiques of these issues by qualified experts will be submitted to you separately.

Phase 1

1. Ambiguous, weakened, and omitted language from DNR's Expert Panel

The Conservation Caucus remains concerned that the final edits to the Board Manual that DNR is proposing unnecessarily weaken the guidance provided by the qualified expert panel and approved by you in November 2014. Examples include deleting the words "recommended", changing what procedures "should" be considered to what "may" be considered, and changing what investigations and analyses "are necessary" to "may be necessary" (Attachment 1). Substantive changes to content proposed by DNR staff could increase the risk to public safety when implemented on the ground. For instance, in Part 6.2 Glacial Deep-Seated Landslide Assessment:

Expert Panel Recommendation (FPB approved November 2014):

7. If the landslide is active/recent or dormant/distinct and has moderate or high delivery potential, in addition to a qualitative assessment of historic pattern of timber harvesting and landslide movement described in (6), if appropriate, perform a quantitative assessment of potential increase in groundwater recharge from timber harvest and effect on stability of the landslide.

DNR Proposal:

7. If the landslide is active/recent or dormant/distinct and has moderate or high delivery potential, in addition to a qualitative assessment ~~of historic pattern of timber harvesting and landslide movement~~ described in (6), the qualified expert may consider additional analyses ~~if appropriate, perform a quantitative assessment of~~ such as assessing whether a potential increase in groundwater recharge from timber harvest ~~and effect on~~ will affect the stability of the landslide.

This pattern of DNR staff weakening and/or omitting language that was originally developed by DNR's expert panel is prevalent throughout the Board Manual before you today (Attachment 1). Our caucus requests that substantive content language and weakened or omitted language, especially that recommended by the expert panel, be restored to the Board Manual. Because the Board Manual is a voluntary guidance document, not Rule (see Introduction, p. 16-3), it is inappropriate to interpret its recommendations as Rule-like requirements - the main reason DNR staff has given us for their weakened revisions and omissions of the expert panel (and previously Board approved) language.

2. Unclear guidance on landslide activity level and reactivation potential

When the potential for reactivation of any portion of a relict or dormant/indistinct glacial deep-seated landslide by harvest within the groundwater recharge area is likely or uncertain, the proposed Board Manual revision does not recommend additional analyses (p. 16-43). This implies that relict and dormant/indistinct glacial deep-seated landslides cannot be reactivated by harvest within the groundwater recharge area, a gross assumption challenged by qualified experts, especially where potential increased risks to public safety is a concern. At a minimum, qualitative topographic, hydrologic, and vegetative indicators should be carefully sought in the field, but a lack of evidence of recent activity nor the landslide activity level are an acceptable surrogate for the potential to reactivate. Similarly, a lack of movement following past logging on or around a landslide is no guarantee that future logging will not destabilize the landslide, because immediately after the past logging, there may not have been a sufficient amount of precipitation and elevated groundwater to cause failure during the period when the landform was most susceptible to failure. In addition, past climatic conditions are inconsistent with future climatic projections that indicate an increased magnitude and duration of precipitation in our region caused by atmospheric rivers.[2]

To address these faulty assumptions with a more precautionary approach, we recommend that where the threat to public safety is moderate, high, or uncertain for a glacial deep-seated landslide of any "activity level", the landowner should quantitatively assess whether a potential increase in groundwater recharge from timber harvest will affect the stability of the landslide (Board Manual Parts 6.3-6.5). Because predictive models of deep-seated landslide runout are not yet readily available, it will also be necessary to describe qualitative methods for deep-seated landslide runout assessment in the Board Manual (see #6).

3. Complex or Composite Rotational Deep-Seated Landslides

The 2014 Hazel landslide that struck Oso, Washington is an example of a complex or composite rotational deep-seated landslide, but this type of failure is not described in sufficient detail in the revised Board Manual. Recognizing this gap, and with the approval of the stakeholder group following a presentation by Anne Weekes, PhD, Research

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[2] Warner, M.D., C.F. Mass, and E.P. Salathé Jr.. 2015. Changes in winter Atmospheric Rivers along the North American West Coast in CMIP5 climate models. J. Hydrometeor 16:118–128.

Geohydrologist, our caucus commissioned Dr. Weekes to write a section on identifying complex or composite rotational deep-seated landslides (Attachment 2). Despite the high relevance of the topic and group support for its inclusion, time was not made available by DNR staff for the stakeholder group to discuss the draft, and the DNR decided against including this section in their proposed draft.

Moreover, DNR was recently awarded $4 million from the state legislature for the acquisition and administration of Light Detection and Ranging (LiDAR) coverage for the purpose of identifying where the most dangerous deep-seated landslides posing the greatest threats to public safety likely exist. Anne Weekes' section specifically addresses how, through the use of LiDAR, forest landowners and managers can identify the greatest threats to public safety from complex deep-seated landslides. Our caucus requests that the Complex or Composite Rotational Deep-Seated Landslides section be added to the Board Manual at 4.4 under Part 4. Characteristics of Unstable and Potentially Unstable Slopes and Landforms.

4. Landslide Assessment Decision Pathway

Recognizing the need in the Board Manual for a more explicit and precautionary approach to the landslide assessment and Forest Practices Application (FPA) review processes, our caucus developed a decision pathway / flow chart that links together the various parts of the Board Manual into a repeatable, defensible decision making process (Attachment 3). For example, the decision pathway leads a FPA to Class IV-Special if it is probable or uncertain a potential or uncertain RIL will deliver to a public resource or threaten public safety (consistent with existing Rule: potentially unstable slopes or landforms WAC 222-16-050(1)(d)(i)). The DNR is ultimately responsible for determining whether or not the information submitted with a FPA provides a sufficient level of certainty.

After multiple iterations of the draft decision pathway to address stakeholder group concerns, not all group members were able to come to an agreement on the concepts of precaution and certainty in RIL verification and potential threat or delivery even though the pathway maintains discretion in defining certainty based on professional judgement and site-specific factors and does not deviate from existing Rule. We request that the Landslide Assessment Decision Pathway be added to Phase 1 (at end of Part 1, Introduction).

Phase 2

5. Shallow Rapid Landslide Coarse Screen

The stakeholder group spent a significant amount of time and money (consultant fees) developing a coarse screening tool for estimating the runout distance of shallow rapid landslides. This tool is intended for general practitioners (foresters) to know when to raise the "red flag" (without the assistance of a qualified expert) where a shallow landslide/debris flow is likely to runout far enough to deliver to public resources and/or threaten public safety

(Attachment 4). It's based on a detailed flow chart adapted from the Tolt Watershed Analysis (plus a synthesis of more recent science from Washington, Oregon and British Columbia), with separate pathways for open slope (non-channelized) landslides, debris flows, and dam-break floods. Without this coarse screen, the Board Manual is not repeatable, nor precautionary with respect to public safety, and a large gap for missing potentially dangerous landslides still exists.

Despite stakeholder consensus of the significant need for the shallow rapid landslide coarse screen in the Board Manual, the large investment of human resources devoted to its development, successful testing of the coarse screen by the group in the field, and general agreement within the group on the science-based structure and numeric topographic criteria within the screen, DNR did not include it in their proposed Board Manual revision. To help resolve the minor remaining disagreements regarding the numeric criteria, our caucus requested that DNR staff conduct an analysis of existing landslide runout databases (given that much of the data is housed at DNR), but this was never done. There is no requirement that Board Manual materials be limited by stakeholder consensus, and our caucus supports this approach as it keeps individual stakeholder groups from holding the veto pen. We do not support the DNR removing key portions of the Board Manual when the group does not reach full consensus (especially when the points of contention are minor). Essentially this promotes a stakeholder's ability to veto by simply disagreeing with the outcome. Final resolution of the coarse screen by the stakeholder group was also impeded when DNR staff arbitrarily deprioritized it late in the group process such that insufficient time remained to complete it as a group. Instead of including a version of the coarse screen at DNR's discretion in its proposed draft revision, the DNR decided to omit the coarse screen entirely. We strongly request that the Shallow Rapid Landslide Coarse Screen be added to the Board Manual before Part 6.6.4 Methods and Models for Predicting Shallow Rapid Landslide Runout and Delivery.

6. Methods for Deep-Seated Landslide Runout Assessment

As noted above, predictive empirical or numeric models of deep-seated landslides are not yet readily available due to a lack of data supporting such models. Our caucus recognized the need to at least include some qualitative methods in the Board Manual to enable a general assessment of deep-seated landslide runout by general practitioners or qualified experts. We wrote a brief paragraph with one figure as an illustrative example (Attachment 5). The stakeholder group briefly discussed and suggested some edits to the proposed material, but again, time to complete the editing process was not made available by DNR staff. Although this section appeared to be highly relevant and non-prescriptive "low hanging fruit", DNR did not include it in the revised Board Manual.

Our caucus requests that the Methods for Deep-seated Landslide Runout Assessment section be added to the Board Manual before the Methods and Models for Predicting Shallow Rapid Landslide Runout and Delivery (#5).

In conclusion, based on past Board discussions, deliberations and motions, we strongly believe your intent in directing DNR staff to revise the Board Manual was to minimize future risk to the public from potential landslide hazards associated with shallow and deep-seated landslides resulting from forest practices. The majority of the items described in this letter were supported by the qualified experts in the group, which is why we continued developing them as a group. Had DNR retained the expert panel approach for Phase 2 Board Manual revisions free from Policy influence as they did for Phase 1, most of these issues would have been resolved.

Finally, until this Board formally defines and clarifies what level of "risk" is acceptable from a public safety perspective, our caucus has maintained that a single landslide hitting a house or other public infrastructure is unacceptable. Using a precautionary approach, based on the best available science, for identification and runout assessments of landslides that pose a risk to public safety is the best way to achieve this goal, and fulfilling the requests outlined in this letter will get us much closer to meeting that goal. Our caucus representatives are available to assist the DNR in making the requested revisions as needed.

Sincerely, on behalf of the Conservation Caucus,

Kara Whittaker, PhD
Kara Whittaker
Senior Scientist & Policy Analyst
Washington Forest Law Center

Chris Mendoza
Science Representative
Conservation Caucus

ATTACHMENT 1

WASHINGTON STATE DEPARTMENT OF
Natural Resources

PETER GOLDMARK
Commissioner of Public Lands

MEMORANDUM

October 12, 2015

TO: Forest Practices Board

FROM: Marc Ratcliff
Forest Practices Policy and Services Section

SUBJECT: Board Manual Section 16, *Guidelines for Evaluating Potentially Unstable Slopes and Landforms* – Approval of revisions to delivery and runout guidance

On November 10, I will request the Board's approval of revisions to Board Manual Section 16. These revisions include DNR staff recommendations for addressing the Conservation Caucus and Washington Forest Protection Association's comments submitted at the August Board meeting and recommendations for completing runout and delivery guidance. As you will recall, the Board postponed the completion for delivery guidance until November.

As directed by the Board at the August Board meeting, the stakeholder group met to discuss the comments specific to guidance clarification. DNR staff addressed each comment submitted, provided the rationale whether revisions were merited, and solicited group feedback. The decision to amend a particular phase or clarify technical language was based on lessening redundancy, providing accurate scientific information, distinguishing rule requirements, and creating a more readable Board Manual.

Stakeholder participants continued to work on amendments for improving runout and delivery guidance through August and September. The amendments include information on landslides associated with rule-identified landforms, factors contributing to debris flow runout, debris fan development and the inclusion of selected methods professionals can use when conducting delivery assessments. The added information focuses on shallow rapid landslides, as these are by far the most common landslide type and predicative runout models have been developed by the scientific community. Guidance for deep-seated landslide runout is not discussed because the complexity of movement and triggering mechanisms do not allow for simple predictive models.

The amendments relating to guidance clarification are shown in tracked changes throughout the document. Since the revisions to Part 6.6 (page 49) are extensive, it is easier to show the new part as finalized text rather than in underline strikeout.

I will be available to provide further explanations to amendments and answer any questions. Please feel free to contact me at 360.902.1414 or marc.ratcliff@dnr.wa.gov.

MR

Section 16

Guidelines for Evaluating Potentially Unstable Slopes and Landforms

PART 1. INTRODUCTION

Board Manual Section 16 contains guidelines to evaluate potentially unstable slopes and landforms on forest lands. Like all Board Manual sections, it does not contain rules or impose requirements. Instead, it is an advisory technical supplement to the forest practices rules. The section:

- Provides general practitioners with tools to better understand potential landslide hazards and risks in the areas of proposed forest practices activities;
- Identifies when a qualified expert is needed;
- Assists qualified experts with tools and methods to conduct geotechnical investigations; and
- Provides guidance to prepare geotechnical reports.

The intended audience is:

- Landowners, foresters, and company engineers or private consultants, referred to in this section as "general practitioners", who assist in field work; and
- Qualified experts, as that term is defined in WAC 222-10-030(5).

The current rules related to potentially unstable slopes and landforms were developed to avoid an increase over natural background rates from forest practices on high-risk sites at a landscape scale.

The rules apply when it is determined that proposed forest practices activities may contribute to the *potential* for sediment and debris delivery to a public resource or cause a threat to public safety. When the potential for slope instability is recognized, the likelihood of landslide movement and damage must be considered. ~~Other~~The factors in determining this likelihood could include initial failure landslide volume, the nature of the landslide, potential landslide runout distance, and slope or channel conditions.

Certain landforms are particularly susceptible to slope instability or indicate past slope instability. Forest practices applications (FPAs) proposing activities on or near these landforms may be classified "Class IV-special" and receive additional environmental review under the State Environmental Policy Act (SEPA). These landforms, commonly referred to as "rule identified landforms", are listed in WAC 222-16-050(1) and described in Part 4.

Board Manual Section 16 is composed of seven parts, a glossary, references, and appendices:

- Parts 2, 3, and 4 contain general background information for all readers on how to recognize the various landslide types in Washington State (Part 2), how to recognize slope form (Part 3), and how to recognize potentially unstable slopes and landforms for purposes of identifying them in the area of a proposed forest practices activity (Part 4).
- Parts 5, 6, and 7 contain procedures and resources for conducting reviews and assessments of potentially unstable areas in relation to proposed forest practices. General practitioners will find 5.1.1 and 5.2.1 most useful for their office reviews and field assessments. The information in 6.6 will be useful to both general practitioners and qualified experts for landslide runout assessments. The remainder of Parts 5 and ~~all of Parts~~ 6, ~~-~~and all of Part 7 give guidance to the work of qualified experts to conduct expert-level office reviews and field assessments, and to prepare geotechnical reports.
- It ends with a glossary of terms that may not be familiar to many readers; a list of the references cited throughout the document; and appendices containing lists of resources that any reader may find informative or useful.

PART 2. LANDSLIDE TYPES IN WASHINGTON

Landslides occur naturally in forested basins and are an important geomorphic process in the delivery of wood and gravel to streams and nearshore environments. Wood and gravel play significant roles in creating stream diversity essential for fish habitat and spawning grounds.[1]

"Landslide" is a general term for any downslope movement of rock, unconsolidated sediment, soil, and/or organic matter under the influence of gravity. It also refers to the landslide deposit itself, and slide materials in mountainous terrain that typically are separated from more stable underlying material by a zone of weakness, commonly referred to as the failure zone, plane, or surface.

Landslides can be classified in several ways. The classification shown in 2.1 describes the type of movement (fall, topple, slide, spread, or flow) and the types of materials involved (rock, soil, earth, or debris). The failure surface can range from roughly planar (called "translational"), to curved (called "rotational"), or a combination of translational and rotational geometries (see Figure 1). Translational failures can also occur on non-planar surfaces (i.e., concave or convex) in shallow

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[1] e.g., Reeves et al. 1995; Geertsema and Pojar 2007; Restrepo et al. 2009.

soils overlying bedrock on steep slopes[2] with little observed rotation or backward tilting of the slide mass. Landslides can be small (a few cubic yards) or very large (millions of cubic yards). They can range from very fast moving as in free fall, to very slow as in creep. Landslides can come to rest quickly or can continue to move for years or even centuries. Landslides that stop moving only to be later reactivated are considered dormant slides while they are at rest. A landslide can also permanently cease moving and undergo erosion and revegetation over long periods of geologic time; this is a "relict" landslide.

Slope instability resulting in landslides occurs when gravitational forces overcome the strength of the soil and rock on a slope. Contributing factors may include:

- The presence of an impermeable stratigraphic layer underlying a permeable stratigraphic layer.
- Soil saturation by snowmelt, rain-on-snow events, or heavy and/or prolonged rains that can create instability in soil and weakened bedrock.
- Erosion by rivers, glaciers, or wave action that causes the over-steepening of slopes and removal of support from the base of the slopes.
- Ground shaking caused by earthquakes that increases the driving force and weakens the supporting soil structure.
- Excess weight from activities such as stockpiling of rock or earth, and road sidecast and landing construction.
- Activities such as timber harvest and construction that disturb soils, weaken or remove the support for slopes, or increase runoff and groundwater recharge over a seasonal timescale or during prolonged heavy precipitation events.
- Activities such as stream pirating or concentrating water in unstable locations during road construction.

2.1 Landslide Types and Effects

Several classification schemes are used by geologists and other professionals to identify and describe landslides. The classification scheme of Varnes (1978), as modified by the U.S. Geological Survey (2004) and Hungr et al. (2001), is used for the purposes of this Board Manual section (see Table 1). This scheme is based on the type of movement and type of materials involved in the slope failure, with further classification possible based on the rate of movement. Hungr et al. (2001) proposed modifications to definitions of flow-type landslides, many of which are commonly associated with forest practices in Washington. For example, a debris flow is defined as a rapid flow of non-plastic debris within a steep stream channel, distinguished from a debris avalanche, which occurs on an open slope.

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[2] Robinson et al. 1999; Turner et al. 2010.

Table 1. Landslide Classification

Based on Varnes (1978) as modified by U.S. Geological Survey (2004) and Hungr (2001).

Type of Movement		Type of Material		
			Soils	
		Bedrock	Predominately Coarse	Predominately Fine[3]
Falls		Rock Fall	Debris Fall	Earth Fall
Topples		Rock Topple	Debris Topple	Earth Topple
Slides	Rotational	Rock Slide	Debris Slide	Earth Slide
	Translational			
Lateral Spreads		Rock Spread	Debris Spread	Earth Spread
Flows-Confined		Rock Flow	Debris Flow	Earth Flow
Flows-Unconfined		Rock Avalanche	Debris Avalanche	Debris Flood
Complex		Combination of two or more principal types of movement		

Materials in a landslide mass are either rock or soil (or both) and may include organic debris. In this context, soil is composed of sand-sized or finer particles and debris is composed of coarser fragments. The types of landslides commonly found in forested areas in Washington are slides, flows, and complex landslides. The types of movement describe the actual internal mechanics of how the landslide mass is displaced: fall, topple, slide, spread, or flow. Thus, landslides are described with two terms that refer to the type of material and method of movement (rockfall, debris flow, and so forth). Landslides may also occur as a complex failure encompassing more than one type of movement. A common example is a debris slide that evolves into a debris flow. Less common, but potentially of great import, are deep-seated landslides that periodically fail as a debris flow or debris avalanche. Some of the landslide types shown in Table 1 can be further divided into shallow or deep-seated depending on whether the failure plane is above (shallow) or below (deep) the rooting depth of trees. Simplified illustrations of the major types of landslides are shown in Figure 1.

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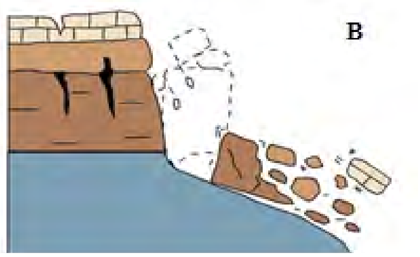
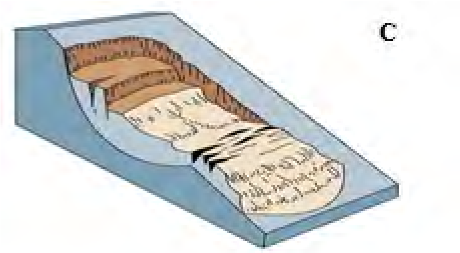
[3] The terms used in the "Predominately Fine" column are seldom used in the forest environment where coarse materials including wood are common.

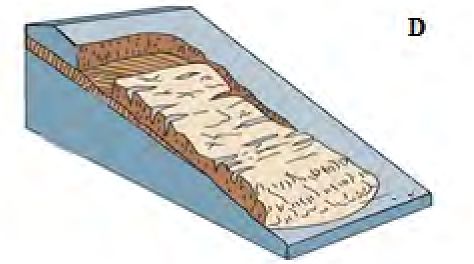
Falls: Falls occur when a mass of rock or soil detaches from a steep slope or cliff, and are often caused by the undercutting of the slope. The failure is typically rapid to very rapid. The fallen mass may continue down the slope until the terrain flattens.



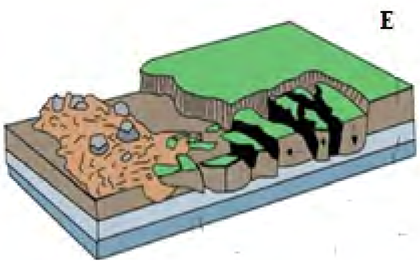
Topples: Landslides where the forward rotation of a mass of rock or soil breaks away or 'topples' from the slope. Their failure rates range from extremely slow to extremely fast.



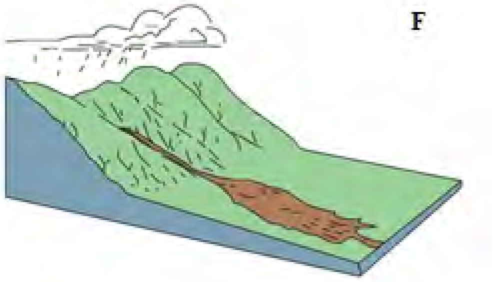
Rotational slides: Landslides where the surface of rupture is concave-up and the slide movement is rotational about an axis that is parallel to the contour of the slope. Glacial deep-seated landslides can be rotational slides developed in glacial sediments common in the Puget Sound area, but they can also involve more complex types of movement.



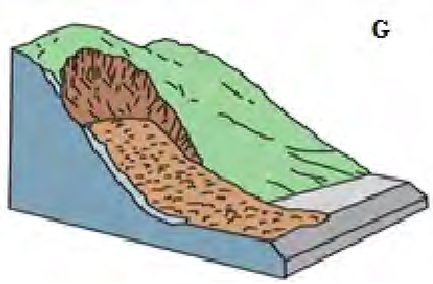
Translational slides: Landslides where the surface of the rupture is roughly planar with a surface roughly parallel to the ground surface. These are called rock slides, block glides, slab slides, or debris slides.



Lateral spreads: Landslides that generally occur on very gentle or level slopes and are caused by subsidence of a fractured mass of cohesive material into softer, often liquefied underlying material.



Debris flows: Channelized landslides where loose rock, soil, and organic matter combine with water to form a slurry that flows rapidly downslope.



Debris avalanches: Rapid to extremely rapid shallow flows of partially or fully saturated debris on steep slopes, without confinement in an established channel.

Earth flows: Landslides consisting of fine-grained soil or clay-bearing weathered bedrock. They can occur on gentle to moderate slopes. Overall, there is little or no rotation of the slide mass.

Figure 1. Illustrations of the major types of landslide movement (all from Highland and Bobrowsky2008, except the earth flows illustration is from U.S. Geological Survey 2004).

2.2 Shallow Landslide Types

Shallow landslides are unstable features that typically fail within the vegetation rooting zone and may respond to rainfall events over periods of days to weeks. They occur on a variety of landforms including bedrock hollows, convergent headwalls, inner gorges, toes of deep-seated landslides, the outer edges of meander bends, and in other areas with steep slopes. The amount of water and the materials contained within shallow landslides affect the manner and distance in which they move.

Debris slides consist of aggregations of coarse soil, rock, and vegetation that lack significant water and move at speeds ranging from very slow to rapid downslope by sliding or rolling forward. The results are irregular hummocky deposits that are typically poorly sorted and non-stratified. Debris slides include those types of landslides also known as shallow rapid, soil slips, and debris avalanches. If debris slides entrain enough water they can become debris flows.

Debris flows are channelized slurries composed of sediment, water, vegetation, and other debris. Solids typically constitute more than 60% of the volume.[4] Debris flows usually occur in steep channels as debris becomes charged with water (from soil water or upon entering a stream channel) and liquefies as it breaks up. Channelized debris flows often entrain material and can significantly bulk up in volume during transport. These landslides can travel thousands of feet or miles from the point of initiation, scouring the channel to bedrock in steeper channels. Debris flows commonly slow where the channel makes a sharp bend and stop where the channel slope gradient becomes gentler than about 3 degrees (~~5~~6%), or the valley bottom becomes wider and allows the flow to spread out. Hyper-concentrated floods may travel greater distances and on shallower slopes than debris flows based on their water content.[5]

Figure 2. Debris flow (DNR 2000).

Debris avalanches. Hungr et al. (2001) defined a debris avalanche as a very rapid to extremely rapid shallow flow of partially or fully saturated debris on steep slopes, without confinement in an established channel. Sharpe (1938) defined a debris avalanche as a shallow landslide that is morphologically similar to a snow avalanche. Debris avalanches may enter steep drainage channels or gullies and become debris flows. Therefore, the term debris avalanche should be reserved for

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[4] Pierson and Scott 1985.

[5] Iverson and Reid 1992.

events that remain poorly channeled over most of their length, without a defined recurrent path and a laterally bounded deposition landform.

Dam break floods are a subset of flow-type landslides defined as very rapid surging flows of water, heavily charged with debris, in a steep channel.[6] They contain a mixture of water and sediment (dominantly sand-sized) and organic debris with solids that range between 20% and 60% by volume.[7] In forested mountains, they are commonly caused by the collapse of dams, such as those formed by landslide dams (Figure 3) or debris jams. Impounded water and debris released when the dam is breached sends a flood wave down the channel that exceeds the magnitude of normal floods, and generally extends beyond the range of influence that has been documented for debris flows.[8] Such floods can rise higher than normal rainfall- or snowmelt-induced flows along relatively confined valley bottoms, driving flood waters, sediment, and wood loads to elevations high above the active channel, and the active floodplain if present.

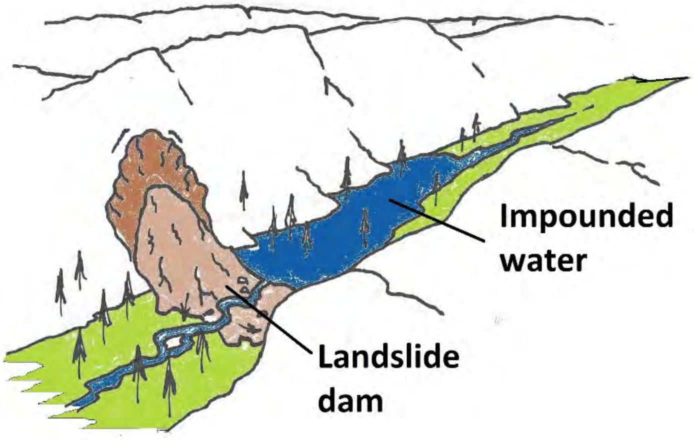

Figure 3. Impounded water caused by landslide dam.

Debris flows and dam break floods can occur in any unstable or potentially unstable terrain with susceptible valley geometry. In natural systems, debris flows and dam break floods are responsible for moving sediment and woody debris from hillslopes and small channels down into larger streams. They can also scour channel reaches, disturb riparian zones, dump debris onto salmonid spawning areas, elevate turbidity, adversely affect water quality downstream, and threaten public safety.

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[6] Hungr et al. 2001.

[7] Pierson and Scott 1985.

[8] Johnson 1991.

Figure 4. Left: Road-initiated debris flows in unstable landforms, Sygitowicz Creek, Whatcom County (Photo: DNR 1983). Right: Same hillslope 28 years later (2011 aerial photo).

The photo on the left in Figure 4 shows debris flows that coalesced and, after exiting the confined channel at the base of the mountain, formed a new debris flow spreading across a 1,000-foot wide swath for a distance of 2,000 feet before entering the South Fork Nooksack River. Between the base of the mountain and the river, the debris flow affected a county road, farmyard, house sites, and more than 60 acres of cultivated farm fields. The photo on the right shows the same hillslope after harvest with leave tree areas in the slide-prone inner gorges.

2.3 Deep-Seated Landslides

Deep-seated landslides are those in which the slide plane or zone of movement is typically below the maximum rooting depth of forest trees (generally greater than 10 feet or 3 meters). They may extend to hundreds of feet in depth and may involve underlying bedrock. They can be a wide range of sizes up to several miles across.

Deep-seated landslides can occur almost anywhere on a hillslope. Many occur in the lower portions of hillslopes and extend directly into stream channels, whereas those confined to upper slopes may not have the ability to deposit material directly into channels. They occur in weak materials such as thinly layered rocks, unconsolidated sediments, deeply weathered bedrock, or rocks with closely spaced fractures. They can also occur where a weak layer is present in otherwise strong rocks. Deep-seated landslides in glacial deposits are usually associated with hydrologic responses in the permeable glacial materials overlying less permeable materials.

Deep-seated slides may respond to rainfall events over periods of days to weeks, or weather patterns over months to years or even decades.[9] The larger deep-seated landslides can usually be identified from LiDAR (Light Detection and Ranging) imagery, topographic maps, and aerial photos, whereas smaller landslides are more difficult to identify and often require a field inspection.

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[9] Washington State Department of Emergency Management 2013.

There are three main parts of a deep-seated landslide: the scarps (head and side); the body, which is the displaced slide material; and the toe, which also consists of displaced materials (Figure 5). A deep-seated landslide may have one or more of these component parts because small deep-seated landslides can be found nested within larger slides. The head and side scarps together form an arcuate or horseshoe shaped feature that represents the surface expression of the rupture plane. The body and toe area usually display hummocky topography, and the flow path of streams on these landslide sections may be displaced in irregular patterns due to differential movement of discrete landslide blocks. The parts of deep-seated landslides that are most susceptible to shallow landslides and potential sediment delivery are steep scarps (including marginal stream side slopes) and toe edges.

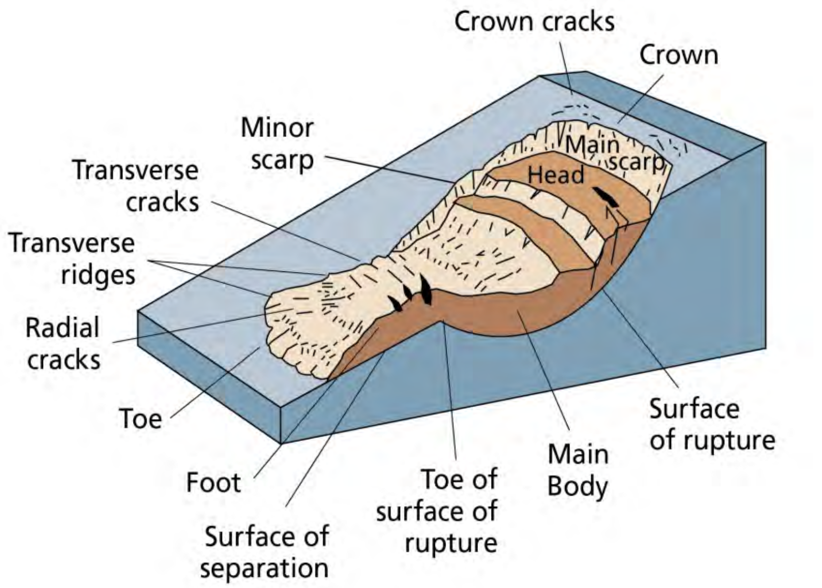

Figure 5. Rotational deep-seated landslide. Rotational displacement of blocks of soil commonly occur at the head of the landslide (adapted from USGS 2004).

Movement of deep-seated landslides can be complex, ranging from slow to rapid, and may include numerous small to large horizontal and vertical displacements triggered by one or more failure mechanisms.[10] Deep-seated landslides are often part of large landslide complexes that may be intermittently active for hundreds of years or more.[11] The bodies and toes of deep-seated landslides and earth flows are made up of incoherent collapsed materials that were weakened from previous movement of the materials, and therefore may be subject to debris flow initiation. As a result, sediment delivery can occur from shallow landsliding on steep stream-adjacent toes of deep-seated landslides, and from steep side slopes along marginal stream channels within the bodies of deep-seated landslides.

Triggering mechanisms of deep-seated landslides can result from over-steepening of the toe by natural means such as glacial erosion or fluvial undercutting, earthquakes, or anthropogenic

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[10] Roering et al. 2005.

[11] Bovis 1985; Keefer and Johnson 1983.

activities such as excavating for land development.[12] Movement in landslides is usually triggered by accumulations of water at the slide zone; therefore, land use changes that alter the amount or timing of water delivered to a landslide can start or accelerate movement.[13] Initiation or reinitiation of such landslides has also been associated with increases in groundwater levels[14] due to individual storms or in response to seasonal accumulation from rainfall or snow melt, depending on soil and bedrock properties, and the degradation of material strength through natural processes. When subsurface water is assumed to influence the movement of a deep-seated landslide, the ~~methods~~process used to identify how groundwater ~~recharge areas associated with glacial deep-seated landslides may apply to other (e.g., non-glacial) deep-seated landslides~~affects the slide zone should be appropriate for the geologic materials within the landslide.

The loss of tree canopy interception of moisture and the reduction in evapotranspiration through timber removal on areas up-gradient of the slide may also initiate movement of the slide. However, ~~many~~ deep-seated landslide~~s~~ movement can be diverse and influenced by geomorphic and hydrologic factors, ~~are~~and is not ~~hydrogeologically connected to groundwater sources~~always associated with up-gradient groundwater sources.[15] Generally, avoiding the following practices will ~~prevent~~ minimize human-caused ~~reinitiating~~ re-initiation or ~~accelerating~~ acceleration of deep-seated landslide movement: removing material during road construction or quarrying at the toe; overloading slopes by placing spoils on the upper or mid-scarp areas; changing subsurface hydrology by excessive soil compaction; and directing additional water into the slide from road drainage or captured streams.

PART 3. SLOPE FORM

Slope form is an important concept when considering the mechanisms behind shallow landsliding. Understanding and recognizing the differences in slope form is essential to recognizing potentially unstable landforms. There are three major slope forms observed when looking across the slope (contour direction): divergent (ridgetop); planar (straight); and convergent (spoon-shaped) (Figure 6a). Landslides can occur on any of these slope forms but divergent slopes tend to be more stable than convergent slopes because water and debris spread out on divergent slopes, whereas water and debris concentrate on convergent slopes. Convergent slopes tend to lead into the stream network, encouraging delivery of landslide debris to the stream system. Planar slopes are generally less stable than divergent slopes but more stable than convergent slopes. In the vertical direction, ridgetops are convex areas (bulging outward) and tend to be more stable than planar (straight) mid-slopes and concave areas (sloping inward) (Figure 6b).

Slope steepness can play a significant role in shallow landsliding. Steeper slopes tend to be less stable. The soil mantle, depending on its make-up, has a natural angle at which it is relatively stable (natural angle of repose). When hillslopes evolve to be steeper than the natural angle of repose of the soil mantle, the hillslope is less stable and more prone to shallow landslides, especially with the addition of water. The combination of steep slopes and convergent topography has the highest potential for shallow landsliding.

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[12] Schuster and Wieczoreck 2002.

[13] Cronin 1992.

[14] van Asch et al. 2005.

[15] van Asch et al. 2009.

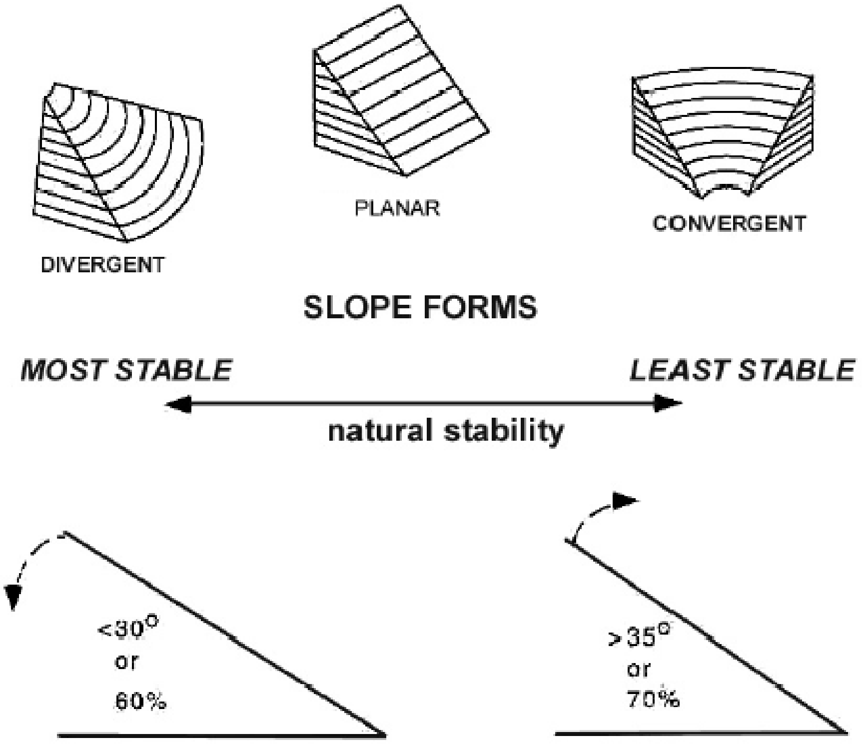

Figure 6a. Slope configurations as observed in map view.

Figure 6a shows three major slope forms (divergent, planar, and convergent) and their relative stability. These slope form terms are used in reference to contour (across) directions on a slope. Typically, convergent areas with slope gradients equal to or greater than 35 degrees (70%) are at a higher risk of sliding.[16]

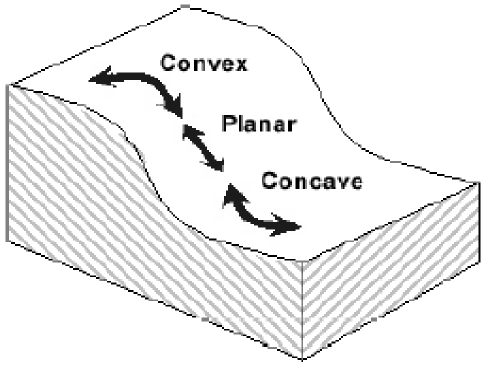

Figure 6b. Slope configurations as observed in profile: convex, planar, and concave. These terms are used in reference to up and down directions on a slope (Drawing: Jack Powell, DNR 2004).

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[16] Benda et al. 1997.

PART 4. CHARACTERISTICS OF UNSTABLE AND POTENTIALLY UNSTABLE SLOPES AND LANDFORMS

This part describes the characteristics of the potentially unstable slopes and landforms listed in WAC 222-16-050(1)(d)(i), commonly referred to as "rule-identified landforms." They are listed in the rule from (A) to (E) as follows:

A. Inner gorges, convergent headwalls, or bedrock hollows with slopes steeper than 35 degrees (>70%) (see 4.1);
B. Toes of deep-seated landslides with slopes steeper than 33 degrees (>65%) (see 4.2);
C. Groundwater recharge areas for glacial deep-seated landslides (see 4.3);
D. Outer edges of meander bends along valley walls or high terraces of an unconfined meandering stream (see 4.4); or
E. Any areas containing features indicating the presence of potential slope instability which cumulatively indicate the presence of unstable slopes (see 4.5).

The rule-identified landforms represent the most common landforms with the potential to fail in response to natural and management factors. They can be identified with a combination of topographic and geologic maps, aerial photographs, LiDAR data, and a variety of private and public agency-derived landform screening maps and tools. Field observation is needed to verify their presence and precisely delineate landform boundaries, measure gradients, and note other characteristics. In addition to the information provided in Part 4, guidance for identifying potentially unstable landforms is offered in Part 5.

In most instances, the landform terms described here are also used in the scientific literature. For the purposes of Washington forest practices, the rule-identified landform terms, definitions, and descriptions supersede those used in the scientific literature. Note that all sizes, widths, lengths, and depths are approximate for the following discussion and are not part of the rule-identified landform definitions unless parameters are specifically provided. Some of the rule-identified landforms have specific slope gradients (degrees and percent). Appendix A provides information on measurements of slope gradients.

4.1 Bedrock Hollows, Convergent Headwalls, Inner Gorges

These three landforms are commonly found together as shown in Figures 7 and 8.

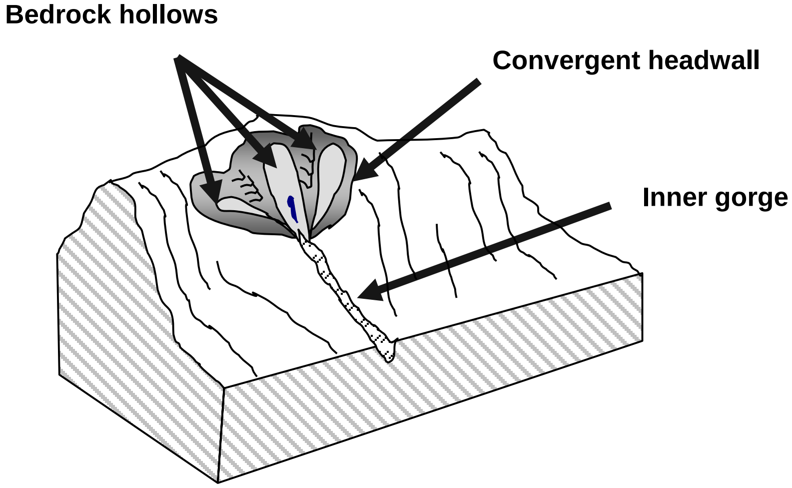

Figure 7. Typical hillslope relationships between bedrock hollows, convergent headwalls, and inner gorges (Drawing: Jack Powell, DNR 2003).

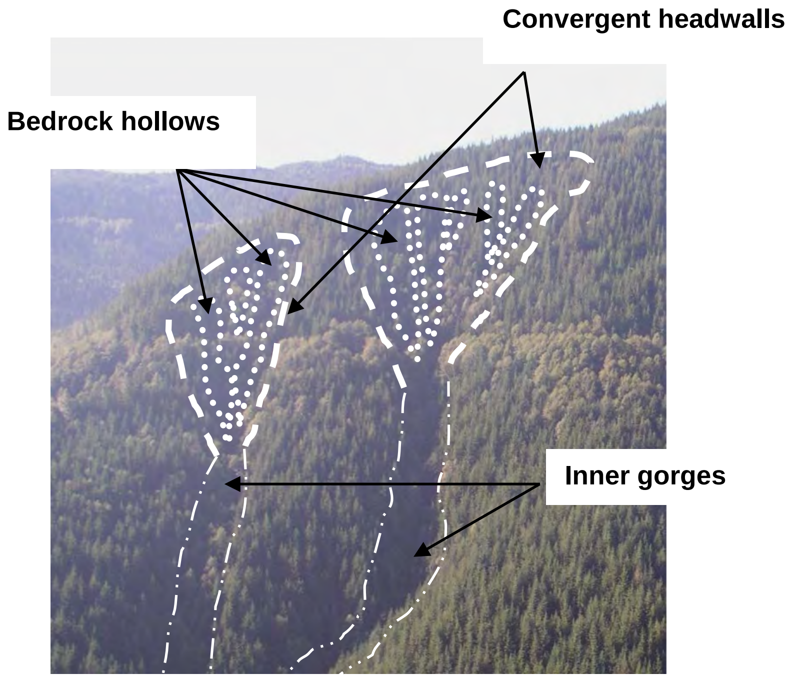

Figure 8. Common hillslope relationship: bedrock hollows in convergent headwalls draining to inner gorges (Photo and drawing: Jack Powell, DNR 2003).

Bedrock hollows are also called colluvium-filled bedrock hollows, zero-order basins, swales, bedrock depressions, or simply hollows.[17] Not all hollows contain bedrock so the term "bedrock" hollow can be a misnomer. In the forest practices rule context, the "bedrock hollows" listed in category A are hollows formed in bedrock. Hollows formed in other materials, such as glacial outwash without a bedrock substrate may also show signs of instability. These would need evaluation similar to hollows containing bedrock and would fit into category E of the rule.

Bedrock hollows are commonly spoon-shaped areas of convergent topography with concave profiles on hillslopes. They tend to be oriented linearly up- and down-slope. Their upper ends can extend to the ridge or begin as much as several hundred feet below the ridge line. Most bedrock hollows are approximately 75 to 200 feet wide at their apex (but they can also be as narrow as several feet across at the top), and narrow to 30 to 60 feet downhill. Bedrock hollows should not be confused with other hillslope depressions such as small valleys, sag areas (closed depressions) on the bodies of large deep-seated landslides, tree windthrow holes (pit and mound topography), or low-gradient swales.

Bedrock hollows often form on other landforms such as head scarps and toes of deep-seated landslides. Bedrock hollows can occur singly or in clusters that define a convergent headwall. They commonly drain into inner gorges (Figure 9).

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[17] Crozier et al. 1990; Dietrich et al. 1986.

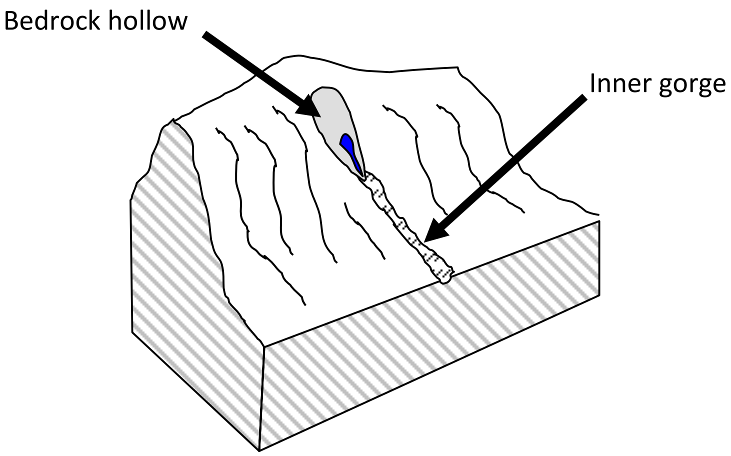

Figure 9. Bedrock hollow and relationship to inner gorges (Drawing: Jack Powell, DNR 2003).

Bedrock hollows usually terminate where distinct channels begin. This is at the point of channel initiation where water emerges from a slope and has carved an actual incision. Steep bedrock hollows typically undergo episodic evacuation of debris by shallow-rapid mass movement (a debris flow), followed by slow refilling with colluvium that takes years or decades. Unless they have recently experienced evacuation by a landslide, bedrock hollows are partially or completely filled with colluvial soils that are typically deeper than those on the adjacent spurs and planar slopes. Recently evacuated bedrock hollows may have water flowing along their axes, whereas partially evacuated bedrock hollows will have springs until they fill with sufficient colluvium to allow water to flow subsurface.

Figure 10 illustrates the evolution of a bedrock hollow. Drawing “a” shows that over a period of tens to hundreds or thousands of years in some places, sediment accumulates in a hollow. When the soil approaches a depth of 3 to 5 feet (1 to 2 meters), the likelihood of landslides increases. Recurrent landsliding within the bedrock hollow slowly erodes bedrock and maintains the form of the bedrock hollow (drawing “b”). After a landslide occurs in a bedrock hollow, seeps or springs may be exposed and the risk of additional sliding may be reduced but not eliminated. Drawing “c” shows soil from the surrounding hillsides (colluvium) slowly re-filling the bedrock hollow. As vegetation and trees establish the site after past failures, the roots help stabilize the soil.

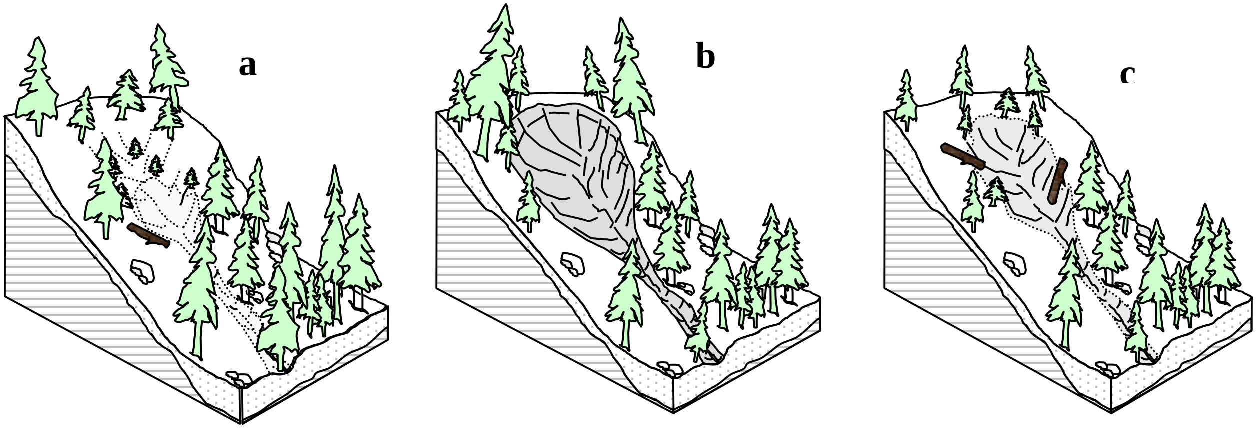

Figure 10. Evolution of a bedrock hollow following a landslide (adapted from Dietrich et al. 1988; drawing by Jack Powell, DNR 2004).

The common angle of repose for dry, cohesion-less materials is about 36 degrees (72%), and saturated soils can become unstable at lower gradients. Thus, slopes steeper than about 35 degrees (70%) are considered susceptible to shallow debris slides. Bedrock hollows form on slopes of varying steepness. Bedrock hollows with slopes steeper than 35 degrees (70%) are potentially unstable in well-consolidated materials, whereas bedrock hollows in poorly consolidated materials may be unstable at lower angles. For the purpose of this document and when considering slope instability, bedrock hollow slopes are measured on the steepest part of the slope, and generally not along the axis unless the bedrock hollow is full (Figure 11).

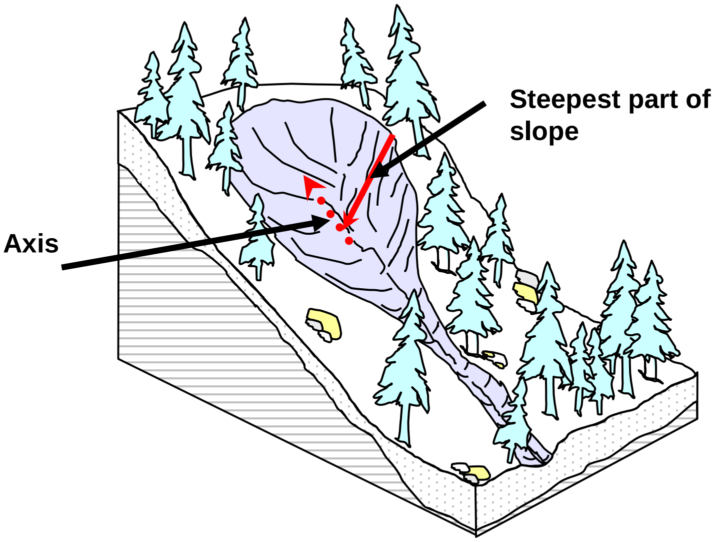

Figure 11. Bedrock hollow slopes are measured at the steepest part of the slope, rather than along the axis (Drawing: Jack Powell, DNR 2004).

Vegetation can provide the critical cohesion on marginally stable slopes and removes water from the soil through evapotranspiration. Leaving trees in steep, landslide-prone bedrock hollows helps maintain rooting strength and should reduce the likelihood of landsliding[18] (Figures 4 and 12). However, windthrow of the residual trees following harvest can be associated with debris slide or debris flow events. In high wind environments, harvest practices that will limit the susceptibility of the residual trees to windthrow and reduce the potential for landslides include leaving wider strips, pruning or topping trees in the strips, or feathering the edges of leave tree strips.

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[18] Montgomery et al. 2000.

Figure 12. Example of leave tree strips protecting unstable slopes (Photo: Venice Goetz, DNR 2004).

Convergent headwalls are funnel-shaped landforms, broad at the ridgetop and terminating where headwaters converge into a single channel. A series of converging bedrock hollows may form the upper part of a convergent headwall. Convergent headwalls are broadly concave both longitudinally and across the slope, but may contain sharp ridges that separate the bedrock hollows or headwater channels (Figures 13 and 14).

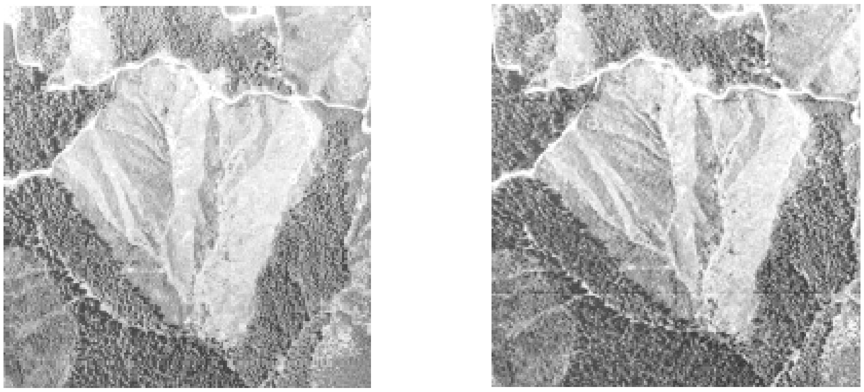

Figure 13. Stereo pair of a clearcut convergent headwall in Pistol Creek basin, North Fork Calawah River, Washington.

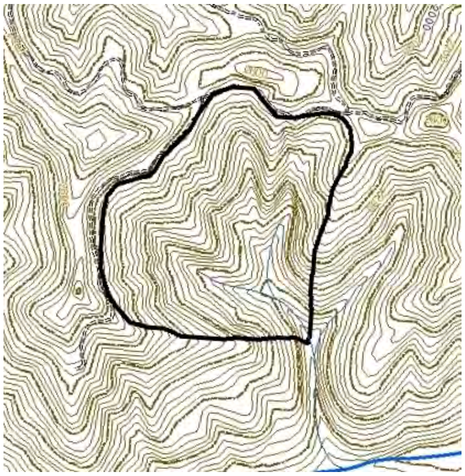

Figure 14. Rotated topographic map and outline of convergent headwall displayed in the stereo pair of Figure 13 (Hunger Mountain and Snider Peak USGS 7.5' quadrangles).

Convergent headwalls generally range from about 30 to 300 acres. Slope gradients are typically steeper than 35 degrees (70%) and may exceed 45 degrees (94%). Soils are thin because landslides are frequent in these landforms. History of erosion and landsliding can be evident by a lack of vegetation or mature trees on the site, or the presence of early seral plant communities such as grasses or red alder. It is the arrangement of bedrock hollows and first-order channels on the landscape that causes a convergent headwall to be a unique mass wasting feature. The highly convergent shape of the slopes, coupled with thin soils, may allow for a more rapid onset of soil saturation. The mass wasting response of these landforms due to storms, disturbances such as fire, and forest practices activities is much greater than is observed on other steep hillslopes in the same geologic settings. In Figure 15 the convergent headwall has approximately 25 bedrock hollows today (not visible through the canopy), and eons of high erosion have caused the entire ridgeline to set back several hundred feet from that of the extended hillslope. Landslide scars from convergent headwalls may be prone to surface erosion.

Figure 15. Convergent headwall in North Fork Calawah River, Washington.

Channel gradients are extremely steep within convergent headwalls, and generally remain so for long distances downstream. Landslides that evolve into debris flows in convergent headwalls typically deliver debris to larger channels below. Channels that exit the bottoms of headwalls were formed by repeated debris flows and are efficient at conducting debris flows. Convergent headwalls commonly have debris fans at the base of their slopes.

Inner gorges are canyons created by a combination of stream down-cutting and mass movement on slope walls.[19] Inner gorges are characterized by steep, straight, or concave sideslope walls that commonly have a distinctive break in slope (Figure 16). Debris flows, in part, shape inner gorges by scouring the stream, undercutting side slopes, and/or depositing material within or adjacent to the channel (Figure 17). Inner gorge side slopes may show evidence of recent landslides, such as raw unvegetated slopes, young even-aged disturbance vegetation, or areas that are convergent in contour and concave in profile. Because of steep slopes and proximity to water, landslide activity in inner gorges is highly likely to deliver sediment to streams or structures downhill. Exceptions can occur where benches of sufficient size to stop moving material exist along the gorge walls, but these are uncommon.

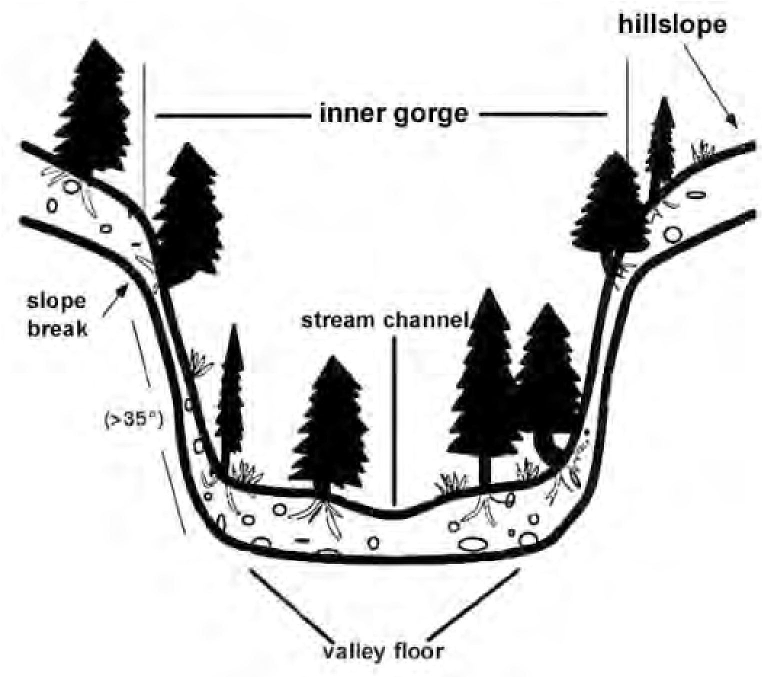

Figure 16. Cross-section of an inner gorge. This view emphasizes the abrupt steepening below the break-in-slope (Drawing: Benda et al. 1998).

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[19] Kelsey 1988.

Figure 17. Photograph showing how debris flows help shape features related to inner gorges: over-steepened canyon wall; U-shaped profile; buried wood; and distinctive break-in-slope along margins of inner gorge (Photo: Laura Vaugeois, DNR 2004).

The geometry of inner gorges varies from simple to complex. Steep inner gorge walls can be continuous for great lengths, such as along a highly confined stream that is actively down cutting, but there may also be gentler slopes between steeper ones along valley walls. Inner gorges can be asymmetrical with one side being steeper than the other. Stream-eroded valley sides along main stem rivers can be V-shaped with distinct slope breaks at the top. These commonly show evidence of small-scale landsliding but do not display severe impact, such as hillslope inner gorges which tend to be U-shaped. In practice, a minimum vertical height of 10 feet is usually applied to distinguish between inner gorges and slightly incised streams.

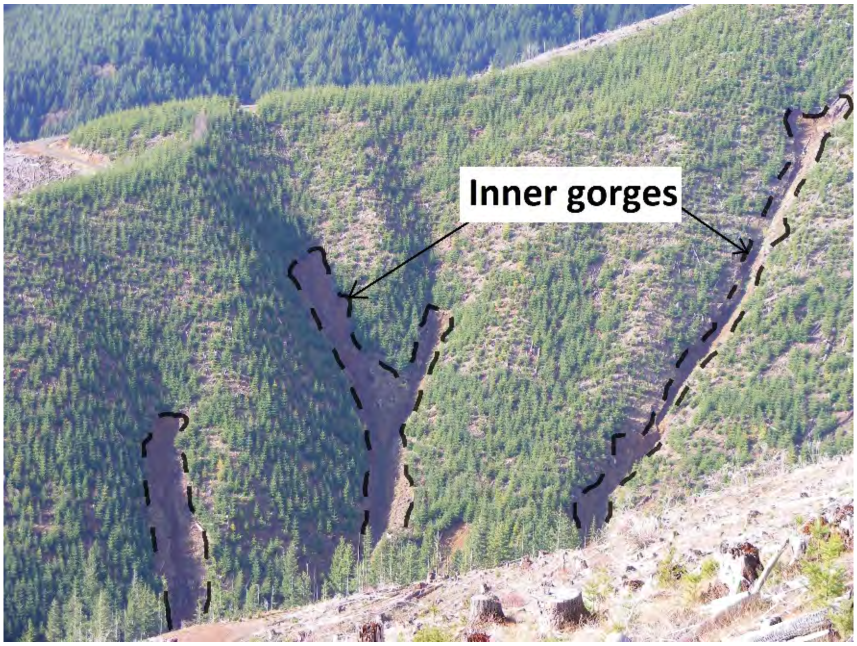

Figure 18. Inner gorges in immature forest stands, Stillman Creek Watershed (Photo: Venice Goetz, DNR 2010)

The upper boundary of an inner gorge is assumed to be a line along the first break in slope of at least 10 degrees, or the line above which gradients are mostly gentler than 35 degrees (70%) and convex. The delineating break-in-slope occurs where over-steepened slopes related to inner gorge erosion processes intersect slopes formed from normal hillslope erosion processes. While the upper inner gorge boundary is typically distinct, in some places it can be subtle and challenging to discern. Inner gorge slopes tend to be especially unstable at the point where the slope breaks because the abrupt change in gradient causes subsurface water to collect within the soil matrix. This can increase the likelihood of landsliding. As with all other landforms, inner gorge slopes should be measured along the steepest portion of the slope (see Figure 11).

The steepness of inner gorges depends on the underlying materials. In competent bedrock, gradients of 35 degrees (70%) or steeper can be maintained, but soil mantles are sensitive to root strength loss at these angles. Slope gradients as gentle as about 28 degrees (53%) can be unstable in inner gorges cut into incompetent bedrock, weathered materials, or unconsolidated deposits.

Stream erosion creates instability by undercutting the toe of the slopes in an inner gorge. Erosion along the inner gorge walls may be exacerbated by the interception of shallow groundwater, which forms seeps along the sides of the inner gorge. Root strength along walls and margins of inner gorges has been found to be a factor that limits the rates of mass wasting. Inner gorge areas can lose root strength when trees blow down. However, downed timber has a buttressing effect providing some slope reinforcement. Effective rooting width of forest trees is approximately the same as the crown width. In some instances, where the inner gorge feature is highly unstable, it is necessary to maintain trees beyond the slope break. The rooting strength of trees adjacent to the landform can often provide additional support.

4.2 Toes of Deep-Seated Landslides

Toes of deep-seated landslides with slopes greater than 33 degrees (65%) are a rule-identified landform. In this context, “toes of deep-seated landslides” means the downslope toe edges, not the entire toe area of displacement material. Figures 5 and 19 show the toe in relation to other landslide features.

Landslides with toe edges adjacent to streams have a high potential for delivery of sediment and wood to streams through natural processes. In such situations, streams can undercut the landslide toes and promote movement. Over-steepened toes of deep-seated landslides can also be sensitive to changes caused by harvest and road construction. The road shown in Figure 19 may have removed a portion of the toe, causing reactivation of the landslide. Resulting instability can take the form of shallow landslides, small-scale slumping, or reactivation of parts or the whole of a deep-seated landslide. Because deep-seated landslides are usually in weak materials (further weakened by previous movement), an angle of 33 degrees (65%) is the regulatory threshold used on the potentially unstable toe edges. Regardless of the surface expression of the toe, it is best to avoid disrupting the balance of the landslide mass by cutting into or removing material from the toe area.

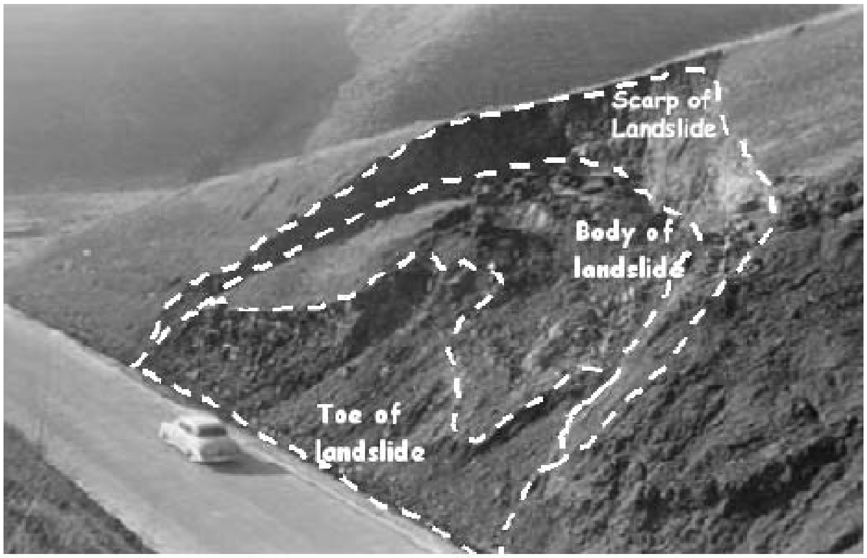

Figure 19. Deep-seated landslide showing the head scarp, side-scarps, body, and toe. Some of the toe has been removed in building and maintaining the highway (adapted from a USGS photo).

4.3 Groundwater Recharge Areas for Glacial Deep-Seated Landslides

Groundwater recharge areas for glacial deep-seated landslides are rule-identified landforms. Part 5.3 provides methods for delineating these areas. In order to identify and delineate a groundwater recharge area in glacial terrain, it is necessary to first identify the associated landslide.

Glacial deep-seated landslides occur in glacial terrain and are defined as ~~a~~ landslide features where most of the slide plane or zone lies within glacial deposits. The depth of the glacial deposits extends below the maximum rooting depth of trees, to depths ranging from tens to hundreds of feet beneath the ground surface. Glacial deep-seated landslides are distinguished from other forms of deep-seated landslides by the materials in which they occur; however, their failure mechanics can be similar to deep-seated landslides developed in other materials.[20]

Glacial deep-seated landslide deposits occur in continental or alpine glacial deposits, or a combination of both. The continental glacial deposits in Washington are located in the northern areas of the state (Figure 20a), and the alpine glacial deposits (Figure 20b) are found in mid-to-high elevation mountain ranges.[21]

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[20] Terzhagi 1951.

[21] Booth et al. 2003; Booth et al. 1994; Thorsen, R.M. 1980; Barnosky 1984; Heusser 1973; Crandall 1965.

Figure 20a. Extent of continental ice sheet in the Pacific Northwest (DNR 2014).

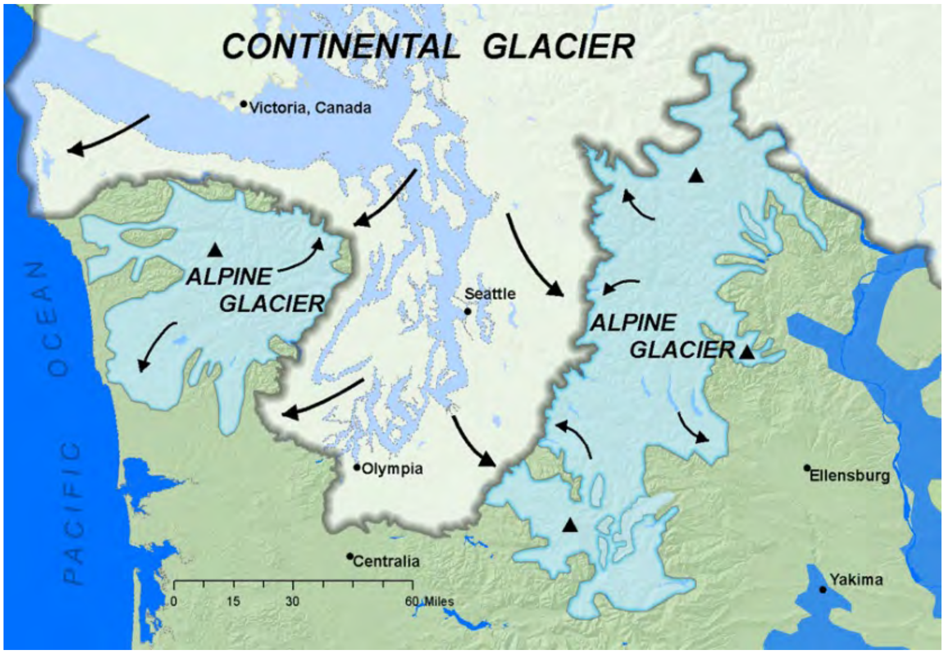

Figure 20b. Continental and alpine glaciation in western Washington (DNR 2014).

Glacial deep-seated landslides can involve rotational and translational movement or flows, or a combination of movement types. They can occur in any type of glacial deposit including till, outwash, glaciolacustrine and glaciomarine silt and clay, or a mix of multiple glacial strata. During interglacial periods, layers of loess (e.g., windblown silt and clay) and fluvial sediments may have been deposited on the surface of glacial deposits or become overlain by glacial deposits from successive glaciations.

Glacial and interglacial deposits display a wide range of hydrogeologic characteristics, including permeability (the rate water moves through a geologic material) and storage capacity (the amount of water released or taken into storage per unit area of geologic material for a given change in hydraulic head). Glacial till is comprised of unsorted and non-stratified glacial materials (ranging in size from clay to boulders) that was generally overrun by glacial ice during periods when the ice was advancing. Till typically has low permeability and low water storage capacity. Glacial outwash typically contains sorted and stratified sediments deposited by water flowing from glacial ice during the advance or the retreat of the glacier, and have higher permeability and water storage capacity than glacial till. Glaciolacustrine deposits are typically fine-grained silts and clays deposited in ice-marginal lakes. Glaciomarine deposits are similar to glaciolacustrine deposits except the materials are deposited directly into marine waters. Glaciomarine and glaciolacustrine deposits typically have low permeability and low storage capacity, similar to glacial till. See Appendix H for the hydrologic properties of various soils.

Glacial deep-seated landslides can be affected by the hydrologic budget of an area (Figure 21). The hydrologic budget is the amount of groundwater present and is calculated based on precipitation (rain and snow), interception of precipitation by vegetation, evapotranspiration, surface storage, surface runoff, and groundwater recharge. Groundwater recharge is the component of a hydrologic budget that infiltrates into the subsurface below the vegetative rooting zone. The groundwater component is composed of water within the unsaturated and saturated zones.

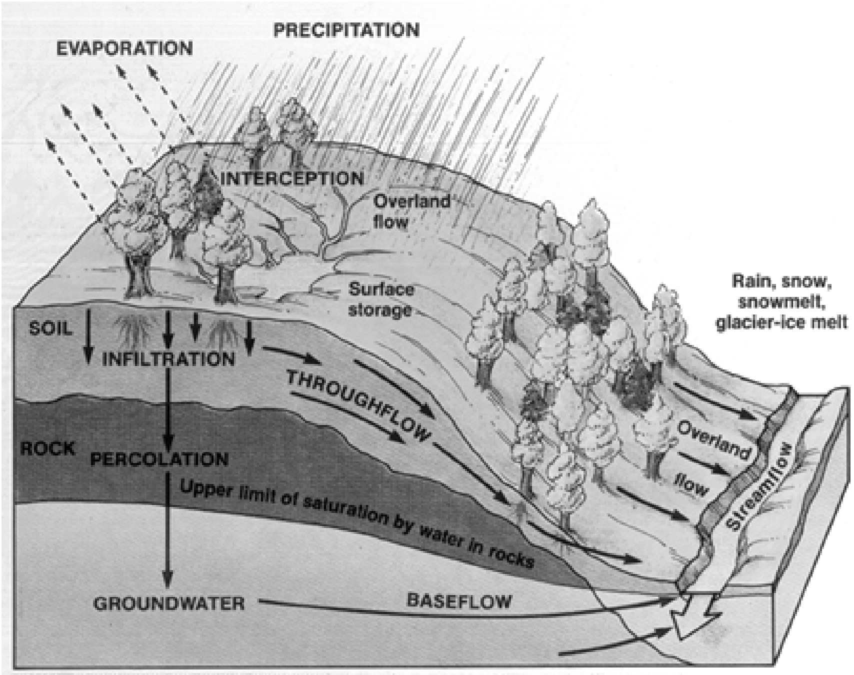

Figure 21. Hydrologic budget of a hillslope (University of Colorado).

Groundwater recharge to a glacial deep-seated landslide can occur in several ways. Groundwater may originate from adjacent non-glacial materials that flows into glacial sediments, or runoff from upland non-glacial materials that contributes groundwater recharge within glacial sediments. A contributing component of groundwater recharge can also be surface flow.

The area that contributes groundwater to a glacial deep-seated landslide, including the landslide itself, constitutes that landslide's groundwater recharge area. However, parts of the landslide may not be hydrologically connected to glacial material, sediments, or deposits. Groundwater flows originating in upland areas can discharge as springs, streams, and other surface water features at lower elevations.

Differences in permeability within glacial sediments control the infiltration and movement of groundwater within the recharge area.[22] Groundwater perching and routing, and the characteristics of the overlying groundwater recharge area can be important factors in a deep-seated failure. This is especially true for landslides in glacial sand and other unconsolidated deposits that overlie less permeable strata such as fine-grained glacial lake deposits, till, or bedrock (Figure 22). This is a common configuration of the glacial deposits in much of the Puget Lowlands (e.g., landslides in Seattle)[23] and in the North Cascades foothill river valleys (e.g., the Stillaguamish River valley)[24], but also occurs in alpine glacial deposits elsewhere in Washington apart from the maximum extent of continental glaciation.

A common example of failure is where groundwater is flowing through permeable sand layers perched above the less permeable clay or till layers. Glacial deep-seated landslides can respond to precipitation events, where the permeable layer (e.g., sand and gravel from recessional outwashes) becomes saturated above a less permeable layer (e.g., glaciolacustrine clay), forming a perched groundwater table that weakens the contact between the clay and sand. The saturated conditions can increase soil pore water pressures and reduce the soil strength. Glacial deep-seated landslide failure planes can occur along these sand/clay contacts. A common predictor of perched groundwater is the presence of springs (groundwater discharge) or hydrophytic (moisture loving) vegetation. Groundwater discharging as springs along the sand-clay contact can aid draining of the aquifer.

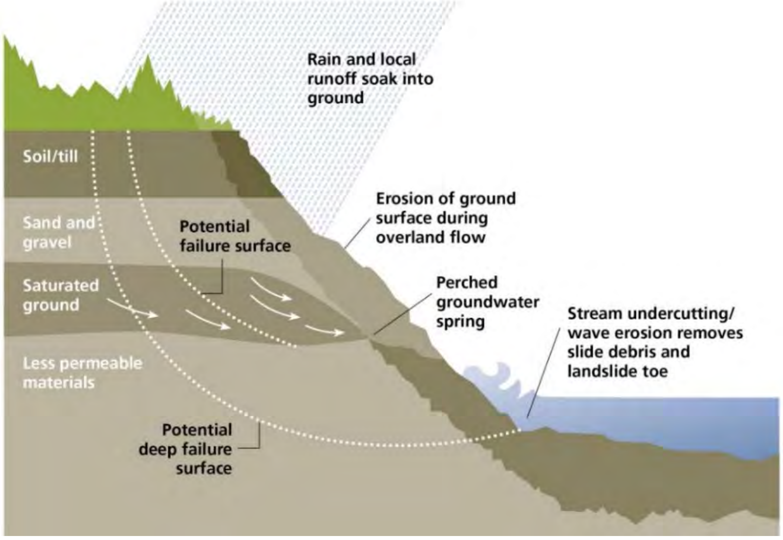

Figure 22. Diagram illustrating failure surface resulting from groundwater recharge to a glacial deep-seated landslide (DNR 2014).

A classic example of a geologic setting where glacial deep-seated landslides are common is in the Puget Sound lowlands where the Esperance Sand or Vashon advance outwash overlies the Lawton Clay. In this setting, groundwater recharge from precipitation infiltrates downward within the

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[22] Bauer and Mastin 1997; Vaccaro et al. 1998.

[23] Gerstel et al. 1997.

[24] Benda et al. 1988.

hillslope until it encounters the relatively impermeable Lawton Clay. Because the water cannot infiltrate into the Lawton Clay at the same rate it is supplied from above, the water table rises vertically above the clay surface. The elevated water table increases the pressure within the Esperance Sand and forms a hydraulic gradient that causes water to flow horizontally along the sand-clay contact, resulting in springs where this contact is exposed at the surface.[25]

Saturation of the pore spaces within sediments reduces grain-to-grain contact which reduces the effective strength of materials. Because soil saturation reduces the effective strength of the soil, which in turn reduces the stability of a slope, certain forest practices activities proposed within recharge areas for glacial deep-seated landslides may be classified "Class IV-special" per WAC 222-16-050(1)(d)(i)(C). Such Class IV-special proposals require further investigation and documentation prepared by a qualified expert. Therefore, it is important to characterize groundwater recharge areas and stratigraphy in terms of the potential for changes in the water balance due to forest practices activities, and the degree to which a potential hydrologic change is delivered to a glacial deep-seated landslide.

The first order approximation of the recharge area is the surface basin (topographically defined) directly above and including the landslide. The spatial extent of a groundwater recharge area can be interpreted from field observation of soil profiles, geologic structure, stratigraphy, well logs or boreholes, and geologic maps, to the extent these resources are applicable. See 5.3 for guidance on delineating groundwater recharge areas for deep-seated landslides.

4.4 Outer Edges of Meander Bends

Streams can create unstable slopes by undercutting the outer edges of meander bends along valley walls or high terraces of an unconfined meandering stream.[26] The outer edges of meander bends are susceptible to deep-seated and shallow landsliding, including debris avalanching and small-scale slumping. They are less susceptible where mature trees exist on lower terraced slopes in riparian or channel migration zones. The roots and woody structure of riparian trees act to deflect erosive flows and lessen undercutting along meander bend walls.

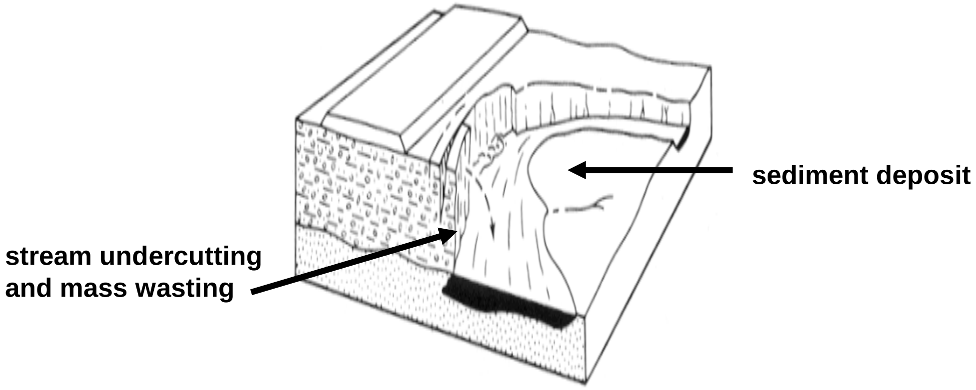

Figure 23. Outer edge of a meander bend showing mass wasting on the outside of the bend and deposition on the inside of the bend (adapted from Varnes 1978).

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[25] Tubbs 1974.

[26] Schuster and Wieczorek 2002.

4.5 Areas Containing Features Indicating the Presence of Potential Slope Instability

Apart from the rule-identified landforms described above, there are other slope indicators that can point to instability. When the feature or landform indicates the presence of slope instability which cumulatively indicates the presence of unstable slopes, the area can be considered a rule-identified landform. Proposed forest practices activities in this situation may be classed as a "Class IV-special" per WAC 222-16-050(1)(d)(i)(E) if there is potential to deliver sediment and debris to a public resource or threaten public safety. General practitioners and qualified experts commonly refer to these features as "category E" landforms.

Active bedrock deep-seated landslides are an example of a category E landform because they display multiple indicators of slope instability. Toes greater than 65% are a rule-identified landform, but other areas, such as portions of the headscarp within a bedrock deep-seated landslide, may have shallow landslide and delivery potential and require protection.

Another common example of a category E landform is concave features greater than 70% in glacial sediments or unconsolidated sediments such as Quaternary terrace deposits. These features are not true bedrock hollows because bedrock is not present, but landslide inventories from watershed analyses and landslide hazard zonation projects have demonstrated that these features are unstable and routinely recognized and protected under category E.

Relatively large and recent topographic indicators of such features can be observed on air photos, topographic maps, and LiDAR images, but identifying smaller and older indicators requires careful field observation. Indicators of slope instability or active movement may include the following:

Topographic indicators

- Bare or raw, exposed, unvegetated soil on the faces of steep slopes. This condition may mark the location of a debris flow or the headwall or side wall of a slide.
- Benched surfaces, especially below crescent-shaped headwalls, indicative of a rotational slide.
- Hummocky topography at the base of steep slopes. This may mark the accumulation zone (runout area) for a flow or slide.
- Boulder piles.
- Fresh deposits of rock, soil, or other debris at the base of a slope.
- Tension cracks in the surface (across or along slopes, or in roads). Tension cracks may mark the location of an incipient headwall scarp or a minor scarp within the body of an existing slide.
- Pressure ridges typically occur in the body or toe of the slide and may be associated with hummocky topography.
- Intact sections (blocks) having localized horst and graben topography.
- Transverse ridges and radial cracks on landslide displacement material.
- Stratigraphic indicators, including disconformities, offset contacts, and overturned sections.
- Back tilted surfaces from rotation within the slide.
- Side scarps, shear margins, or lateral scarps; multiple scarps in a downward direction.
- Displaced surface features like roads, railroads, foundations, and fence lines.

Hydrologic indicators

- Ponding of water in irregular depressions in undrained swampy or poorly drained areas on the hillslope above the valley floor. These conditions are often associated with hummocky topography which can be a signature of landslide activity.

- Seepage lines or spring and groundwater piping. These conditions often mark the contact between high permeability and low permeability soils.
- Sag ponds (ponded water in a tension crack or low depressions on a landslide body).
- Deflected or displaced streams (streams that have moved laterally to accommodate landslide deposits).
- Chaotic drainage patterns resulting from landslide activity.

Vegetative indicators

- Jack-strawed, back-rotated, or leaning trees and stumps. These are typically indicative of active or recently active landslides.
- Trees with curved-based lower stems and vertical upper boles may indicate slope movement stabilizing over time.
- Bowed, kinked, or pistol-butted trees. These are typically indicative of soil creep, but may indicate incipient land sliding, particularly if other indicators are present.
- Split trees and split old growth stumps. These may be associated with tension cracks.
- Hydrophytic (water-loving) vegetation (skunk cabbage, devil's club, salmon berry, etc.) on slopes. These conditions may indicate the presence of groundwater seeps and associated hydrogeologic conditions.
- Other patterns of disturbed vegetation. Changes in stand composition (early seral stage or lack of mature trees within a hillslope) or small groupings of alder in a conifer-dominated forest may indicate recent or historic slope failure.

No single indicator necessarily proves that slope movement is happening or imminent, but a combination of several could indicate a potentially unstable site.

Additional information about landslide processes, techniques for hazard assessment, and management practices on unstable terrain is available in: "A Guide for Management of Landslide-Prone Terrain in the Pacific Northwest" by the British Columbia Ministry of Forests[27]; Hillslope Stability and Land Use[28]; Landslides, Processes, Prediction and Land Use[29]; and Slope Stability Reference Guide for National Forests in the United States[30].

PART 5. IDENTIFYING POTENTIALLY UNSTABLE SLOPES AND LANDFORMS

The identification, delineation, and characterization of unstable and potentially unstable landforms should be completed to address the relevant questions for each site. Each step of the review process might uncover new information that could modify assessment methods and findings. General practitioners (landowners, foresters, engineers) typically conduct an initial screening and field review of project sites. In some cases, a qualified expert may be engaged to review and verify the general practitioner's slope assessment or perform additional geologic investigation.

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[27] Chatwin et al. 1994.

[28] Sidle et al. 1985.

[29] Sidle and 2006.

[30] USFS 1994.

The steps in the investigation process typically include office screening (5.1) and field assessments (5.2 and 5.3). If desired by the landowner or required by rule, further geotechnical assessments may include:

- deep-seated landslide activity assessment (6.1);
- glacial deep-seated landslide assessment (6.2);
- quantitative field assessment methods for the qualified expert's subsurface investigations (6.3);
- water budget and slope stability modeling assessments for glacial deep seated landslides (6.4);
- slope stability sensitivity assessment (6.5);
- runout and delivery assessment (6.6);
- synthesis and evaluation (7.1); and
- geotechnical reports (7.2).

The appropriate investigation process cannot be defined by the rigid application of a set of procedural rules.[31]~~; however, t~~ The following is a general overview of the typical sequence and elements of a slope-stability assessment:

1. Preliminary fact-finding to answer: What actions do the proposed forest practices activities include (e.g., partial cut, clear cut, road building, stream crossing)? In which landslide province (Appendix B) are the proposed forest practices activities located and what are the geologic conditions and types of landforms expected to be present? Are any site-specific resources available for review, such as previously completed geotechnical reports or watershed analysis reports?
2. Office review of geologic maps, topographic maps, aerial photographs, LiDAR data, and other information identified during the preliminary fact-finding phase.
3. Field review to observe the site, confirm office review findings, and identify unstable and potentially unstable landforms not recognized during the office review. The field review may also involve a more detailed geologic investigation for collecting additional geologic data and hydrogeologic mapping.
4. Data analysis and assessment regarding the potential for landslide activity that could result from the proposed forest practices activity, and the potential for delivery of sediment to public resources or threats to public safety.

5.1 Office Review

An office review is the initial screening of a selected site using available remotely sensed information and previously prepared materials or documents (e.g., reports, studies, field data, and analyses). "Remote sensing" generally refers to information that can be acquired for a particular site or physical feature without visiting the site or collecting data in the field.

A typical office review utilizes all pertinent site-specific and regional remote sensing data to help identify, delineate, and interpret potentially unstable slopes and landforms (e.g., aerial imagery, LiDAR, GIS-based model predictions of earth surface attributes derived from digital high-resolution topographic data). It may also include existing documents and databases (e.g., maps, geotechnical reports and studies, published and unpublished scientific literature, landslide inventories, local and regional databases containing meteorologic, hydrologic, and geologic information) to screen sites for potential slope stability concerns, identify public resource and public safety considerations, and make a determination regarding next steps in the site assessment. Please

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[31] Turner and McGuffy 1996.

see appendices C through E for data sources, and 5.1.3 and 5.1.4 for information regarding remote sensing tools and topographic data.

5.1.1 General Practitioner's Office Review

The goals of the general practitioner's office review are to: identify and locate potential and existing areas of slope instability within or around proposed forest practices activities using descriptions provided in Part 4; locate areas of public resource sensitivity or public safety exposure in the area of the planned operations that could be adversely affected by mass wasting processes; and develop a strategy for assessing the landforms in the field.[32]

Summary of Procedures.

The following are typical resources for a general practitioner's office review:

- Maps and imagery to screen areas for visual indicators of potentially unstable slopes and landforms. Relevant maps typically include surface topography and its derivatives (e.g., slope class maps), hydrology (e.g., streams and water types), geology and soils (e.g., rock units, soil types), landslides (landslide inventories and hazard zonation), and information needed to identify public safety exposures (e.g., road networks, parcel boundaries with existing building structure information). Imagery includes aerial photography and LiDAR-derived hillshade images available on public websites and referenced in Appendix D.
- Publicly available documents that might identify site-specific slope stability concerns or place the site in a broader landscape context with regard to potentially unstable landforms and processes (e.g., watershed analyses conducted under chapter 222-22 WAC; see Appendix F).
- Sources that may be available to the user online via the Forest Practices Application Review System (FPARS) and Washington State Geologic Information Portal. The Geographic Information System (GIS) with map display and analysis capabilities (e.g., ESRI ArcGIS) can provide an efficient and spatially accurate means for overlaying digital maps and images for geospatial analysis. However, if these tools are not available, an initial screening can be performed manually by inspecting each map or image separately. Various county websites also offer online interactive GIS information for maps and imagery products. Sources of imagery, data, maps, reports, and other documents are listed in appendices C through G.

In addition, the general practitioner's past knowledge about site-specific conditions will supplement the information gathered during the office review process.

The office review may not identify all potential unstable landforms, particularly if features are too small or subtle to be identified from available maps and imagery. For example, identifying the full extent of a groundwater recharge area from topographic maps, or detecting landslides under a mature forest canopy using aerial photography exclusively may be unreliable. Therefore, one or more follow-up field assessments are needed to verify results of the initial screening. The final step of an office review may be to create a site map for field use showing areas of potential slope stability concerns, natural resource sensitivities, and public safety exposures within or around the proposed operation.

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[32] The general practitioner can use this information when completing a Forest Practices Application (FPA).

Outcome.
The initial office review will help the general practitioner determine any portions of the proposed harvest and construction area that may need further assessment in the field. The general practitioner might also elect to have a more thorough office review conducted by a qualified expert.

5.1.2 Qualified Expert's Office Review

A qualified expert is needed when an investigation of potentially unstable slopes is beyond a general practitioner's expertise, or when activities are proposed on rule-identified landforms. The qualified expert's objective is to develop a preliminary geologic assessment of landform characteristics and landslide potential prior to initiating field work; field work can then refute or verify initial interpretations. The qualified expert's office review is generally more in-depth than a general practitioner's initial screening, and applies professional expertise in engineering geology, hydrogeology, geomorphology, and associated fields to detect and interpret landscape processes.

Depending on the site-specific conditions and the proposed forest practices activities, the qualified expert typically:

1. Screens the site with pertinent data in order to identify physical indicators of past, existing, and potential landslide instability, noting their spatial and temporal distributions;
2. Delineates on preliminary maps the identified features and associated potentially unstable landforms;
3. Formulates initial hypotheses regarding landslide and landform behavior and failure mechanisms to be evaluated further in the field; and
4. Determines the type and level of field investigation needed to assess any potential for delivery of sediment or debris to a public resource or threat to public safety.

Summary of Procedures.
The office review involves compiling and evaluating pertinent information. Most qualified experts have GIS capabilities, are experienced in using remotely sensed data techniques and modeling tools, and can provide feedback on proposed forest practices activities in relation to their potential for affecting slope instability. The office review typically precedes a field review whose objectives include assessing the accuracy, limitations, and uncertainties of remotely sensed information and previously prepared materials assembled during the office review, as well as adjusting any preliminary interpretations of landform features based on these data sources. The qualified expert determines the appropriate combination of assembled information based on the project objectives, requirements, and desired level of confidence in assessment products.

Outcome.
The office review typically leads to a field review of the findings by either a general practitioner or the qualified expert, especially where potentially unstable slopes and landforms are suspected or known and verification is required. Interpretations based solely on remote sensing data should not be used as substitutes for site-specific field assessments. If the expert determines from the office review that potentially unstable slopes or landforms are likely present, the landowner may exclude these areas from the proposed forest operations. Any reports or information provided to DNR should include relevant results of the qualified expert's office review findings.

5.1.3 Remote Sensing Tools Available for Office Reviews

Common sources of remotely sensed information used in identifying, delineating, and interpreting landforms can be grouped broadly in two categories: (1) aircraft- or satellite-based earth imagery and photogrammetry; and (2) LiDAR and high-resolution topographic data. Previously prepared materials or documents often incorporate field and remotely sensed data. These sources include maps and surveys, physical databases technical reports, and other published and unpublished literature. Among the available remote sensing technologies, LiDAR has proven to be a valuable source of topographic data with distinct advantages over traditional analytical methods (e.g., aerial photo interpretation) for mapping landslides and interpreting landform characteristics (see Figure 24).[33] However, LiDAR is not a panacea; rather it complements traditional aerial photo interpretation and the analysis of both information sources are useful. For more information about LiDAR processing, applications, and data sources, see Appendix E.

5.1.4 LiDAR Use in Identifying Potentially Unstable Landforms

It is beneficial to obtain the best available topographic maps derived from hillshade and slope maps when unstable areas exist around the proposal.

Hillshade, contour, and slope class maps derived from bare earth LiDAR digital elevation models (DEMs) are the most common LiDAR products used to identify landforms and landslides. A hillshade map is created by simulating sunlight shining on the topographic surface at a specified angle, while a slope map shows the magnitude of the topographic gradient, estimated by differencing the elevations of adjacent points in the DEM. Hillshade maps tend to have less contrast on slopes facing the incident sun angle and more contrast on slopes facing away from the incident sun angle, either of which can obscure topographic features. Analyzing several hillshade maps generated with different sun angles or employing methods such as those described in Burns and Madin (2009) may minimize illumination and topographic shadowing effects (i.e., multi-directional oblique-weighted hillshade algorithm). Additional maps such as topographic curvature, surface roughness, and elevation contours can also be useful to identify deep-seated landslide features. Contours should be generated with spacing similar to the LiDAR data resolution and/or the scale of the geomorphic features of interest.

Key topographic features revealing potential instability that are visible in LiDAR-derived maps, but might not be visible in other remote sensing data, are similar to those observed in the visual indicators listed in 4.5. Hummocky topography, benched surfaces, tension cracks, scarps, horst and graben features, pressure or transverse ridges, and irregular drainage patterns are often visible, but only when the scale of the feature is larger than the resolution of the LiDAR data. The difference in screening for and depicting potentially unstable features between high and low-resolution LiDAR data can be seen in Figures 24(b), (e), and (f). In Figure 24(f), a hillshade map derived from 3-foot LiDAR data is shown which allows the user to approximately delineate the landslide's main scarp, body, and toe, whereas such features may not be recognized using lower resolution quality (i.e., 30-meter resolution).

LiDAR hillshades can be used to delineate and interpret deep-seated and, with less certainty, shallow landslides, although some depositional surfaces (for example debris fans) can be identified. Various measures of surface roughness are commonly used to recognize and quantify deep-seated landslide morphology in landslide mapping studies.[34] Recent regional examples of deep-seated landslide mapping that used LiDAR-based protocols include Burns and Madin (2009), Schulz (2005, 2007), and Haugerud (2014).

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[33] e.g., Haugerud et al. 2003; Burns and Madin 2009; Roering et al. 2013; Tarolli 2014.

[34] McKean and Roering 2004; Glenn et al. 2006; Booth et al. 2009; Berti et al. 2013.

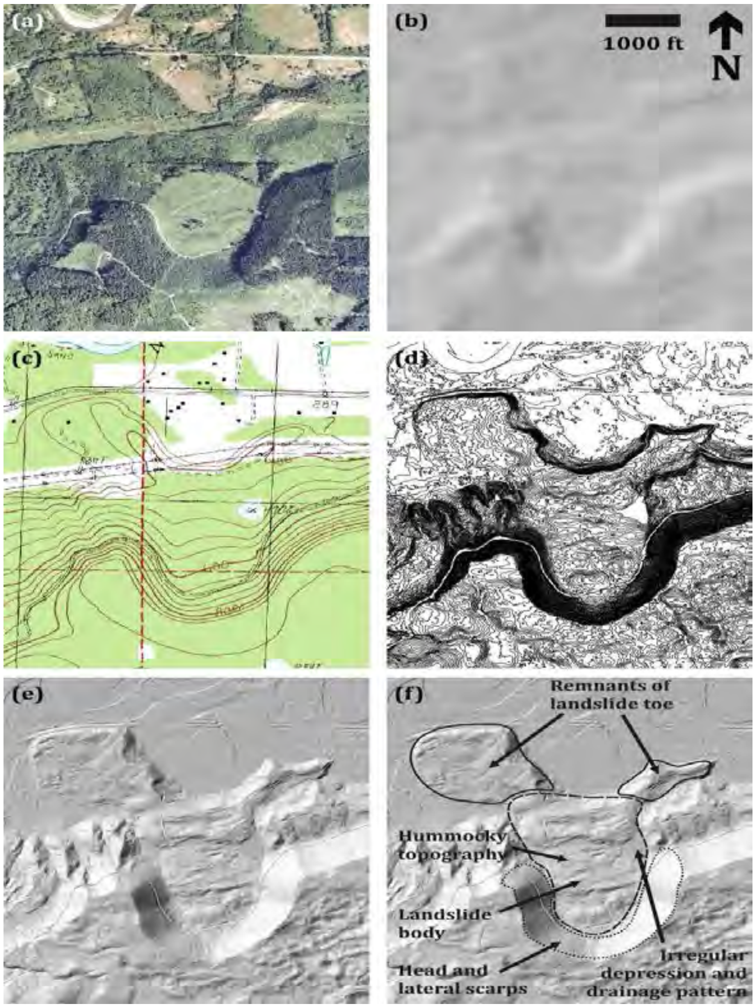

Figure 24. Example of a dormant glacial deep-seated landslide as seen in different types of remotely sensed data and in varying resolution quality:
(a) Digital Orthophoto Quadrangle, (b) hillshade map derived from 30-meter resolution ASTER Global Digital Elevation Model, (c) topographic map, (d) 6-foot contour map derived from 3-foot resolution airborne LiDAR, (e) hillshade map derived from 3-foot resolution airborne LiDAR, and (f) an annotated version of (e) (Adam Booth, Portland State University 2014).

5.2 Field Assessment

The purpose of the field assessment is to confirm the findings of the office review, and to identify unstable and potentially unstable landforms not recognized during the office review. While the office review can provide important information and a starting point, on-site observation of field indicators on the ground surface is essential for identifying potentially unstable landforms.

5.2.1 General Practitioner’s Field Assessment

The objective of the general practitioner’s field assessment is to determine the presence or absence of rule-identified landforms described in Part 4. The general practitioner surveys the operations area for any landforms missed in the office review. This assessment is typically accomplished while performing reconnaissance and laying out the proposed forest practices activities (e.g., marking unit boundaries, establishing riparian management zones, laying out road systems). When the field assessment indicates complex geological features are present or the scenario is beyond the general practitioner's expertise, the landowner may wish to have a qualified expert complete a further assessment. The practitioner should refer to 4.5 for indicators of slope instability and 5.3.2 for field review on groundwater recharge systems.

Outcomes.
Common results of the general practitioner's field assessment are one of the following:

- The general practitioner does not identify any potentially unstable slopes or landforms within or around the planned area for the forest practices activities.
    - The landowner documents the finding in the slope stability sections of the FPA.
- The general practitioner identifies potentially unstable slopes or landforms in or around the planned operations area, and the landowner avoids timber harvest or construction on them.
    - The landowner documents the finding in the slope stability sections of the FPA, along with any additional required information DNR may have requested, and submits the FPA.
- The general practitioner identifies potentially unstable slopes or landforms in or around the planned operations area, and the landowner proposes timber harvest or construction activities on them.
    - The landowner retains a qualified expert to conduct geologic office and field reviews, and prepare a geotechnical report (see 7.2 for information required in a geotechnical report).[35] The landowner documents the finding in the slope stability sections of the FPA, along with the geotechnical report prepared by the qualified expert.

5.2.2 Qualified Expert's Field Assessment

When it is determined an investigation by a qualified expert is necessary, the objectives of the field assessment are to: verify the presence or absence of potentially unstable slopes and landforms identified in office reviews; identify those that were missed or misidentified by the general practitioner; or identify those that were missed due to insufficient remote sensing data coverage or resolution. To meet the objectives, the qualified expert should collect sufficient information to describe the landforms in or around the site and may:

1. Refine any preliminary maps constructed during office reviews. This may include features not detected in the office review;
2. Assess failure mechanisms and the likelihood that the proposed forest practices will cause movement on, or contribute to further movement of potentially unstable slopes or landforms;
3. Analyze cause-effect relationships relative to the proposed activity;
4. Assess the likelihood of delivery of sediment or debris to public resources or threats to public safety;
5. Determine any possible mitigation for the identified hazards and risks;
6. Evaluate levels of confidence in office and field findings; and
7. Produce geologic information when requested, or write a geotechnical report when required, summarizing review findings, conclusions, and recommendations (see 7.2 for guidance on preparing in a geotechnical report).

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[35] The Department of Natural Resources' Forest Practices Division maintains a qualified experts list that can be viewed online at http://www.dnr.wa.gov/Publications/fp_geo_experts.pdf.

Summary of Procedures.
The qualified expert determines the nature of the field review required to meet the objectives stated above. The field work can take one or more days, and the landowner may ask the qualified expert to return to the field for an interdisciplinary team meeting if required by DNR. Depending on the analyst's level of confidence in potentially unstable landform identifications, delineations, and interpretations for any given site, the field assessment might range from qualitative to more quantitative in nature.

An example of a qualitative assessment would be one in which visual observations and photos of geological features and other site indicators at identified locations (e.g., GPS waypoints) are summarized in a geotechnical report to substantiate landform and process interpretations. A more quantitative investigation might include such data collection techniques as topographic surveying for measuring landslide surfaces (i.e., that needed for slope stability modeling), soil sampling to test material properties, and subsurface sampling that could be important in analyzing the depths, materials, and hydrology of deep-seated landslides.

Preparation of a site-specific geomorphic map is helpful because most published geologic maps, although useful for understanding and locating bedrock and Quaternary sediment deposits, are insufficient to identify small-scale landforms that could have a significant effect on the proposed activity. In addition, some geologic information may not have been field verified or developed with high-resolution LiDAR. The purpose of mapping is to capture surface conditions, provide a basis for the interpretation of subsurface conditions, and prepare more site-specific descriptions of relevant features.

A geomorphic map ideally includes the location, elevation, and attitude of known geologic contacts and relevant landforms, although such data collection is not feasible or necessary in all situations. In glacial materials, particular emphasis should be placed on the contact between high permeability soils and underlying low permeability soils or bedrock and the location of groundwater seeps or springs, especially where deep-seated landslide activity is suspected or encountered. The location of pertinent geologic components and potentially unstable indicators should be identified on the map or in the geotechnical report. Ideally, mapped products should be prepared on a scale of 1:12,000 or less using high-resolution LiDAR-generated topography, aerial photos, and field data. If high-resolution LiDAR is not available, base maps can consist of U.S. Geological Survey 7.5-minute topographic maps, DNR forest practices activity maps, or aerial photographs.

Geologic field data collection, analysis, and map compilation are undergoing a revolution in methods, largely precipitated by GPS and GIS-equipped mobile computers.[36] To facilitate the review, geologic reports prepared for FPAs can include GPS locations of landforms and other relevant features with sufficient accuracy for others to identify the landforms in the field. It is also effective to include photographs of significant landforms, or their components if the spatial scales are compatible with ground-based photography. It is important to note indicators of potential slope instability or active movement during the field review. These include topographic, hydrologic, and the vegetative indicators described in 4.5.

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[36] Whitmeyer et.al 2010; U.S. Geological Survey 2008; Edmondo 2002.

Outcomes.
Each site contains a unique set of slopes and landforms, and will require a distinct set of possible management strategies. In some cases, the qualified expert may recommend avoidance of a rule-identified landform, setbacks to a feature, or specific mitigation measures to lessen impacts to a landform. Common results of a qualified expert's field assessment may include one of the following:

- The finding that areas of concern identified in the preliminary office review and field assessment do not meet the definitions of the rule-identified landforms (Part 4).
    - The qualified expert reports these findings to the landowner; the landowner documents the findings in the slope stability sections of the FPA.
- The finding that potentially unstable slopes or landforms in or around the operations area have minimal potential to deliver sediment or debris to a public resource or threaten public safety.
    - The qualified expert reports these findings to the landowner; the landowner documents the findings in the slope stability sections of the FPA.
- The finding that potentially unstable slopes or landforms within, or when appropriate, around the operations area have the potential to deliver sediment or debris to a public resource or threaten public safety.
    - The qualified expert prepares information listed in WAC 222-10-030(1) in a geotechnical report, and provides the report to the landowner. In most cases, this scenario would fall under a Class IV-special definition in WAC 222-16-050(1) and require the landowner to submit a SEPA checklist or Environmental Impact Statement. The landowner documents the findings in the slope stability sections of the FPA and attaches the report to the FPA.

5.3 Delineating Groundwater Recharge Areas for Glacial Deep-Seated Landslides

As explained in Part 4, the groundwater recharge area for a glacial deep-seated landslide is a rule-identified landform. It is the area up-gradient of a landslide that can contribute water to the landslide. When timber harvest or construction activities are proposed on or around a verified glacial deep-seated landslide or its associated groundwater recharge area, a landslide activity assessment needs to be performed (see 6.1), including whether a groundwater recharge area exists, and if so, determining its spatial extent. DNR requires that a qualified expert make the final determinations about the existence and boundaries of a groundwater recharge area for a glacial deep-seated landslide. However, a general practitioner may have a role in office reviews and field work under the direction of the qualified expert.

Typically, once a landslide has been mapped, an initial designation of the topographic groundwater recharge area is a straightforward task that can be performed on a detailed topographic map of the area. The most accurate tool available for mapping surface topography is high resolution DEM generated from LiDAR. Figure 25a shows the approximate groundwater recharge area for a landslide based on upslope topographical delineation. The cross section shown in Figure 25b illustrates the approximate stratigraphy through the groundwater recharge area and landslide body. The recharge, occurrence, and movement of groundwater through water-bearing units (aquifers), and confining units that inhibit groundwater movement, can have an effect on slope stability.

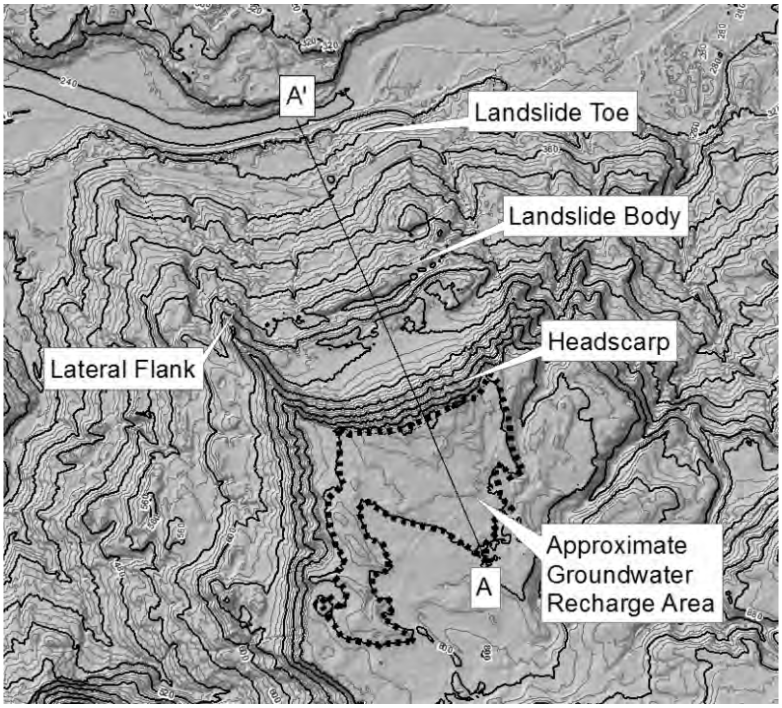

Figure 25a. Glacial deep-seated landslide. The dash-lined polygon is an approximate delineation of a groundwater recharge area based on LiDAR data (DNR 2014).

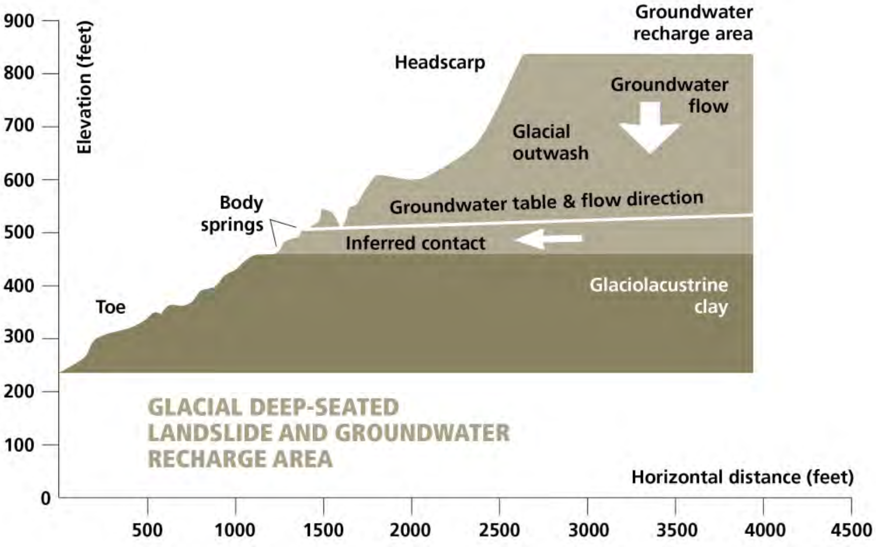

Figure 25b. Hillslope cross-section (A-A' in figure 25a) derived from 2-meter DEM of a glacial deep-seated landslide showing groundwater recharge area, geologic units, and generalized groundwater flow paths (DNR 2014).

The recommended first step in delineating the groundwater recharge area is to evaluate its stratigraphic and/or topographic relationship to the landslide. Further investigations and analyses may be necessary ~~W~~when uncertainties remain as to the accuracy of the recharge area boundary~~,~~ ~~further investigations and analysis are necessary~~. DNR uses ~~T~~the results of these analyses provided by the qualified expert in a geotechnical report ~~are used by DNR~~ to determine ~~the~~ FPA classifications and other decisions based on the applicant's proposed activity.

5.3.1 Office Review for Groundwater Recharge Areas

The office review should include an assessment of the surrounding topography, land cover and vegetation, soils, and the distribution of hydrogeologic units. Groundwater movement from areas of recharge to discharge may vary over several orders of magnitude, depending on the hydraulic characteristics of the hydrogeologic units, which include water-bearing and non-water-bearing rocks and sediments (aquifers) and confining units, respectively.

In a simplified hydrogeologic setting in a humid environment, the groundwater table forms a subdued replica of surface topography with groundwater flow from high altitude areas of recharge to low altitude areas of discharge.[37] The surficial contributing area may be delineated from digital elevation models (DEMs) derived from LiDAR, or U.S. Geological Survey topographic quadrangles. Topography developed from high-resolution LiDAR is the most accurate tool available for mapping surface topography. This analysis provides an approximation of the potential area of recharge, but may not be valid in heterogeneous rocks and sediments with complex topography, depositional history, or deformational environments.

The land cover of the recharge area can influence the magnitude of groundwater recharge. Vegetation type and distribution effect the amount of precipitation intercepted by foliage and leaf litter and the resultant through-flow that is available for recharge. In addition, land development and agricultural uses may influence groundwater recharge.

The reviewer may also find the following resources useful in the office review:

- Remotely-sensed land cover data available nationally at a spatial resolution of 30 meters from the U.S. Geological Survey's National Land Cover Database;
- Geologic maps for providing a basis for delineating the areal extent, orientation, and stratigraphic relationships of rocks and sediments that influence the occurrence and movement of groundwater. The U.S. Geological Survey, DNR, and others have published geologic maps at scales of at least 1:100,000 across Washington and locally at larger scales (1:24,000).
- Well logs and geotechnical borings may supplement geologic mapping by revealing the vertical extent of rocks and sediments and providing information about grain size distributions, sorting, and other physical properties that may influence the hydraulic characteristics of hydrogeologic units. The Washington State Department of Ecology maintains a searchable database of well logs for Washington State; however, subsurface data will generally be confined to developed areas rather than the forested environment.
- Hydrogeologic frameworks, which define the groundwater recharge environment and the subsurface environment in which groundwater occurs, have been developed from mapped geologic units, driller's logs, and hydrologic data at regional scales such as Puget Sound[38] and the Columbia Plateau[39]. However, it is also important to understand groundwater movement at smaller local scales. Hydrogeologic reports are available from sources such as the U.S. Geological Survey and the Department of Ecology.

5.3.2 Field Assessment for Groundwater Recharge Areas

Groundwater recharge areas may occupy a range of hillslope gradients, shapes, and soil and rock types. Therefore, it is necessary to conduct a field inspection to determine if the initial designation

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[37] Freeze and Cherry 1979.

[38] Vacarro et al. 1998.

[39] Bauer and Hansen 2000.

accurately reflects the recharge area topography, including the topography up-gradient of the landslide. It is helpful to collect GPS waypoints along the topographic boundaries of the groundwater recharge area for mapping and revisiting the site if necessary. The field inspection should include:

- Examining the characteristics of the surface materials within the initially delineated groundwater recharge area~~;~~, and documenting whether the soil types and subsurface geologic units are consistent with maps examined during the office review. In some cases, published soil and geologic data in forested areas may be inaccurate at the scale of an FPA activity map.
- Mapping the stratigraphic units that compose the hillslope (i.e., the distribution of geologic units or horizons with depth below the groundwater recharge area) in order to describe the likely flow paths that could potentially connect the groundwater recharge area with the failure plane of the landslide. Often landslide failure planes are co-incident with subsurface aquitards such as silt or clay beds that form elevated groundwater tables within hillslopes. Understanding the morphology and orientation of these aquitards can help inform the spatial extent of the groundwater recharge area beyond the surface topographic expression of the hillslope up-gradient of a landslide. Subsurface investigations may be needed to adequately determine geologic units where mapping cannot be accurately accomplished by surface data alone.
- Examining observable strata in exposures along marginal streams on the edges of the groundwater recharge area, or in head scarps at the top of the landslide. The distribution of geologic units with increasing depth below the surface may also be available from well driller's logs or other subsurface information such as geologic mapping and reports.
- Mapping and evaluating infrastructure such as road construction and landings with respect to relative water volumes flowing to or from a landslide or groundwater recharge area.
- Identifying surface water and stream drainages on or adjacent to deep-seated landslides and assessing the potential of water flowing to or away from a landslide and recharge area.

Although rarely applied in the forested environment~~When conditions warrant~~, excavating test pits, driving soil probes, drilling monitoring wells, or using geophysical techniques such as seismic or electric resistivity methods ~~should be considered~~ ~~in order to~~can better characterize and reduce uncertainties about subsurface groundwater conditions where topographic indicators are inconclusive.

PART 6. ADDITIONAL ANALYSES FOR UNSTABLE SLOPES

Part 5 provided guidance for office and field reviews appropriate for both general practitioners and qualified experts. The preliminary assessment of landslide risk, and the potential for forest practices to affect risk, has occurred during the office and field reviews. A proposed forest practice in or around a glacial deep-seated landslide and its associated groundwater recharge area may require the additional analyses discussed in Part 6. These analyses may also be useful for other situations, such as assessing the landslide activity level of a bedrock deep-seated landslide or calculating the slope stability and failure potential of an individual unstable hillslope where a forest practice is proposed. The qualified expert identifies which analyses are needed on a site-by-site basis.

Part 6 provides guidance on:

- Landslide Activity Assessment (6.1);
- Glacial Deep-Seated Landslide Assessment (6.2);
- Quantitative Field Assessment Methods for the Qualified Expert's Subsurface Investigations (6.3);

- Water Budget and Hydrologic Contribution to Glacial Deep-Seated Landslides (6.4);
- Computational Slope Stability Assessment Methods (6.5); and
- Runout and Delivery Assessment (6.6).

6.1 Landslide Activity Assessment

~~When forest practices harvest or construction activities are proposed on or have the potential to influence deep-seated landslides, it is recommended that a qualified expert assess the landslide activity. The~~A landslide activity assessment is an important component of evaluating ~~the~~ potential landslide hazard and ~~potential~~ risk, ~~associated with planned activities. It will also likely~~and can contribute to ~~the information~~ a qualified expert's ~~will need to prepare a~~ geologic evaluation.

The three components of landslide activity for evaluation during the office and field review process are the state of activity, the distribution of activity, and the style of activity.[40]

The *state of activity* refers to the timing of landslide movements and ranges from active (current or recent movement) to dormant (has not moved in recent decades or centuries) to relict (clearly developed in the geomorphic past under different conditions than are currently present). If the conditions that contributed to prior movement are still present even though the landslide is dormant, it may become reactivated at a later time. The landslide may be considered stabilized if the conditions promoting failure have naturally changed to promote stability or if human intervention has protected against future movement.

Interpretation of vegetation cover, surface morphology, and toe modification by a stream, if present, all aid in determining the state of activity based on local knowledge of typical rates of biologic and geomorphic processes.[41] The characteristics described by Keaton and DeGraff (1996) have been successfully applied in the Pacific Northwest. A modified version is presented in Table 2. New vegetation generally begins to colonize a landslide's scarp, lateral flanks, or other areas of disturbed ground once the landslide becomes dormant and progresses to mature vegetation cover according to the local climate. The scarp, flanks, and internal hummocky morphology of the landslide also tend to become increasingly subdued with time after the landslide becomes dormant, and the internal drainage network of the landslides tends to become more connected and organized. If the toe of the landslide enters a stream, that stream progressively modifies the toe as recorded by terraces and the establishment of a floodplain comparable to reaches unaffected by landslide activity.

The *distribution of activity* refers to the geometry and spatial pattern of landslide movements and how these patterns may change with time. One key distinction is if the landslide is advancing by extending downslope in the main direction of movement, or headcutting by extending in the upslope direction. A landslide can also widen or narrow in the direction perpendicular to movement, and more generally can be enlarging or diminishing if its total volume is increasing or decreasing.
The *style of landslide activity* will be one of the movement types shown in Table 1, Landslide Classification. Many landslides involve different styles of landslide activity. Movements should be described as "complex" if they happen in succession, or as "composite" if they happen simultaneously at different parts of the landslide. Many landslides may reactivate repeatedly over time; their movements are described as "multiple" if the same style of activity affects any

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[40] Cruden and Varnes 1996.

[41] Keaton and DeGraff 1996, Table 2.

previously displaced material, or "successive" if the same style of activity affects previously stable material in the immediate vicinity of the previous landslide.

Table 2. Guidelines for estimating deep-seated landslide activity level based on vegetation and morphology

(modified from Keaton and DeGraff 1996)

Active State	Main Scarp	Lateral Flanks	Internal Morphology	Vegetation+	Toes Relationships
Active/recent*	Sharp; unvegetated	Sharp; unvegetated streams at edge	Undrained depressions; hummocky topography; angular blocks separated by scarps	Absent or sparse on lateral and internal scarps; trees tilted and/or bent	Main valley Stream pushed by landslide; floodplain covered by debris; lake may be present
Dormant-distinct	Sharp; partly vegetated	Sharp; partly vegetated; small tributaries to lateral streams	Undrained and drained depressions; hummocky topography; internal cracks vegetated	Younger or different type or density than adjacent terrain; older tree trunks may be bent	Same as for active class but toe may be modified by modern stream
Dormant-indistinct	Smooth; vegetated	Smooth; vegetated; tributaries extend onto body of slide	Smooth, rolling topography; disturbed internal drainage network	Different type or density than adjacent terrain by same age	Terraces covered by slides debris; modern stream not constricted but wider upstream floodplain
Relict	Dissected; vegetated	Vague lateral margins; no lateral drainage	Smooth, undulating topography; normal stream pattern	Same age, type, and density as adjacent terrain	Terraces cut into slide debris; uniform modern floodplain

*Recent is defined as being within the photo history or within the period of forest management.

+Vegetative indicators are identified as forest and not grasses, forbs or shrubs. It is important to note that in most areas of western Washington, landslide scars re-vegetate within 15 years and may be difficult to detect from aerial photographs 10 to 15 years after the slide occurred.

6.2 Glacial Deep-Seated Landslide Assessment

Below is a list of basic steps appropriate for the assessment of a glacial deep-seated landslide and its associated groundwater recharge area. The steps provide a guide for assessing the risk associated with a particular landslide based on the level of landslide activity and how likely the landslide is to deliver sediment to public resources. Working through steps 1 through 4 ~~and following procedures in 6.6 (delivery assessment)~~ will help the qualified expert determine if the next step should be 5, 6, or 7. Where it is appropriate to follow step 5, 6, or 7, step 8 may need to be accomplished as well.

1. Identify the glacial deep-seated landslide and associated groundwater recharge area.

2. Classify landslide activity using the protocol (modified from Keaton and DeGraff 1996) for deep-seated landslides as:
    - active;
    - dormant/distinct;
    - dormant/indistinct; or
    - relict.
3. Map the glacial deep-seated landslide and associated groundwater recharge area.
4. Evaluate delivery potential if the landslide were to move for:
    - public safety (e.g., houses and public roads); and
    - public resources (water, fish, wildlife, and capital improvements).
5. If the landslide is relict or dormant/indistinct, and the potential for reactivation of any portion of the landslide by harvest within the groundwater recharge area is highly unlikely, then additional analysis may not be necessary. Documentation of this analysis may be provided by a letter, memo, or other appropriate form.
6. If the landslide is active/recent or dormant/distinct with a low delivery potential, perform a qualitative assessment of factors contributing to landslide movement including natural disturbance, channel influences, and historic patterns of timber harvesting within the groundwater recharge area. Recent evidence of landslide movement may be detected from aerial photographs, LiDAR, and other screening methods.
7. If the landslide is active/recent or dormant/distinct and has moderate or high delivery potential, in addition to a qualitative assessment described in (6), the qualified expert may consider additional analyses ~~may be conducted~~ such as assessing whether a potential increase in groundwater recharge from timber harvest will affect the stability of the landslide.
8. Design appropriate landslide mitigation measures commensurate with delivery potential and hazard.

6.3 Quantitative Field Assessment Methods for the Qualified Expert's Subsurface Investigations

~~Where the potential to deliver sediment to public resources or threaten public safety is identified during the office review and field assessment, additional field analysis by a qualified expert may be needed to more quantitatively assess the hazard.~~ Subsurface investigations can be necessary for assessing proposed forest practices activities where more detailed information on landslide geometries, soil properties, or groundwater conditions is needed. ~~Subsurface investigations~~They can be designed to gather data necessary to evaluate the landslide in accordance with the evapotranspiration, recharge, groundwater flow, and slope stability modeling.

The qualified expert's selection of exploration methods should be based on the study objectives, size of the landslide area, geologic and hydrogeologic conditions, surface conditions and site access, limitations of budget and time, and risk potential. A qualified expert should supervise the subsurface investigation so that the field activities are properly executed and the desired results can be achieved. Subsurface exploration to assess landslides is generally described by McGuffey et al. (1996) as summarized in the following paragraphs.

Test Pits. Shallow test pits can be dug by hand with a shovel. Trackhoes or excavators can be used to advance test pits to depths of up to 20 feet in certain soils. They are useful for exposing subsurface soil and rock conditions for purposes of mapping or logging the underlying conditions, and to identify shallow groundwater elevations and failure planes.

Hand Auger. A hand auger can be used to identify soil types to depths up to nearly 20 feet (in loose soils) but does not provide significant information regarding soil material properties.

Drive Probe. A simple hand probe can be used to estimate soil density and the depth to dense soil. The Williamson Drive Probe (WDP)[42] was developed as an inexpensive and portable alternative for determining soil relative densities and groundwater table elevations. Sections of hardware pipe are coupled and driven into the ground manually with a sliding hammer. The number of blows, in even distance increments, required to drive the probe is used to describe soil conditions. Blow-count data has been empirically correlated with the Standard Penetration Test (American Society for Testing and Materials 2014).[43]

Method limitations include manual labor intensity, which can limit the number of holes drilled in a given day. The WDP can also be used to estimate depth to groundwater if perforated pipe is used. With these many uses and the low cost, the WDP is an effective alternative to other tests that require expensive equipment and are less portable.

Drill Rigs. Borings constitute a method for collecting geotechnical data. Access limitations can be addressed if logging roads are fortuitously located, or by using track-mounted equipment. In some cases, undisturbed or lightly disturbed soil samples can be collected for quantitative laboratory testing (i.e., direct shear, bulk density, moisture content, etc.). For long-term monitoring, a drill rig can also be used to install groundwater monitoring wells that contain pressure transducers, and as a conduit for geotechnical instrumentation (i.e., inclinometer, extensometer, etc.).

Geophysical Methods. Surface-based geophysical methods are used to collect general subsurface information over large areas of rugged terrain. These include ground penetrating radar, electromagnetic, resistivity, and seismic refraction methods. These techniques can provide information on the location of boundaries between coarse-grained and fine-grained strata and the depth to the water table.

6.4 Water Budget and Hydrologic Contribution to Glacial Deep-Seated Landslides

~~When the preceding assessments indicate a potential influence from a forest practice, it is recommended that the qualified expert evaluate components of the water budget.~~ The water budget of a groundwater/surface-water system describes the input, movement, storage, and output of water from a hydrologic system. Water enters a hydrogeologic system through precipitation in the form of rainfall, snowmelt, and other confined/unconfined groundwater sources. Not all precipitation, however, becomes groundwater, some is intercepted by vegetation or surface duff/debris and evaporates before reaching the ground or sublimates from the snowpack (see 6.4.1). Water that reaches the ground may run off directly as surface flow or shallow near-surface runoff, infiltrate or evaporate from the soil, or transpire through vegetation foliage. Water that percolates below the root zone and reaches the water table is considered to be groundwater recharge. Groundwater moves from areas of high hydraulic head to areas of low hydraulic head where it leaves the groundwater-flow system through wells, springs, streams, wetlands, and other points of groundwater discharge. The occurrence and movement of groundwater through the subsurface depends on the hydraulic properties of subsurface material as well as the distribution of groundwater recharge.

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[42] Williamson 1994.

[43] Adams et al. 2007.

Further assessments for evaluating the influence of water to a glacial deep-seated landslide may be necessary when preliminary assessments suggest that the proposed forest practices ~~activities~~activity increases the potential for contributing to movement of unstable landforms. The extent of the analysis depends on site-specific geological and hydrogeological conditions. ~~Such assessments and modeling may be useful when there is potential for delivery of sediment or debris to public resources or threats to public safety.~~ The following discussions of evapotranspiration and groundwater flow may aid the qualified expert.

6.4.1 Modeling Evapotranspiration

Modeling evapotranspiration is a data intensive exercise that requires regional and/or site-specific information regarding precipitation types and rates, wind speed, relative humidity, temperature, solar energy, and plant community stand characteristics.[44] The goal of evapotranspiration modeling is to derive estimates of the potential increase in water available to the groundwater recharge area from changes in energy balances, wind speeds, and plant community characteristics (i.e., aerodynamic roughness) after forest harvest.

Effects of evapotranspiration on the soil water budget can be partitioned as follows: (1) canopy interception of rainfall or snow and subsequent evaporation loss to the atmosphere; (2) transpiration of infiltrated water to meet the physiological demands of vegetation; and (3) evaporation from the soil or litter surface. Different vegetation covers have different balances of these fundamental water loss processes. The effects of evaporation on soil water budgets are relatively small compared to canopy evapotranspiration and interception.[45]

Transpiration is the dominant process by which soil moisture in densely vegetated terrain is converted to water vapor. Transpiration involves the adsorption of soil water by plant roots, the translocation of the water through the plant and release of water vapor through stomatal openings in the foliage. Transpiration rates depend on availability of solar energy and soil moisture as well as vegetation characteristics, including vegetation type (e.g., conifer or deciduous), stand density, height and age, rooting depth, leaf area index, leaf conductance, albedo of the foliage, and canopy structure. Rates of transpiration are similar for different vegetation types if water is freely available.[46]

Transpiration is typically quantified using Soil-Vegetation-Atmosphere Transfer (SVAT) models where the movement of water from the soil through the plant to the atmosphere is represented by several resistances in series: (1) the integrated soil-root system; (2) the stem; (3) the branch; and (4) the effective stomatal resistance. Eddy correlation techniques are commonly used to estimate transpiration fluxes.[47]

Interception by vegetation cover controls both the amount and timing of precipitation reaching the soil surface. The interception capacity of vegetation types is important because intercepted water has a high surface area to volume ratio that promotes efficient evaporation by convection. Intercepted rainfall is mostly stored on the surface of foliage and stems, while intercepted snowfall bridges between gaps in tree crowns, facilitating an accumulation of snow over large surface areas

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[44] Jassal et al. 2009.
[45] Bosch and Hewlett 1982.
[46] Campbell 1986.
[47] Hanks and Ashcroft 1980.

of the canopy. Interception and subsequent evaporation of water from vegetation cover is particularly significant in coniferous forests[48]; snow or rain losses from these dense canopies can account for up to 30 to 50 percent of gross annual precipitation[49]. Moore and Wondzell (2005) estimated that interception loss in Pacific Northwest conifer forests ranged from 10 to 30 percent. Dingman (2002) reported similar values for Pacific Northwest plant communities, ranging from 21 to 35 percent, based on canopy characteristics and climate conditions. Hanell (2011) reported hydrologic modeling[50] that predicts a 27 percent decrease in evapotranspiration resulting from forest conversion to shrub for a site on the western Olympic Peninsula.

The proportion of rainfall intercepted by forest canopies is inversely related to both antecedent wetness and rainfall intensity. Gentle short-duration rainfall may be almost totally intercepted, while interception may account for as little as 5 percent of precipitation during intense winter storms.[51]

Approaches for estimating changes in evapotranspiration typically involve some combination of the Penman-Monteith model for calculating the canopy resistance, the Bowen ratio energy balance technique to estimate evaporation from plant surfaces, and the Priestly-Taylor formula to estimate evaporation from the soil surface. Reviews and demonstrations of these techniques can be found in Avery and Fritschen 1971; Fritschen 1975; Ziemer 1979; Hanks and Ashcroft 1980; Campbell 1986; Simpson 2000; Martin et al. 1997; and Sias 2003.

6.4.2 Groundwater Recharge and Groundwater Flow Modeling

Groundwater recharge is difficult to measure directly, but several empirical and numerical methods exist for estimating recharge within the surface-water, unsaturated zone, and saturated zone, including physical, tracer, and numerical-modeling techniques.[52] Recharge is commonly estimated by calculating the residual component of the water budget where recharge equals the difference between precipitation and the sum of losses through evapotranspiration, surface runoff, and shallow groundwater flow. The accuracy of recharge estimated through this method is limited by the large uncertainties inherent in the estimating components of the water budget such as evapotranspiration, which is typically large in magnitude relative to groundwater recharge. Examples of numerical models capable of estimating recharge based on a water budget include the Deep Percolation Model[53], the Precipitation Runoff Modeling System[54], and the Variable Infiltration Capacity Model[55]. Once the spatial distribution of groundwater recharge is estimated, the movement of groundwater within the subsurface may be modeled using groundwater-flow models. The movement of groundwater from areas of recharge may be modeled using groundwater flow models such as MODFLOW.[56] Groundwater-flow models are based on a hydrogeologic framework that incorporates the hydraulic properties of geologic materials and their stratigraphic relations. Groundwater models are calibrated using hydrologic data including groundwater levels within

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[48] Link et al. 2004.

[49] Dingman 1994.

[50] DHSVM; Wigmosta, Njssena and Stork 2002.

[51] Ramirez and Senarath 2000.

[52] Scanlon et al. 2002.

[53] Bauer and Vaccaro 1987.

[54] Leavesley et al. 1983.

[55] Liang et al. 1994.

[56] Harbaugh et al. 2000.

major water-bearing hydrogeologic units, and can be used to characterize the movement of groundwater from areas of recharge to areas of discharge.

6.5 Computational Slope Stability Assessment Methods

Quantitative assessments of slope stability, performed by the qualified expert, may be necessary to characterize slope failure potential at a given site, and evaluate potential impacts of forest practices activities to public resources and public safety. This quantitative assessment may entail one or more methods. Limit equilibrium and numerical stability analyses may be used to evaluate the potential effects of increased groundwater recharge on glacial deep-seated landslides, but other methods may be necessary under certain conditions.

Limit-equilibrium analysis calculates a factor of safety for sliding along a critical failure surface, which is expressed as a ratio of the shear strength of the earthen material resisting slope failure to the shear stresses driving instability. Relative stability is defined by a factor of safety exceeding a value of one. A two-dimensional limit-equilibrium analysis method may be applied to deep-seated landslides but can also be useful for smaller local site situations. Computation of the most critical failure surface is an iterative process generally supported by commercially available or public-domain software.[57] Field-developed cross sections, back calculation of soil strength parameters, and estimation of groundwater elevations can be done where field accessibility is limited using the methods of Williamson (1994).

Development of a two dimensional model for analysis requires the following information to define an initial state of stability:

- An engineering geologic section through the slope of concern (generally cut through the steepest portion of the slope) showing the thickness and position of each engineering geologic unit. The topographic surface profile can be field-surveyed or derived remotely from DEM topographic data whereas the subsurface failure plane geometry might need to be interpolated between known or hypothesized points (i.e., the locations at which the failure plane intersects the ground surface) in the absence of field data acquired from boreholes or with other geotechnical methods;
- Location/elevation of groundwater regimes along this critical section; and
- Saturated and unsaturated unit weights and shear strength of each engineering geologic unit.

The potential effects of the proposed forest practices activities on slope stability can then be evaluated by modifying the initial model with the expected condition based on the proposed activities, such as placement of fill for road construction or elevating groundwater levels (pressures) due to forest canopy removal. Limit-equilibrium models also allow the analyst to reconstruct pre-failure slope conditions of existing landslides by varying the input parameters (e.g., surface topography, engineering geologic unit~~y~~ properties, failure plane geometries, groundwater table elevations) such that the reconstructed original slope fails. These exercises are useful for evaluating reasonable strength parameters of subsurface materials, likely failure plane geometries, and groundwater table elevations in the absence of real data or field indications. Two-dimensional models can also be used to evaluate downslope material impacts to public resources and threats to public safety, as well as upslope impacts in situations where retrogressive failure mechanisms are suspected. Turner and Schuster (1996) and many other references provide more details on the process and methodologies for performing limit-equilibrium stability analyses, including method

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[57] e.g., LISA, DLISA, STABL, SLOPE-W.

assumptions and limitations. All of the above steps require considerable engineering geologic/geotechnical data (e.g., subsurface, instrumentation, laboratory) and expertise to achieve an accurate and meaningful representation of the actual conditions at the site.

~~6.6 Delivery Assessment~~

~~The forest practices rules apply where there is potential for sediment and debris to deliver to a public resource or threaten public safety. When the potential for instability is recognized, the likelihood that sediment and debris would travel far enough to threaten a public resource or public safety should be evaluated. Many factors are part of that evaluation, including:~~

- ~~Proximity to a public resource or safety concern;~~
- ~~Nature of the geologic material involved;~~
- ~~Initial failure volume of a landslide;~~
- ~~Landslide type of failure mechanism;~~
- ~~Slope of channel conditions; and~~
- ~~Observed deformation characteristics of nearby landslides with comparable geologic/geomorphic attributes.~~

~~It is difficult to prescribe guidelines for delivery distances because each situation has a special combination of process and topography. Deep-seated landslides can move anywhere from a few inches to a few miles depending on the friction of the slip plane, the forces pulling the landslides down, and the shear strength resisting those forces. Larger landslides are more likely to move great distances at gentle gradients, but are less likely to be significantly affected by forest practices activities.~~

~~Because many factors can influence landslide mobility and debris runout, it is not practical to provide generalized prescriptive guidelines to predict delivery for a broad range of conditions. In many cases, an evaluation of deliverability will require a field assessment, an inquiry of historic landslide activity and behavior, and the application of experienced judgment in landslide processes and mobility.~~

~~Timber harvest and road building can cause shallow landslides on steep slopes. Travel distances for such landslides depend on the amount of water contained in or entrained by them. Considering that rain, snowmelt, or some other water inputs trigger the majority of landslides in the Pacific Northwest, it should be noted that almost all landslides contain some amount of water that tends to mobilize the soil or rock. Debris slides that do not reach streams (i.e., do not absorb large volumes of additional water) usually deposit debris on the hillslope, and typically do not move far across large areas of flat ground. However, since most landslides occur during storm conditions, a large proportion of debris slides do reach flowing channels and create the opportunity to entrain enough water to become debris flows. These flows are quite mobile and can travel great distances in steep or moderate gradient channels.~~

~~When channel gradients drop below 12 degrees (20%), debris flows no longer scour and generally begin to slow down. On slopes gentler than about 3 to 4 degrees (5 to 7%) debris flows commonly start to lose their momentum and the solids entrained in them (rock, soil, organic material) tend to settle out. Travel distances over a low-gradient surface is a function of the debris flow's volume and viscosity. The solid volume of a debris slide or flow deposit is a function of soil depth, distance traveled down the hillslope, and the gradient of the traveled path. The proportion of water is the~~

~~main control on viscosity. Field or empirical evidence should be used to determine the runout distance of the debris flow.~~

~~Even if the main mass of a landslide or debris flow comes to rest without reaching a public resource, there is the possibility that secondary effects may occur. Bare ground exposed by mass movement and disturbed piles of landslide debris can be chronic sources of fine sediment to streams until stabilized by revegetation. If flowing water (seepage, overland flow, or small streams) can entrain significant volumes of fine sediment from such surfaces, the possibility of secondary delivery must be evaluated along with the likelihood of impact by the initial movement event itself.~~

~~To assess the potential for delivery and estimate runout distance, analysts can evaluate the history of landslide runout in the region, use field observations, and/or use geometric relationships appropriate from the scientific literature. In any situation where the potential for delivery is questionable, it is best to have a qualified expert examine the situation and evaluate the likelihood of delivery. If forest practices are to be conducted on a potentially unstable landform with questionable or obvious potential to impact a public resource, a geotechnical report written by a qualified expert is required.~~

NEW 6.6 Runout and Delivery Assessment

The forest practices rules apply where there is *potential* for sediment and debris to deliver to a public resource or threaten public safety. When forest practices are proposed on a rule-identified landform, the likelihood that sediment and debris would travel, or runout, far enough to threaten a public resource or public safety should be evaluated.

The following information is provided in 6.6:
- 6.6.1 provides an overview of the common landslide types associated with rule-identified landforms.
- 6.6.2 and 6.6.3 cover the factors to consider in a debris flow runout assessment. Shallow-rapid landslides are discussed because they are the single most common type of landslide and because extensive research about the factors influencing runout has been accomplished over the past three decades.
- 6.6.4 contains summaries of scientifically-derived methods for predicting shallow-rapid landslide deposition and runout distances. Predictive methods for calculating deep-seated landslide runout are not discussed because they are still under development by the scientific community.
- 6.6.5 provides a brief overview of the use of barrier trees for mitigating potential landslide delivery.

Runout and delivery distance, the total distance landslide debris is transported and deposited, depends on a combination of processes and topography. For example, debris flows are highly mobile and can move miles in steep confined channels. Deep-seated landslides can move anywhere from a few inches to a few miles depending on the friction of the slip plane, the forces pulling the landslides down, and the shear strength resisting those forces.

Factors to consider in a runout and delivery assessment may include the following depending on the landform and landslide type:
- Initial failure volume of a landslide;
- Type of failure mechanism;
- Nature of the geologic material involved;

- Channel length, gradient, and confinement;
- Topographic features of potential runout paths;
- Historic landslide activity and runout characteristics in the area;
- Proximity to a public resource or safety concern; and
- For deep-seated landslides, observed deformation characteristics of nearby landsides with comparable geologic/geomorphic attributes.

Because each site has a unique set of geomorphic characteristics, it is not practical to provide prescriptive guidelines to predict delivery. An evaluation of deliverability will require a field assessment and professional judgment in landslide processes and mobility. However, professionals often rely on observed patterns and simple evaluations to determine whether an extensive delivery assessment and runout calculation is needed. For example, deposition generally will not continue where the channel becomes unconfined and transitions to a gradient of 6 percent or less. Also, historical deposits may reveal patterns. If a debris fan exists at the base of a confined channel, the extent of future deposition may predictably occur close to the existing debris fan. Or if many shallow rapid landslides have occurred in the area, the deposition in that area will likely mimic that history.

To assess the potential for delivery and estimate runout distance, analysts can evaluate the history of landslide runout in the region, use field observations, and use appropriate geometric relationships from the scientific literature. Historical patterns can be evaluated by gathering aerial photos and landslide inventories. LiDAR data is valuable for mapping evidence of previous deep-seated and larger shallow-rapid landslide deposits, and identifying likely initiation points during initial investigations. Site visits can verify potential initiation points and depositional areas, and are useful for measuring previous landslide events.

In a situation where the potential for delivery is questionable, it is best to have a qualified expert examine the site and evaluate the likelihood of delivery. If forest practices are planned on a potentially unstable landform with questionable or obvious potential to impact a public resource or public safety, a geotechnical report written by a qualified expert is required.

6.6.1 Landslide Types Associated with Rule-Identified Landforms

High hazard landforms and associated geomorphic criteria provide the basis for the rule-identified landforms (refer to Part 4 for more information on rule-identified landforms). Inherent in the assessment of rule-identified landform presence is the detection of these criteria as well as estimating landslide travel distance relative to the location of at-risk public resources or areas that could result in a risk to public safety. Once a potential rule-identified landform has been identified, considerations are made as to the type of landslide that might occur, the rate of movement, potential volume, flow properties, and the topography of runout paths (e.g., gradient, confinement) before delivery potential can be determined.

The type of landslide and travel distance that can occur is typically constrained by factors such as landform scale, soil depth, and topographic features within and below an unstable landform. For example, the width and depth of shallow landslides from bedrock hollows rarely exceed tens of meters, and failures typically occur at the soil-bedrock interface where soil depths are typically one meter or less.[58] Failures are commonly translational, move very rapidly, and accumulate additional

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[58] Dietrich et al. 2007

materials significantly with travel distance unless they enter confined channels and continue to propagate as debris flows. Landslides that initiate within inner gorge landforms are predominantly shallow with rapid sediment delivery. Inner gorge landslide volumes tend to be relatively small compared to convergent headwall landslides, and they may not propagate down the receiving channel as debris flows. Conversely, active deep-seated earthflows may move less than a few feet per year. They can deliver sediment to streams, but rarely are considered a high public safety hazard due to the typically episodic and slow rate of movement. However, secondary failures along lateral stream channels and on deep-seated landslide toes may be subject to rapid debris flow initiations. Table 3 identifies common associations between rule-identified landforms, mass movement modes and rates, and composition and relative depth of the failed mass.

Table 3. Landslide types associated with rule-identified landforms.

Rule-identified Landform	Typical mass movement mode(s)	Common landslide types	Material / Depth of failure
Bedrock hollow	Translational and rapid	Debris slides and debris flows	Colluvial soil mantle / Shallow
Convergent headwall	Translational and rapid	Debris slides and debris flows	Colluvial soil mantle / Shallow
Inner gorge	Translational or rotational, rapid or slow	Debris slides, debris flows, debris avalanches, shallow or deep slumps	Colluvial soil mantle, residual soil mantle, bedrock outcrops; glacial, fluvial, and lacustrine deposits / Shallow
Deep-seated landslide toe	Rotational or translational, rapid or slow	Debris slides, debris flows, debris avalanches, deep-seated slumps, earth flows	Colluvium / Variable depths
Outer edges of meander bends	Translational and rapid	Debris slides, debris flows, debris avalanches, shallow or deep slumps	Colluvial soil mantle; glacial, fluvial, and lacustrine deposits / Shallow
Groundwater recharge areas associated with glacial deep-seated landslides	Rotational or translational, rapid or slow	Deep-seated slumps, debris flows, debris avalanches, earth flows	Glacial, fluvial, and lacustrine deposits / Variable depths

6.6.2 Factors Influencing Debris Flow Runout

Debris flow runout distances within valleys or inner gorges and across debris fans, have been studied by empirical observation in the Pacific Northwest.[59] Generally, it has been demonstrated that basin topography controls the flow types that reach a fan at the base of the hillslope, causing fan gradient and the presence of various deposits to be somewhat predictable.[60] Predictive models based on simple height and gradient parameters have been developed, and several are described in 6.6.4.

There is considerable variability in the empirical observations. A debris flow may stop as a discrete deposit, debris fan, or sediment wedge above wood accumulations; or it may deposit gradually

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[59] e.g., Benda and Cundy 1990; Robison et al. 1999; May 2002; Guthrie et al. 2010.

[60] e.g., Melton 1965; Scheidl and Rickenmann 2010.

along a significant length of channel. In general, gradients are steep at initiation sites, remain steep where scour-to-bedrock occurs, and moderate in transport and deposition areas. Figure 26 is a generalized illustration of debris flow processes.

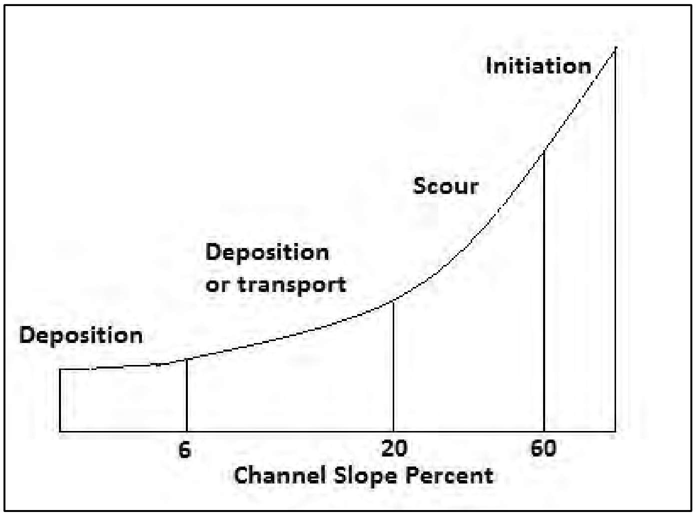

Figure 26. Debris flow characteristics relative to channel slope (adapted from Benda et al. 1998).

Initiation and Gradient

Initiation typically occurs on hillsides steeper than 70% but sometimes occurs on slopes as low as 60%.[61] When channel gradients drop below 20%, debris flows no longer cause significant scour and start to lose their momentum. On slopes gentler than about 5 to 7%, debris flows further slow and the solids entrained in them (rock, soil, and organic material) tend to settle out and deposit. Travel distance over a low-gradient surface is a function of the debris flow's volume and viscosity. The solid volume of a debris slide or flow deposit is a function of soil depth, distance traveled down the hillslope, and the gradient of the traveled path. The proportion of water is the main control on viscosity.

Many data sets show significant overlap in the gradient ranges of erosional and depositional behavior where erosion can occur at lower slope angles (approximately 3 to 10%) and deposition can occur at higher gradients (55 to 80%).[62] Figure 27 displays detailed field data that demonstrates both the real differences and the large overlap.[63] Two of the larger data sets show that net deposition generally occurs from 14 to 21% [64] and from 21 to 27%[65]. Guthrie et al. (2010) specifically conclude that, "Deposition and scour occur on steeper and flatter slopes, respectively, than previously reported…", in part because of the detailed field work they conducted. Benda and Cundy (1990) found that debris flows from their Oregon Coast Range study sites almost always stop within the confined channel network where the channel gradient drops below about 6% and where the tributary junction angle is greater than 70 degrees. They do note that the deposit typically continues 150 to 500 feet further downstream. A conservative approach would be to predict deposition only after 1000 feet of a channel with a gradient of less than 6%.

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[61] Robison et al. 1999.

[62] e.g., May 2002; Guthrie et al. 2010.

[63] May 2002.

[64] Hungr et al. 1984.

[65] Guthrie et al. 2010.

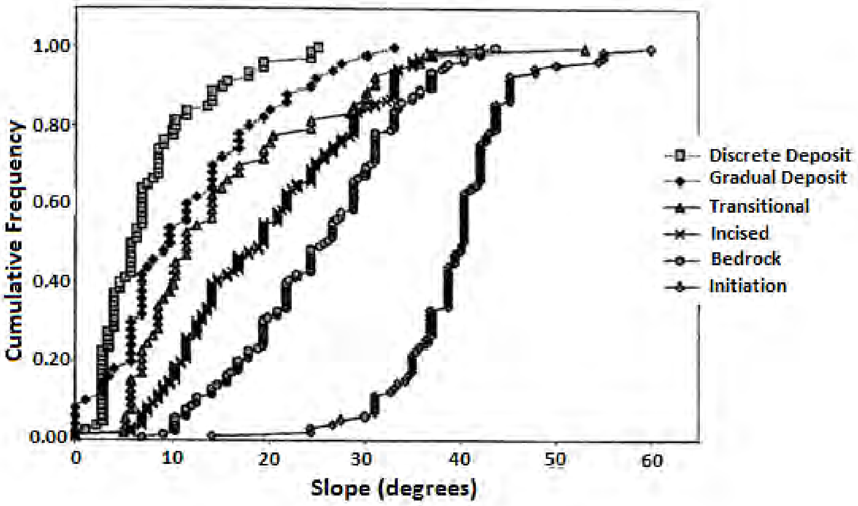

Figure 27. Slope distributions for depositional zones (discrete and gradual), transitional zones, erosional zones (incised and bedrock), and initiation sites for debris flows (from May 2002).

The overlap between erosional and depositional behavior within generally confined valley settings means that factors other than just channel gradient are influencing debris flow runouts. Several studies[66], but not all[67], find that runout length has been strongly correlated with event volume such that larger events travel further than smaller events.

Confinement

Channel confinement, the ratio of valley width to channel width, plays a role in debris flow runout. For example, Lancaster et al. (2003) and Benda and Cundy (1990) found that deposition may begin at higher channel gradients where confinement is low, while erosion may continue at lower channel gradients where confinement is high. Confinement alone appears to account for much of the overlap in gradient between erosional and depositional behavior, and in turn exerts influence on runout lengths. Additionally, Fannin and Rollerson (1993) demonstrated that a ratio of channel width to channel gradient delineated the zones of scour and deposition.

Saturation

Initial water content of the landslide mass and the amount of water in the receiving channel both influence landslide saturation. Saturation of the landslide and the resulting debris flow influences mobility, which is a function of landslide speed and travel distance. Considering that rain, snowmelt, or other water inputs trigger the majority of landslides in the Pacific Northwest, almost all landslides contain some amount of water that tends to mobilize the soil or rock. Debris slides that do not reach streams (i.e., do not absorb large volumes of additional water) usually deposit on the hillslope and typically do not travel across large areas of flat ground. However, since most landslides occur during storm events, a large proportion of debris slides do reach flowing channels and create the opportunity to entrain enough water to become debris flows that can travel considerable distances in steep or moderate channels.

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[66] e.g., May 2002; Sheidl and Rickmann 2010.

[67] Prochaska et al. 2008.

Lithology

Lithology and its influence on soil development may affect runout distances. Qualified experts in Washington State have noted that debris fans are steep and short where local material includes large boulders, and that fine-grained silt loams may liquefy and flow across nearly level surfaces. Krogstad and O'Conner (1997) noted that relatively cohesion-less soils in the South Fork Skokomish produced long runout distances but had limited scour ability. However, the relationship between lithology and/or soil type and runout distance has not been systematically studied. Qualified experts are encouraged to conduct empirical studies (e.g., a landslide inventory with emphasis on runout and delivery) to better predict the probability of delivery and impact in a local area for an individual lithology.

Vegetation

Runout distances are also influenced by standing forest vegetation along the runout path. Using empirical data, May (2002) reported shorter runout lengths in older stands. She found that large trees or large woody debris scoured or entrained by debris flows may reduce runout distances.[68] Lancaster et al. (2003) created simulations designed to mirror natural debris flows and concluded that without wood, basin sediment yield increases, runout length increases, and deposits are concentrated in low-gradient reaches. See 6.6.5 for further information on influence of trees along the runout path.

Potential for debris flows to evolve into debris floods or hyper-concentrated flows

The prediction of both channelized and unconfined runout distances is complicated by the potential for debris flows to evolve into debris floods and/or hyper-concentrated flows. A debris flood as classified by Hungr et al. (2001) is a torrent with substantial transport of coarse sediment – basically a debris flow with a higher water content. Hyper-concentrated flow is a slurry of finer particles, usually with a predominance of sand and coarse sand with some gravel.[69] Pierson and Scott (1985) describe the transformation of debris flows to hyper-concentrated flows from the 1980 eruption of Mt. St. Helens as they traveled down the Toutle River. Their basic hypothesis is that the debris flow entrained additional channel water as it flowed down valley, which caused coarser materials to settle out and become bedload, while the sand-rich hyper-concentrated flow increased its velocity and pulled ahead of the coarser materials. (In this relatively channelized environment, a tail of debris flow materials actually deposited on top of the hyper-concentrated flow deposits.) They describe the hyper-concentrated flow deposits as poorly sorted (i.e., less than typical alluvial materials but more so than debris flow deposits) sands, with faint horizontal stratification but an overall massive appearance, and thin lenses of gravel.

6.6.3 Debris Fan Formation

Identifying debris fans and understanding their formation is part of a runout assessment. The presence and size of a debris fan indicates past accumulations of sediment deposits and debris flows. Fans may be constructed from stream deposits (alluvial fans), debris flow deposits (debris fans), or multiple depositional processes (composite fans). They are typically located at the mouths of canyons. They can also form anywhere a channel loses sufficient confinement to promote deposition as well as at the base of steep slopes.

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[68] May 2002; Lancaster et al. 2003; Robison et al. 1999.

[69] Beverage and Culbertson 1964; Pierson and Scott 1985.

Landslide runout distances and the amount of direct delivery are influenced by the presence or absence and size of fans. These factors are in turn influenced by the area of the contributing basin and valley width where the fan forms. May and Gresswell (2004) found that smaller drainages had lower recurrence rates of debris flows which led to smaller fans, and where valley width was narrow no fans were present (or were truncated) because rivers and streams eroded the fans faster than they were created. Debris flow delivery potential, particularly from small and confined drainages across narrow valley bottoms, is likely to be high. Conversely, larger drainages had higher recurrence rates which led to larger fans, particularly where valley widths were greater. Also, the higher recurrence rates down higher order channels sometimes precludes debris flows from continuing to bulk up in the lower channels because they are already devoid of material. Delivery, from larger drainages across wider valley bottoms, may be limited by deposition on a large fan where the mainstem is less likely to, or less capable of, eroding.

The processes that create a fan surface (e.g., alluvial or debris flow) can be predicted by the fan gradient and the "Melton number" of the watershed above the fan. The empirical studies that have contributed to this work are summarized in Scheidl and Rickenmann (2010). The Melton number stems from Melton (1965), although it was not identified as such in the original reference. It is calculated by dividing the height of the watershed taken as the maximum elevation, minus the elevation of the fan apex by the square root of the area of the watershed. An ESRI user forum provides clarification of the Melton number, also called the Melton Roughness Number.

Figure 28 from Scheidl and Rickenmann (2010) displays average fan slope on the vertical axis and the Melton number on the horizontal axis. Three diagonal lines labelled "A" are derived from previous empirical studies, and represent observed transitions between purely alluvial processes and mixed processes. The two diagonal lines labelled "B" are also derived from previous empirical studies, and represent observed transitions between mixed processes and debris flow processes.

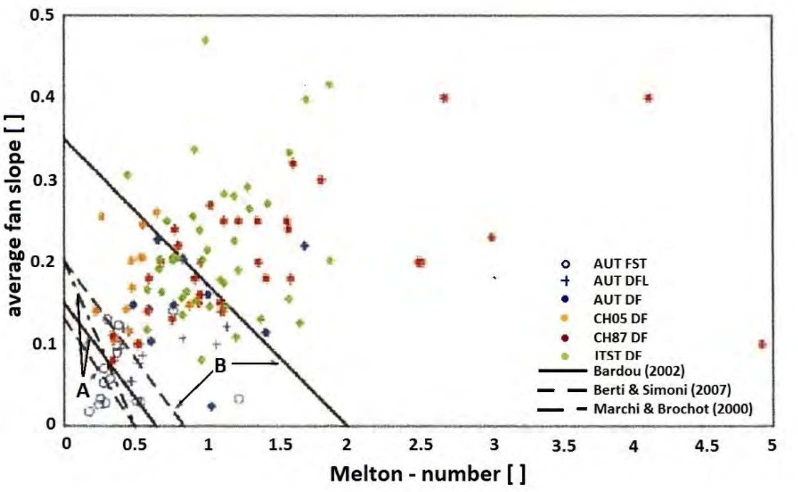

Figure 28. Relation between average fan slope (S_f) and Melton number (M_E) for European landslide datasets. Threshold lines (A and B) distinguish zones with dominant process types, and symbols represent three process types: DF = debris flow, DFL = debris flood, FST = fluvial sediment transport (from Scheidl and Rickenmann 2010).

6.6.4 Methods and Models for Predicting Shallow Rapid Landslide Runout and Delivery

This part contains brief summaries of selected methods, listed roughly in chronological order of publication, which landslide scientists have developed for estimating shallow rapid runout distances for various landslide types. Although it is not an exhaustive list, these are included because of their applicability on forest lands in the Pacific Northwest. *If reviewed in their entirety*, they may contain helpful information to supplement professional judgment and experience.

Empirically-based methods for assessing debris flow hazards rely on quantitative data, whereas numerical simulation models use mathematical equations and procedures to arrive at estimates for erosion and depositional processes. Those summarized below are based on data from shallow-rapid landslide events occurring in the Pacific Northwest and British Columbia, and in most cases are based on hundreds of observations. The simplest models can be applied at the field scale using clinometers and range finders in conjunction with digital elevation data. The methods should be applied to conditions similar to those on the site being assessed.

Other methods not listed here may be viable and the appropriate method for a site is left to the analyst. While many of them are at the technical level of a qualified expert, several may be useful for a general practitioner such as the 2003 guidance in the methods in the Tolt Watershed Analysis[70] and the Oregon Department of Forestry's Technical Notes 2 and 6[71].

Benda and Cundy 1990

Benda and Cundy's 1990 article, *Predicting deposition of debris flows in mountain channels,* describes an empirically-derived method for predicting potential impacts from debris flows. It is typically referred to as the Benda-Cundy model. The technique uses easily measured topographic criteria (channel slope, channel confinement, and tributary junction angle) to calculate debris flow runout distance from the point of initiation and the final deposition volume of debris flows in steep mountain channels.

The method was developed and tested using data from debris flows in the Oregon Coast Range and the Washington Cascades. An Oregon Department of Forestry study of 361 debris flows[72] validated the model, and numerous resource professionals in the Pacific Northwest have reported good success in applying it to mountain debris flows regionally.

Tolt Watershed Analysis 1993

The Tolt Watershed Analysis[73] contains mass wasting prescriptions for determining landslide delivery potential based on physical processes from empirical results in northwestern Washington and western Oregon. The *Mass Wasting Delivery Flow Chart Road and Harvest* procedure in the analysis is summarized in the following paragraph. Although intended for use in the Tolt River basin, the method can be applied in other similar physiographic provinces.

In this method, delivery potential for a hypothetical mass failure is determined by considering topographic conditions at the failure initiation site, along the runout path, and at the deposition zone. The assessment is based on slope gradient changes as material travels downslope. If a

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[70] Ward 1993.

[71] ODF Technical Note 2 2003 and ODF Technical Note 6 2003.

[72] Robison et al. 1999.

[73] Ward 1993.

failure becomes channelized, it becomes a debris flow deposit. As debris flow deposition continues downslope, the potential for a dam-break flood is evaluated based on channel confinement. Estimated runout distances are provided as outputs from the above hillslope and up-channel geomorphology. A description and flow chart illustrating the method is included in the mass wasting prescription chapter. The Tolt Watershed Analysis can be accessed on the Washington State Department of Natural Resources web site at https://fortress.wa.gov/dnr/protectionsa/ApprovedWatershedAnalyses.

Coho and Burges 1994

Coho and Burges identified and characterized a relatively infrequent but distinctive and destructive type of flood wave known as a dam-break flood that can occur and travel long distances in forested watersheds. The study relied on data from observed dam-break floods in the Olympic Mountains and Washington Cascades. Their report contains a simple strategy for evaluating the dam-break flood potential and runout distance with easily measured field and topographically derived criteria (valley width, channel gradient, presence of sufficient small organic debris, and riparian condition) to identify susceptible stream channels and the affected downstream extent.

Dynamic Analysis (DAN) 1995

To understand the internal strength, erosion ability, and rheology of a landslide, Hungr (1995) developed a numerical model called Dynamic Analysis (DAN). The model was originally developed as a tool for modelling post-failure motion of rapid landslides and can be used for predicting runout. It allows for the selection of a variety of material rheologies, which can vary along the slide path or within the slide mass. The model is calibrated by back analysis and has been widely used in many inverse or back analysis calculations[74] and has been improved over several years.[75] Currently, there are two models used worldwide: DAN-W (release 10) and DAN3D. Both models work best for rock and debris avalanches and but have utility with debris flows.[76] The model was validated on mine tailing failures in southern British Columbia.

Corominas 1996, Hunter and Fell 2003

Corominas (1996) provided an equation for estimating a travel distance angle based on the type of landslide, slide volume, and degree of confinement. Hunter and Fell (2003) reanalyzed the data and found that for landslides smaller than one million cubic yards, a size typical in Pacific Northwest forests, the following equation is more applicable. For unconfined shallow landslides, the volume and expected height of the landslide from topographic data is applied as follows:

$$\frac{H}{L} = 0.77(\tan\alpha_2) + 0.087$$

H and L are the landslide height and travel distance respectively; α_2 is the downslope angle (Figure 29).

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[74] Pirulli et al. 2003, Revellino et al. 2004.

[75] Shu et al. 2014.

[76] Oldrich Hungr, personal communication, June 2015.

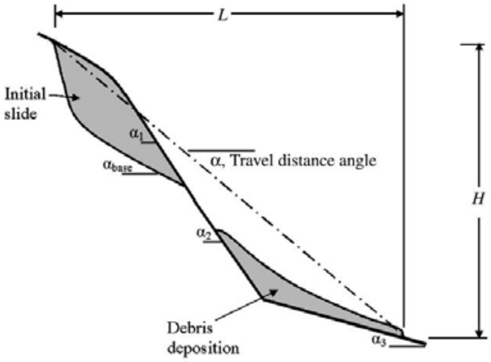

Figure 29. Cross section showing travel distance, travel distance angle, and slope geometry (Hunter and Fell 2003). The equation above could be applied to unconfined shallow rapid landslides.

Acme Watershed Analysis 1999

A sediment delivery model for open slopes was developed for the Acme Watershed in Washington.[77] It is based on empirical observations that debris flows can develop a coulomb-viscous rheology controlled by the shear stress of the moving debris and the resistance to that stress, which determines the critical thickness (the landslide thickness at deposition). Use of the model requires assumptions regarding landslide initiating volume, moisture content of the debris, gradient of the slope over which the debris is transported, yield strength of the debris, and slope roughness as influenced by trees, stumps, and surface morphology. The model should not be applied to thin soils on hillslopes greater than 70%. Other model limitations are described in the Acme Watershed Analysis mass wasting document. Model predictions are presented in tabular form to aid the field practitioner in using a range of hillslope gradients and landslide volume classes. The Acme Watershed Analysis can be accessed on the Washington State Department of Natural Resources web site at https://fortress.wa.gov/dnr/protectionsa/ApprovedWatershedAnalyses.

UBCDFLOW (University of British Columbia) 2001

The UBCDFLOW model is based on field observations of landslides from clearcuts.[78] Four sites in coastal British Columbia with 449 events were used to develop the model for predicting debris flow travel distance. All of the sites were glaciated and included areas in western Vancouver Island with similar geology and climate as Washington State. The study found that the total entrainment volume along runout paths does not equal the total volume deposited. Inspection of the survey data showed that "…reach morphology exerts a strong influence on flow behavior."[79] The model, complete with a user guide and tutorial, is available at http://dflow.civil.ubc.ca/.

Oregon Department Forestry Technical Guidance 2003

The Oregon Department of Forestry developed technical guidelines to maintain regulatory compliance with the landslides and public safety rules for shallow, rapidly moving landslides. The guidance is detailed in two technical documents[80] to guide forest practices activities where

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[77] Crown Pacific Limited Partnership 1999.

[78] Fannin and Wise 2001.

[79] Ibid.

[80] ODF Technical Notes 2 and 6.

shallow landslide hazards exist, and is based on published empirical data from the Pacific Northwest and British Columbia.[81] Technical Note Number 2, *High Landslide Hazard Locations, Shallow, Rapidly Moving Landslides and Public Safety: Screening and Practices*, is intended for engineers and foresters in conducting the initial public safety screening. Technical Note Number 6, *Determination of Rapidly Moving Landslide Impact Rating*, assists geotechnical specialists in completing detailed, field-based investigations of associated upslope hazards and downslope public safety risks.

The scale of the investigation is on the order of small tributary basins, rather than entire mainstem watersheds, for which direct links between slope stability hazards and public safety risks can be established with a relatively high level of certainty. Once potential high hazard landforms have been field verified, other features are identified that are considered potentially hazardous to downslope public safety under certain topographic and material conditions. These features may include proposed and/or existing fillslopes, sidecast deposits, and waste disposal areas on steep slopes.

Further Review Areas (FRAs) are identified for each structure (e.g., high traffic road, home, public utility). FRAs are the downslope areas, such as channel reaches, between the potential shallow landslide initiation sites and structures. For example, it is assumed that debris flows slow down or stop when they reach unconfined low-gradient channels or open-slope areas. Distance and angle measurements within an FRA do not require any greater precision than achieved by a clinometer and rangefinder. Where a channel loses confinement (e.g., at the mouth of a canyon), the FRA extends 500 feet from that point. Where debris fans are present at canyon mouths, the FRA extends to the outer edge of the fan.

For shallow open slope debris slides and non-channelized debris flows in soils typical in the Pacific Northwest, the Oregon Department of Forestry has developed forest practices guidance for estimating runout based primarily on slope steepness. Landslide deposition is expected to begin where slope gradients of 40% or less occur. Deposition is also expected to occur at the base of steep slopes and can occur on mid-slope benches that are usually 50 feet in length. Open slope debris flows are expected to stop within 100 feet when downslope gradient drops to and remains below 40% gradient.

Hungr et al. 2005; Corominas et al. 2014

Evaluating where previous landslides have deposited is applicable to forecasting the extent of possible future debris flow hazards.[82] Using historic landslide inventory data is appropriate because it is based on field observations of past landslide runout behavior.[83] These measurements are then used to forecast future runout distances. However, the shortcomings of this technique include the fact that old deposits may be modified by more recent events that erode or cover them up, and the technique is best to use in areas where large events occur infrequently.[84] Additionally, this technique may not be transferable to other areas because the size, type, and driving forces may be different for future events in other locations.[85] Because

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[81] e.g., Bend and Cundy 1990; Corominas 1996; and Robison et al. 1999.

[82] Hungr et al. 2005.

[83] Corominas et al. 2014.

[84] Ibid.

[85] Ibid.

landslide deposits have similar textural properties to glacial deposits (e.g., unsorted and unstratified), Hungr et al. (2005) suggest that careful evaluation of the deposits is necessary to differentiate between the two in glaciated areas.

Prochaska et al. 2008

Prochaska et al. (2008) provide a simple topographic model that utilizes parameters that can be measured without estimating initiation point, initiation volume, or the down-valley bulk-up process. The model only applies to debris flows that reach a fan apex. Prochaska et al. (2008) do not present a final formula and do not show any of their calculations, nor do they provide sufficient data to check any of their calculations. For that reason, a user-friendly formula is provided below.

The model predicates on determining the elevation of the highest point in the drainage and the elevation of the apex of the fan. The half-height, which is the elevation half way between the first elevations, is located on the stream in the example below. β is the angle in degrees between the half-height and the MAX and fan apex; it is calculated by measuring the horizontal distance to the fan apex. α equals 0.88 times β where α is the angle in degrees from 0.5 times height to the end of the runout. Using α to project the runout down the fan surface requires knowing the fan gradient. A licensed professional engineer created a formula where β can be calculated in percent and the fan gradient measured in percent; the calculation then requires arctan to convert β to degrees before multiplying by 0.88, and then tan to convert the α value back to percent. α does not actually appear in the formula; it is present as [(arctan (β%))*(0.88)].

$$\text{Runout} = 0.5\ h\ [(\beta\% - f\%)/((\tan[(\arctan(\beta\%))*(0.88)] - f\%)\ -1]$$

Where:
h = elevation of highest point of the drainage – elevation of fan apex
β% = 0.5 h / horizontal length between the midpoint of elevation and the fan apex (this value is a decimal %, not a degree)
f% = average gradient of the fan in decimal %

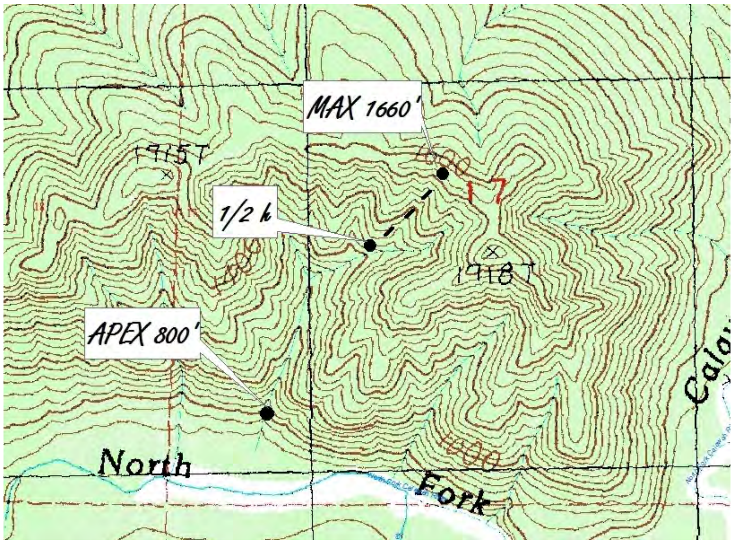

Figure 30. From USGS 7.5' Deadmans Hill Topographic Quadrangle. Maximum elevation of the small watershed is 1660 feet. Fan apex is 800 feet. The variable 1/2h (labeled) equals 1230 feet. B% is 0.243 (calculated from topo sheet); f% is 0.10 (field measured). Runout is 163 feet as estimated by the formula presented above.

Guthrie et al. 2010

Using over 1700 field observations supplemented by aerial photography interpretation in British Columbia on Queen Charlotte and Vancouver Islands, Guthrie et al. (2010) examined landslide deposits from open sloped and channelized (gullied) debris flows. They used these data to develop a sediment balance approach (erosion versus deposition) to estimate runout in similar terrain. Their study found that deposition occurred on open slopes between 32% and 45%. These are steeper angles than those found in other local studies.[86] Channelized debris flows deposited between 21% and 27%. The study also determined that one of the reasons for the steeper deposition slope angles was boundary trees. After traveling through logged slopes, most of the debris flows stopped entirely within 150 feet of the boundary in 72% of the examined flows.

6.6.5 Runout Mitigation Strategy: Barrier Trees

If landslide initiation site avoidance, application of rule-required RMZs, or other mitigation measures appear inadequate, debris flow runout may be further mitigated by leaving "barrier trees" in the low gradient depositional reaches of debris flow-prone streams. Barrier trees can be retained to encourage the deflection, deceleration, and/or deposition of debris flows[87] and dam-break floods.[88]

In most cases, riparian forests adjacent to larger channelized streams act as natural barriers to debris flows or add woody debris, independent of management practices. However, standing trees in mature forests may promote more rapid deposition, which can minimize landslide size.[89] Therefore,

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[86] Hungr et al. 1984: Fannin and Wise 2001; Horel 2007.

[87] VanDine 1996, Benda et al. 1998, Guthrie et al. 2010.

[88] Coho et al. 1994.

[89] Guthrie et al. 2010.

leaving mature trees where forest practices rules do not require RMZs (i.e., portions of Type N waters) may reduce landslide impacts. Figure 31 shows the path of an open slope debris flow initiated from a clearcut, through a small stand of older forest to where it narrows considerably following the contact with the forest edge. The debris flow increased in width as it entrained additional material below the intact forest, and a slight reduction in width is evident below the road before it stopped at the lower gradient valley floor.

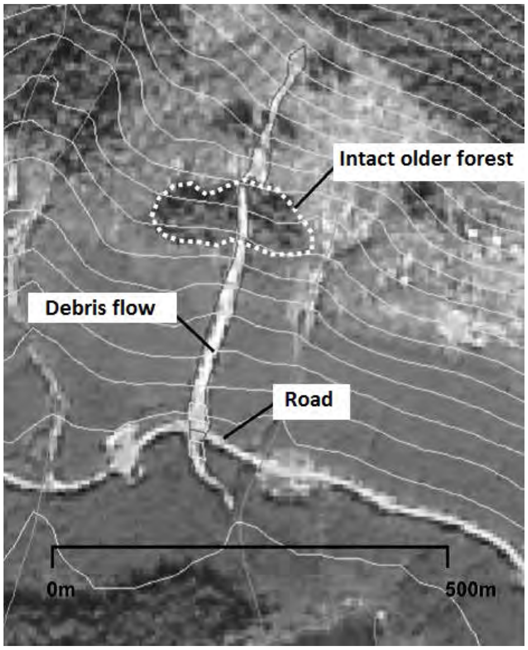

Figure 31. Debris flow path (from bottom to top of the photo) showing width changes from traveling through an older forest stand (Guthrie 2010).

Large trees near the areas of debris flow deposition (such as on fans at the mouths of steep tributaries) may be the most effective in inhibiting movement and protecting structures and highways.[90] Barrier trees can also be retained or restored on the sides of a potential debris flow runout path to constrain its lateral movement and protect structures on a debris fan.[91]

PART 7. SYNTHESIS OF RESULTS, EVALUATION, AND GEOTECHNICAL REPORTS

This step is generally reserved for qualified experts when preparing geologic evaluations. The following questions and guidance are provided to assist the qualified expert when synthesizing the information assembled in the office review and field assessment, and can be useful when preparing a geologic evaluation or report.

7.1 Synthesis and Evaluation

Consideration of the following questions may help to synthesize findings:

- Based on an analysis of available information, what is the geotechnical interpretation of physical processes governing unstable slope/landform movement, mechanics, and chronologies of each identified feature?

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[90] Benda et al. 1998.

[91] Eisbacher and Clague 1984.

- What are the project limitations (e.g., quantity or quality of technical information, site access, project timeframe) that might influence the accuracy and precision of identifying, delineating, and interpreting unstable slopes and landforms?
- What are the scientific limitations (e.g., collective understanding in the scientific community of landform physical processes) that might influence the identification, delineation, and interpretation of unstable slopes and landforms?
- What is the potential for material delivery from each relevant unstable slope and landform to areas of public resource sensitivity or where public safety could be threatened?
- What are the relative roles of natural processes and land management activities in triggering or accelerating instability?
- What level of confidence is placed in the identification, delineation, and interpretation of unstable slopes and landforms? How does the confidence level impact any recommendations for unstable slope management and/or mitigation?

Models such as those for slope stability and sensitivity (see 6.5) may be used to support analyses of potentially unstable slope and landform characteristics and mechanics. If modeled results are included in reports, they should be accompanied by a statement of model assumptions, analysis limitations, and alignment with existing information (e.g., field data). For example, it would not be appropriate to include a modeled reconstruction of landslide failure-plane geometry based on data from one borehole or drive probe sample. The modeled results would likely be misleading and could result in spurious conclusions.

To provide the necessary information for DNR to evaluate a proposal, ~~T~~the analytical methods and processes used by the qualified expert to identify, delineate, and interpret unstable slopes and landforms should ~~can~~ be described in their reports along with information sources, data processing techniques, and the limitations of analysis results. Reports should describe all assumptions regarding input parameters or variables, such as groundwater surface elevation estimates employed in stability sensitivity analyses, as well as the reasoning for their use. Reports may also include an assessment of the sensitivity of the analytical method or model results to parameter variability. This is especially true where only a range of parameter values is available, or where input values are extrapolated or estimated from other locations or databases.

Confidence levels in the slope stability analysis and model results are influenced by many factors including project complexity and objectives; site characteristics (e.g., acreage and accessibility); project timeframes; quantity and quality of available information (e.g., reports, databases) and remotely sensed data; accuracy and precision of field observations and collected data; and the rigor of available analytical methods and models. A discussion of the primary limiting factors will assist the landowner and report reviewer when evaluating the potential public resource, public safety, and liability risks associated with implementing a project.

Documentation of the project analysis may include annotated images (e.g., LiDAR-derived hillshades, aerial photos); geologic or topographic profiles; maps; sketches; results of subsurface investigations; summaries of computational or simulation modeling; summaries of available (i.e., previously published) information; and remotely sensed or field-derived data and text to explain the concrete evidence and logical train of thought for the conclusions and recommendations that will be presented in the geotechnical report.

7.2. Geotechnical Reports

When harvesting timber or building roads on potentially unstable slopes, a written report is required to be part of the FPA to explain whether the proposed forest practices are likely to affect slope stability, deliver sediment and debris to public resources, or threaten public safety. For the purposes of this Board Manual section, such a report is called a "geotechnical report." The geotechnical report must be prepared by a qualified expert and must meet the requirements described in WAC 222-10-030(1). If the FPA is classed as a "Class IV-special", the applicant must also include a SEPA checklist and additional information listed in WAC 222-10-030.

Qualified experts must be licensed with Washington's Geologist Licensing Board. Specific rules addressing a geologist's professional conduct are listed in WAC 308-15-140(1) and (2). For more information about the geologist licensing process, refer to WACs 308-15-010 through 308-15-150, or see the Geologist Licensing Board's web site at (www.dol.wa.gov/business/geologist). The education and field experience on forest lands is required, in addition to the appropriate geologist license.

The qualified expert is encouraged to consult with DNR Region geologists when preparing a geotechnical report to ensure all important elements are covered. Region contact information can be found on DNR's web site at www.dnr.wa.gov.

The report should be as detailed as necessary to address these and any other relevant elements:

(a) *Prepare an introductory section*. This section should describe the qualified expert's qualifications. It should also reference the FPA number if previously submitted, landowner and operator names, and a brief description of site observations to the area, including dates and relevant weather conditions.

(b) *Describe the geographic, geologic, and soil conditions of the area in and around the application site*. Include a legal description of the proposal area; the county in which it is located; and, where appropriate, the distance and direction from the nearest municipality, local landmarks, and named water bodies. Provide elevations and aspect. Describe the underlying parent materials, including their origin (i.e., glacial versus bedrock); the name(s) of any rock formations and their associated characteristics; and geologic structure relevant to slope stability. Describe soils and rocks on site based on existing mapping, field observations, and any available local information. Describe soil and rock texture, depth, and drainage characteristics typically using standard soil and rock classification systems.[92]

(c) *Describe the potentially unstable landforms within and around the site*. Include a general description of the topographic conditions of the site. Specifically, identify the potentially unstable landforms located in the area (i.e., those defined in WAC 222-16-050 (1)(d)(i)), in addition to any other relevant landforms on or around the site. Describe in detail the gradient, form (shape), and approximate size of each potentially unstable landform. Include a description of the mass wasting processes associated with each identified landform, as well as detailed observations of past slope movement and indicators of potential future landslide activity.

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[92] e.g., Unified Soil Classification System (USCS), American Association of State Highway and Transportation Officials (AASHTO) and Rock Mass Rating (Bieniawski 1989).

Relevant field observations, important features, and sampling locations used in project analysis can be displayed on a map in the geotechnical report. Descriptive, photo, or data-sampling observation points should be geo-referenced (i.e., with GPS waypoints) and mapped. GPS track locations of field traverses can ~~be used to clarify~~indicate which portions of the project site were evaluated. In addition, field-derived cross sections and geologic profile locations should be geo-referenced. Assign a unique alphabetic or numeric identifier label to each landform or observation point relevant to the assessment and note these on a detailed site map of a scale sufficient to illustrate site landforms and features. Where the proposal involves operations within the groundwater recharge area of a glacial deep-seated landslide, specifically discuss the probable direct and indirect impacts to groundwater levels and those impacts to the stability of the glacial deep-seated landslide.

(d) *Analyze the possibility that the proposed forest practice will cause or contribute to movement on the potentially unstable slopes*. Explain the proposed forest management activities on and adjacent to the potentially unstable slopes and landforms. Clearly illustrate the locations of these activities on the site map, and describe the nature of the activities in the text. Discuss in detail the likelihood that the proposed activities will result in slope movement (separate activities may warrant separate evaluations of movement potential). The scope of analysis should be commensurate with the level of resource and/or public risk. Include a discussion of both direct and indirect effects expected over the short- and long-term. For proposals involving operations on or in the groundwater recharge area of a glacial deep-seated landslide, conduct an assessment of the effects of past forest practices on landslide/slope movement. Explicitly state the basis for conclusions regarding slope movement. Conclusions may be based on professional experience, field observations, unpublished local reports, watershed analyses, published research findings, and/or slope stability model output. Input parameters, model assumptions, and methods should be fully substantiated within the report.

(e) *Assess the likelihood of delivery of sediment and/or debris to any public resources, or to a location ~~and in a manner~~ that would threaten public safety, should slope movement occur*. Include an evaluation of the potential for sediment and/or debris delivery to public resources or areas where public safety could be threatened. Discuss the likely magnitude of an event, if one were to occur. Separate landforms may warrant separate evaluations of delivery and magnitude. Explicitly state the basis for conclusions regarding delivery. Conclusions may be based on professional experience, field observations, unpublished local reports, watershed analyses, published research findings, and/or landslide runout model results, which should have site-specific data. Input parameters, model assumptions, and methods using best available data should be fully substantiated within the report.

(f) *Suggest possible mitigation measures to address the identified hazards and risks*. Describe any modifications necessary to mitigate the possibility of slope movement and delivery due to the proposed activities. If no such modifications are necessary, describe the factors inherent to the site or proposed operation that might reduce or eliminate the potential for slope movement or delivery. For example, an intact riparian buffer downslope from a potentially unstable landform may serve to intercept or filter landslide sediment and debris before reaching the stream. Discuss the risks associated with the proposed activities relative to other alternatives, if applicable. Some geotechnical reports might include recommendations regarding additional work needed to supplement the report, including but not limited to monitoring by the landowner or their designated qualified expert of geologic conditions (e.g., groundwater, slope movement) and review of plans and specifications.

Conclusions should include documentation of the outcomes of the slope stability investigation based on the synthesis of all geologic and hydrologic information and interpretations used in the office review and field assessment, qualitative information and data analyses, geo- and hydro-technical modeling, and evaluation of material deliverability. Conclusions might also include a description of the suitability of the proposed activity for the site and likely direct and indirect effects of the activity on the geologic environment and processes. Conclusions should be substantiated by the evidence presented and the expert's logical thought processes during analysis and synthesis.

GLOSSARY

Aquifer	Saturated permeable geologic unit that can transmit significant quantities of water under ordinary hydraulic gradients.
Aquitard	A less permeable bed in a stratigraphic sequence.
Confined aquifer	An aquifer that is confined between two aquitards. Confined aquifers occur at depth.
Debris avalanche	The very rapid and usually sudden sliding and flowage of incoherent, unsorted mixtures of soil and weathered bedrock.
Discontinuity	~~Sudden or rapid change with depth in one or more of the physical properties of the materials constituting the earth~~A plane or surface that marks a change in physical or chemical characteristics in a soil or rock mass (bedding, joint, fracture, or fault plane).
Driller's log	The brief notations included as part of a driller's tour report, that describes the gross characteristics of the well cutting noted by the drilling crew. It is useful only if a detailed sample log is not available. Driller's logs may also include information on groundwater elevation.
Earthflow	A slow flow of earth lubricated by water, occurring as either a low-angle terrace flow or a somewhat steeper but slow hillside flow.
Engineering geology	Performance of geological service or work including but not limited to consultation, investigation, evaluation, planning, geological mapping, and inspection of geological work, and the responsible supervision thereof, the performance of which is related to public welfare or the safeguarding of life, health, property, and the environment, and includes the commonly recognized practices of construction geology, environmental geology, and urban geology.
Evapotranspiration	A combination of evaporation from open bodies of water, evaporation from soil surfaces, and transpiration from the soil by plants. Commonly designated by the symbols (Et) in equations.
Factor of safety	The ratio of the resistant force acting on the sliding surface to the driving force acting on the potential slide mass. When the factor of safety is greater than one (1), the slope is stable; when the factor of safety is less than one (1), the slope is unstable.
Fluvial	Pertains to the deposits and landforms produced by the action of a river or a stream.
Glacial outwash	Sediment deposited by meltwater streams beyond a glacier, typically sorted and stratified sand and gravel.

Graben	A block, generally long compared to its width, that has been downthrown along faults relative to the rocks on either side.
Groundwater	Subsurface water that occurs in soils and geologic formations. Encompasses subsurface formations that are fully saturated and near-surface, unsaturated, soil-moisture regimes that have an important influence on many geologic processes.
Groundwater Recharge area	An area or drainage basin in which water reaches the zone of saturation following infiltration and percolation. Beneath it, downward components of hydraulic head exist and groundwater moves downward into deeper parts of the aquifer. "Groundwater recharge areas for glacial deep-seated landslides" is defined in WAC 222-16-010.
Glacial terrace	A relatively flat, horizontal, or gently inclined surface formed by glacial processes, sometimes long and narrow, bounded by a steeper ascending slope on one side and a steeper descending slope on the opposite side.
Glaciolacustrine	Pertains to, derived from, or deposited in glacial lakes. Glacialacustrine deposits and landforms are composed of suspended material brought by meltwater streams flowing into lakes.
Glaciomarine	Pertains to sediments which originated in glaciated areas and have been transported to an ocean's environment by glacial meltwater.
Glacial till	Matrix-supported, ~~N~~non-sorted, non-stratified sediment carried or deposited by a glacier. If over-ridden by a glacier, it can become compacted. Compacted till can be nearly impermeable and can sometimes perch water.
Hydrogeology	The science that involves the study of the occurrence, circulation, distribution, chemistry, remediation, or quality of water or its role as a natural agent that causes changes in the earth; the investigation and collection of data concerning waters in the atmosphere or on the surface or in the interior of the earth, including data regarding the interaction of water with other gases, solids, or fluids.
Hydraulic head	Combined measure of the elevation and the water pressure at a point in an aquifer which represents the total energy of the water; since groundwater moves in the direction of lower hydraulic head (i.e., toward lower energy), and hydraulic head is a measure of water pressure, groundwater can and often does flow uphill.
Hydrologic budget	An accounting of the inflow to, outflow from, and storage in a hydrologic unit such as a drainage basin, aquifer, soil zone, or water body. For watersheds, the major input is precipitation and the major output is stream flow.

LiDAR	Light Detection and Ranging. A detection system that works on the principle of radar, but uses light from a laser.
Lithology	The study of general physical characteristics of rocks.
Resistivity method	A geophysical method that observes the electric potential and current distribution at the earth's surface intended to detect subsurface variation in resistivity which may be related to geology, groundwater quality, porosity, etc.
Rheology	The branch of physics that deals with the deformation and flow of matter, especially the non-Newtonian flow of liquids and the plastic flow of solids.
Seismic method	A geophysical method using the generation, reflection, refraction, detection and analysis of seismic waves in the earth to characterize the subsurface.
Soil	~~An aggregate of solid particles, generally of minerals and rocks, either transported or formed by the weathering of rock in place~~The unconsolidated mineral or organic material on the immediate earth's surface that serves as a natural medium for the growth of plants.
Strata	Plural of stratum.
Stratum	A section of a formation that consists throughout of approximately the same material. A stratum may consist of an indefinite number of beds, and a bed may consist of numberless layer. The distinction of bed and layer is not always obvious.
Stratification	A structure produced by the deposition of sediments in beds or layers (strata), laminae, lenses, wedges, and other essentially tabular units.
Unconfined aquifer	Aquifer in which the water table forms the upper boundary. Unconfined aquifers occur near the ground surface.
Water table	The surface on which the fluid pressure in the pores of a porous medium is exactly atmospheric. The location of this surface is revealed by the level at which water stands in a shallow well open along its length and penetrating the surficial deposits just deeply enough to encounter standing water at the bottom.

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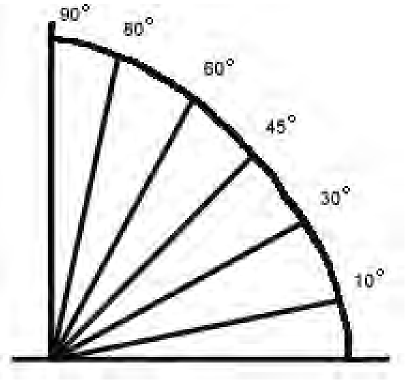
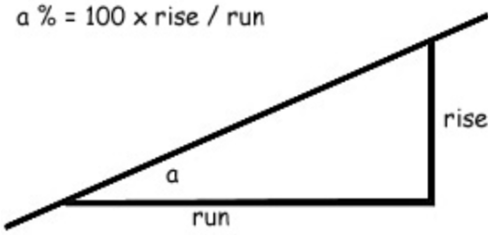
APPENDIX A – MEASUREMENTS OF SLOPE GRADIENTS

The forest practices rules contain specific slopes gradients (degrees and percent) for potentially unstable slope or landform descriptions. Slope gradients are commonly expressed in two different but related ways, as degrees of arc or percent rise to run. It is important to understand the relationships between them.

Degrees
A circle is divided into 360 degrees of arc. Each degree is further divided into 60 minutes (60'), and each minute into 60 seconds (60"). The quadrant of the circle between a horizontal line and a vertical line comprises 90 degrees of arc.



Angles in degrees.

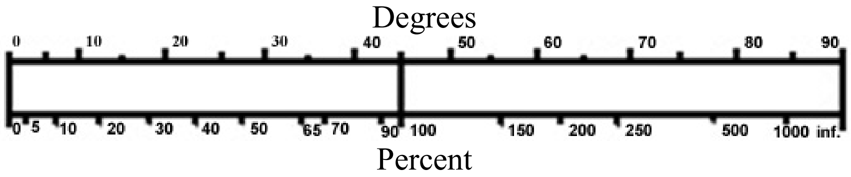


Angles in percent.

Percent
In the figure directly above, the horizontal distance between two points (distance between the points on a map) is called the run. The vertical distance (difference in elevation) is called the rise. The gradient can be expressed as the ratio of rise divided by run, a fraction that is the tangent of angle α. When multiplied by 100, this fraction is the percent slope.

Relationship of Degrees to Percent
Because of the differences in the ways they are calculated, each of these two slope measurements is better for certain applications. Because it is more precise at gentle slopes, percent is best for measuring and expressing small angles, such as the gradients of larger streams. But for steeper slopes, the constant angular difference and smaller numbers (an 85 degree slope is 1143%) make degrees more useful.

The figure below shows approximate equivalences for gradients expressed in degrees and percent. Note that there is a rough 2:1 ratio in the 30 to 40 degree range (e.g., 35 degrees = 70% slope), but beware - this relationship changes dramatically at gentler and steeper angles.



Slope gradients in degrees and percent.

APPENDIX B – LANDSLIDE PROVINCES IN WASHINGTON

Landsliding is a widespread geomorphic process which actively modifies the varied topography and diverse underlying geologic materials present throughout Washington State. This overview focuses on areas within the state where forest practices activities are prevalent and draws from Thorsen's (1989) organization and discussion by physiographic provinces.

Puget Lowlands-North Cascade Foothills

This region has been extensively modified by the continental, and to a lesser extent, alpine glaciations. Unconsolidated sediments formed by glaciation include thick layers of fine-grained glacial lake sediments (fine sand, silt, and clay), coarse-grained outwash (sand, gravel, cobbles, and boulders), and till. Much of these sediments are very compact, having been overridden by thousands of feet of ice. Groundwater systems are complex and often vertically and laterally discontinuous within these deposits. Perched and confined aquifers are commonly present above and between fine-grained aquitards. Glacial meltwater and subsequent river and marine erosion have left over-steepened slopes on the margins of river valleys and marine shoreline, which are often highly susceptible to a great variety of landslide types. Falls and topples are common on near-vertical exposures of these sediments. Translational landslides controlled by bedding surfaces and rotational failures that cross-cut bedding are widespread and can be very large. They initiate rapidly or reactivate episodically. Debris flows can reoccur within steep drainages incised in these deposits. Translational and complex landslides occur within some of the very weak bedrock units exposed within the foothills and lowlands, such as the Chuckanut Formation, Darrington Phyllite, and Puget Group rocks.

Olympic Peninsula

Somewhat similar geologic materials are present on the Olympic Peninsula. The lowlands and major river valleys are underlain by sediments derived by both continental and alpine glaciations, which are in turn underlain by very weak sedimentary and volcanic rocks. Large landslide complexes, predominantly in glacial sediments, are widespread along Hood Canal and lower reaches of the Quinault, Queets, Hoh, and Bogachiel valleys. Large rock slides and rock avalanches are common in the steep upper reaches of Olympic mountain drainages. Translational landslides and large landslide complexes are also abundant in the very weak marine sedimentary rocks (often occurring along inclined bedding surfaces) and mantling residual soils in the western and northwestern portions of the Peninsula, such as the Twin Creek Formation, and the Western Olympic and Hoh Lithic Assemblages.[93] Debris flows and avalanches are often generated in steeper drainages and slopes.

Southwest Washington

The Willapa Hills of Southwest Washington are comprised primarily of very weak marine sedimentary and volcanic rocks. Because the region has not been glaciated, thick and especially weak residual soils have developed on these rocks. Translational landslides and coalescing landslides forming earthflows are widespread in these weak rocks and overlying soils, such as in the Lincoln Creek Formation.[94] Thick, deeply weathered loess deposits are sources for shallow landslides, debris flows, and avalanches.[95] These deposits are prevalent along the lower Columbia

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[93] Tabor and Cady 1978; Badger 1993.

[94] Gerstel and Badger 2002.

[95] Thorsen 1989.

River valley, as well as other areas where colluvial deposits have accumulated on slopes and in drainages underlain by strong and relatively unweathered rock.

Cascade Range

The Cascade Range is generally divided on the basis of rock types into northern and southern provinces occurring geographically in the vicinity of Snoqualmie Pass. Strong crystalline rocks intensely scoured by alpine glaciations occur to the north. Weaker volcanic flows, typically pyroclastic and volcaniclastic rocks occur to the south, much of which was beyond the reach of the last continental glaciation. Rockfalls and complex rock slides are dominant in the steep bedrock slopes in the North Cascades. In the South Cascades and Columbia Gorge, weak interbeds control large translational failures in the Chumstick and Roslyn Formations[96], the Columbia River Basalts and other volcanic flow rocks, and Cowlitz Formation and Sandy River Mudstone[97]. Shallow landslides generating debris avalanches and flows are common on steep slopes and drainages.

Okanogan Highlands

Pleistocene glacial sediments that mantle the mostly crystalline core of the Okanogan Highlands are prone to both shallow and deep-seated landslides. The debris flows in this region can be a hazard during intense thunderstorms, usually moving through the area during late spring to late summer. Deep-seated landslides are most common in the areas surrounding Lake Roosevelt and landslide movement usually occurs in areas where relict to dormant deep-seated landslides exist. Rockfalls and rock slides are common from the many steep bedrock exposures in the region.

Columbia Basin

This province is largely composed of thick sequences of lava flows known as the Columbia River Basalts. Catastrophic flood events scoured the soils and a portion of the bedrock in much of this region before re-depositing it in watersheds along the edges of the main floodway. Landslides include slope failures in bedrock along the soil interbeds and in the overlying flood sediments and loess deposits. Bedrock slope failures are most common in the form of very large deep-seated translational landslides, deep-seated slumps or earth flows. The Blue Mountains in southeastern Washington also have experienced recurring and widespread shallow landsliding and debris flows related to storm events.[98]

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[96] Tabor et al. 1987.

[97] Wegmann 2003.

[98] Harp et al. 1997.

APPENDIX C – MAPS AND SURVEYS

Map and survey data resources available to the qualified expert include:

Multi-disciplinary map and survey data resources:

- Washington State Geologic Information Portal – create, save, and print custom digital maps of Washington State or download map data for GIS applications; includes a variety of base layer selections with interactive Geologic Map, Seismic Scenarios Catalog, Natural Hazards, Geothermal Resources, Subsurface Geology Information, and Earth Resource Permit Locations; available on Washington Dept. of Natural Resources website.
- Forest Practices Application Review System (FPARS) – online mapping tool with a variety of digital map base layer selections including topography, surface water (streams, water bodies, wetlands), soils, transportation network, forest site class, and potential slope instability (designed for shallow landslide susceptibility mapping only). Available on the DNR website.
- County interactive GIS map viewers – create, save, and print custom digital maps with some combination of the following data: topography (LiDAR and/or U.S. Geological Survey (USGS) DEM), surface water, soils, wetlands, sensitive areas, 100-year floodplain designations, transportation systems, property ownership and structure location. Available online at select county websites (e.g., King County iMAP).
- Washington State Coastal Atlas Map – interactive map utility for shoreline areas with multiple data layers including shoreline geomorphology (coastal slope stability and landforms), biology (plant communities), land and canopy cover, beaches and shoreline modifications, wetlands and estuaries, historic shoreline planforms, assessed waters, and Shoreline Management Act (SMA) designations; see Department of Ecology website.
- DNR surface mining permits.

Topographic maps:

- USGS topographic 7.5 minute quadrangle maps. Available from a number of government and non-government online vendors and free downloadable websites.
- LiDAR-based topographic maps (LiDAR-derived DEM (LDEM), typically 1- to 3- meter resolution); see Appendix C for LiDAR map and data sources.

Geologic maps:

- Geologic maps of various scales, in print and compiled by DNR, Division of Geology and Earth Resources as Map Series, Open File Reports, Bulletins, and Information Circulars; see most recent “Publications of the Washington Division of Geology and Earth Resources”; this publication and a status map of 7.5 minute quadrangle geologic mapping efforts (USGS STATEMAP program) are available on the Division of Geology and Earth Resources website with links to online publications where available.
- Geologic maps, various scales, out-of-print or historic; all sources including dissertations and theses. See catalog of the Washington Geology Library, available through the DNR website with links to online publications where available.
- Geology digital data; small-scale geology coverage in ArcGIS shapefile format, available on the Division of Geology and Earth Resources website.
- Geologic maps, various scales, available via The National Geologic Map Database (NGMDB); compiled by USGS and Association of American State Geologists; see NGMDB website catalog) and USGS Online Store (paper and digital copies).

Geologic hazards and landslide inventory maps:

- Washington State Geologic Information Portal, referenced previously.
- Landslide Hazard Zonation (LHZ) Project – mapped existing and potential deep-seated landslides and landforms in select watersheds; hazard classifications provided with supporting documentation for completed projects. Available on the DNR website.
- Landslide inventory and Mass Wasting Map Unit (MWMU) maps contained in Watershed Analysis reports prepared under chapter 222-22 WAC – mapped landslides (including deep-seated and earthflows) for select Watershed Administrative Units (WAU); Adobe pdf versions of DNR-approved Watershed Analysis Reports are available through the DNR website.
- Modeled slope stability morphology (SLPSTAB, SHALSTAB, SINMAP) output maps.
- U.S. Forest Service watershed analyses – available from US Forest Service offices for select watersheds; some documents and maps are available online.
- Washington State tribal watershed analyses – available from tribal agency offices; some documents and maps are available online;
- Washington State Coastal Atlas Map – slope stability maps developed prior to 1980, based on aerial photography, geologic mapping, USGS topographic quadrangle map, and field observations. Maps have not been updated with landslide data since 1980 but are used currently in land-use planning and in the Department of Ecology interactive Coastal Map tool; read data limitations on Department of Ecology's website.
- Qualified expert reports on deep-seated landslides in glaciated and non-glaciated terrain, for select timber harvest units or other forest management projects regulated by the Washington Forest Practices Act. Often contain mapped landslides.
- TerrainWorks (NetMap) – provides digital landscape and analysis tools for slopes stability data/analysis and risk assessments.

Soil surveys:

- Natural Resources Conservation Service (NRCS) soil survey maps and data – online soil survey, map and database service; historical soil survey publications (CD or paper copies); NRCS website administered through the U.S. Department of Agriculture.
- Geochemical and mineralogical soil survey map and data – USGS Mineral Resources Program, open-file report available online (Smith et al., 2013) in Adobe pdf.
- National Cooperative Soil Survey Program (NCSS), Washington State – online soil survey data and link for ordering in-print surveys not available electronically. See NRCS website.

APPENDIX D – EARTH IMAGERY AND PHOTOGRAMMETRY

The most common sources of imagery for landslide and landform identification, mapping, and photogrammetric analysis include:

- Aerial photography – historic and recent aerial photos produced in color or black and white and taken at various altitudes (typical scales in the 1:12,000 to 1:60,000 range). Aerial photos acquired by the U.S. Soil Conservation Service are available in some areas as early as the 1930s. Multiple flight years are required for chronologically reconstructing deep-seated landslide activity and developing time-constrained landslide inventories. Forest landowners typically purchased photos from regional vendors on a 2 to 10 year cycle until recently when other freely acquired imagery became available (e.g., Google Earth, ESRI World Imagery). Stereo-pair photos are highly valued for landslide detection and reconstruction because they allow stereoscopic projection in three dimensions and can display high-quality feature contrast and sharpness;
- Google Earth – map and geographic information program with earth surface images created by superimposing satellite imagery (DEM data collected by NASA's Shuttle Radar Topography Mission), aerial photos, and GIS 3D globe. Ortho-rectified, generally 1-meter resolution, three dimensional (3D) images are available for multiple years (Historical Imagery tool), allowing chronologic deep-seated landslide mapping. Google Earth supports desktop and mobile applications, including managing 3D geospatial data. See Google website for download information.
- Bing Maps Aerial View – part of Microsoft web mapping service; overlays topographic base maps with satellite imagery taken every few years. See Microsoft site for download information.
- ESRI World Imagery – ArcGIS online image service utilizing LandSat imagery based on the USGS Global Land Survey datasets and other satellite imagery, with onboard visualization, processing, and analysis tools that allow imagery integration directly into all ArcGIS projects. Requires ArcGIS capability; see ESRI website.
- NAIP (National Agriculture Imagery Program) aerial imagery – ortho-rectified, generally 1-meter resolution earth surface images taken annually during peak growing season ("leaf-on"), acquired by digital sensors as a four color-band product that can be viewed as a natural color or color infrared image. The latter are particularly useful for vegetation analysis. Data available to the public via the USDA Geospatial Data Gateway and free APFO viewing software, as well as through ESRI for ArcGIS applications; See USDA Farm Service Agency website;
- Washington State Coastal Atlas Map and Photos – oblique shoreline photos spanning 1976-2007; part of an interactive map tool; see Department of Ecology's website.
- United States Geological Survey EarthExplorer (http://earthexplorer.usgs.gov/) archive of downloadable aerial photos.

APPENDIX E – LiDAR: PROCESSING, APPLICATIONS, AND DATA SOURCES

The process to create high-resolution data begins with airborne LiDAR. LiDAR is a remote sensing technique that involves scanning the earth’s surface with an aircraft-mounted laser in order to generate a three-dimensional topographic model.[99] During a LiDAR acquisition flight, the aircraft’s trajectory and orientation are recorded with Global Positioning System (GPS) measurements and the aircraft’s inertial measurement unit, respectively. Throughout the flight, the laser sends thousands of pulses per second in a sweeping pattern beneath the aircraft. Energy from a single pulse is commonly reflected by multiple objects within the laser’s footprint at ground level, such as the branches of a tree and the bare ground below, generating multiple returns. The first returns are commonly referred to as “highest hit” or “top surface” points and are used to measure the elevations of vegetation and buildings, while the last returns are commonly referred to as “bare earth” points and undergo additional processing to create a model of the earth’s ground surface.

To generate a DEM, the aircraft trajectory and orientation measurements are combined with the laser orientation and travel time data to create a geo-referenced point cloud representing the location of each reflected pulse. These irregularly spaced points are commonly interpolated to a regularly spaced grid with horizontal spacing on the order of 1 meter to create a high resolution digital elevation model. Bare earth digital elevation models undergo additional filtering to identify ground returns from the last return point cloud data.[100] These bare earth DEMs are most commonly used for interpreting and mapping deep-seated landslide features, especially in forested terrain where vegetation would normally obscure diagnostic ground features.[101]

Repeat LiDAR acquisitions of a site are becoming more common. This allows the qualified expert to review more than a single LiDAR data set to interpret deep-seated landslide morphology; instead they can measure topographic changes related to slope instability with pairs of LiDAR scenes.[102] Vertical changes can be measured by differencing LiDAR-derived DEMs, while manual or automated tracking of features visible on hillshade or slope maps between scenes can be used to estimate horizontal displacements. Note that many active deep-seated landslides move at rates that may be undetectable given the uncertainties in the LiDAR data, so this technique is most helpful for relatively large topographic changes, typically on the order of several meters.[103] Care should be taken to precisely align the repeat LiDAR DEMs.

New remote sensing techniques for terrain characterization are being developed at a rapid pace, due in part to the expanding availability of publicly acquired, high-resolution topographic data. For example, major advances in deep-seated landslide characterization methods are combining high-resolution LiDAR data with other remotely sensed information and developing quantitative LiDAR analysis techniques to map and quantify landslide movement.[104] Examples include using LiDAR-derived Digital Elevation Models (LDEM) and Digital Terrain Models (DTM) with: (1) radar data (for example infrared or InSar) and historical aerial photographs to quantify deep-seated landslide

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[99] Carter et al. 2001.

[100] For a review of filtering techniques, see Liu 2008.

[101] Van Den Eeckhaut et al. 2007.

[102] Corsini et al. 2007; Delong et al. 2012; Daehne and Corsini 2013.

[103] Burns et al. 2010.

[104] Tarolli 2014.

displacement and sediment transport[105]; (2) ortho-rectified historical aerial photographs to map earthflow movement and calculate sediment flux[106]; (3) GIS-based algorithms for LiDAR derivatives (e.g., hillslope gradient, curvature, surface roughness) to delineate and inventory deep-seated landslides and earthflows[107];and (4) subsurface investigations[108].

Sources for viewing and downloading airborne LiDAR of Washington State include the following (URLs may change without notice):

- King County iMAP: Interactive mapping tool (http://www.kingcounty.gov/operations/GIS/Maps/iMAP.aspx) – Displays shaded relief maps derived from LiDAR data at locations where it is available. LiDAR data have been filtered to remove vegetation and manmade structures and can be overlain with a wide range of additional maps relating to county infrastructure, property, hydrographic features, and planning.
- National Oceanic and Atmospheric Administration Digital Coast (http://csc.noaa.gov/digitalcoast/) – Archive of downloadable LiDAR data focused on coasts, rivers, and lowlands. Options for downloading point cloud, gridded, or contour data that require geographic information system software such as ArcGIS to view and analyze.
- National Science Foundation Open Topography facility (http://www.opentopography.org/index.php) – Archive of downloadable LiDAR data collected the National Center for Airbore Laser Mapping (NCALM) for research projects funded by the National Science Foundation. Options for downloading point cloud or gridded data for use with geographical information system software, or LiDAR derived hillshade and slope maps that can viewed in Google Earth.
- Oregon Lidar Consortium (http://www.oregongeology.org/sub/projects/olc/) – Small amount of Washington State data available along the Columbia River. LiDAR Data Viewer displays hillshade maps that have been filtered to remove vegetation and manmade structures.
- Puget Sound LiDAR Consortium (http://pugetsoundlidar.ess.washington.edu/) – Archive of LiDAR data from Western Washington, downloadable as quarter quad tiles. Data format is ArcInfo interchange files and requires GIS software to view.
- Snohomish County Landscape Imaging: SnoScape (http://gis.snoco.org/maps/snoscape/) – Displays hillshade maps of bare or built topography derived from LiDAR data where it is available. Can be overlain with a wide range of additional maps relating to county infrastructure, property, hydrographic features, and planning.
- USGS EarthExplorer (http://earthexplorer.usgs.gov/) – Archive of downloadable LiDAR data acquired by the USGS through contracts, partnerships, and purchases from other agencies or private vendors. File format is LAS and requires GIS software for viewing.

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[105] Roering et al., 2009; Handwerger et al. 2013; Scheingross et al. 2013.

[106] Mackey and Roering 2011.

[107] e.g., Ardizzone et al. 2007; Booth et al. 2009; Burns and Madin 2009; Tarolli et al. 2012; Van Den Eeckhaut et al. 2012.

[108] Travelletti and Malet 2012.

APPENDIX F - TECHNICAL REPORTS AND RESOURCES

In addition to library and online sources, the following technical reports, published and unpublished papers, and searchable databases are available online:

- Catalog of the Washington Geology Library. Searchable database of the Washington Department of Geology Library containing a comprehensive set of dissertations and theses, watershed analyses, environmental impact statements, and refereed and un-refereed publications on state geology. See DNR website with links to online publications where available.
- USGS Open File Reports. Searchable online database containing reports covering deep-seated landslide investigations and related topics. See USGS Online Publications Directory, USGS website.
- Watershed Analysis Mass Wasting Assessment reports per chapter 222-22 WAC. Adobe pdf versions of DNR-approved reports are available via the DNR website at https://fortress.wa.gov/dnr/protectionsa/ApprovedWatershedAnalyses (the URL may change without notice)
- US Forest Service watershed analysis reports. Available from U.S. Forest Service offices for select watersheds; some electronic documents are available online through the U.S. Forest Service website for national forest of interest.
- Interagency watershed analysis reports. Collaborative projects between federal agencies (U.S. Geological Survey, U.S. Forest Service, U.S. Fish and Wildlife Service), tribal agencies, and industry (e.g., Cook and McCalla basins, Salmon River basin, Quinault watershed). Documents available online through the USGS, Washington Water Science Center.
- Washington Soil Atlas. Available as downloadable Adobe pdf file from the Natural Resources Conservation Service website.

APPENDIX G – PHYSICAL DATABASES

Meteorological databases:

- National Weather Service (NWS) cooperative weather stations – coordinated by National Oceanic and Atmospheric Administration (NOAA) – database managed by Western Regional Climate Center
- NWS Weather Surveillance Radar – Doppler and NEXRAD
- Remote Automatic Weather Stations (RAWS) – operated by US Forest Service and Bureau of Land Management – database managed by Western Regional Climate Center

Stream-flow gauge database: USGS National Water Information System website

Seismic data: Pacific Northwest Seismic Network (PNSN) – database managed by USGS, University of Washington, and Incorporated Research Institute for Seismology Consortium in Seattle. Contains records from seismometers located throughout Washington and Oregon. See the PNSN website.

Climate Data for Washington: The availability of climate data is highly variable for the State of Washington. The following sites provide access to most of the available data useful for evapotranspiration modeling (the URLs may change without notice):

- USGS, Washington Water Data - http://wa.water.usgs.gov/data/
- National Surface Meteorological Networks - https://www.eol.ucar.edu/projects/hydrometer/northwest/ northwest.html
- National Weather Service - http://www.wrh.noaa.gov/sew/observations.php
- National Climate Data Center - http://www.ncdc.noaa.gov/
- University of Washington Atmospheric Sciences - http://www.atmos.washington.edu/data/
- Washington State University - http://weather.wsu.edu/awn.php
- Community Collaborative Rain, Hail, and Snow Database - http://www.cocorahs.org/
- Western Regional Climate Summary for Washington - http://www.wrcc.dri.edu/summary/climsmwa.html
- Natural Resource Conservation Service - http://www.nrcs.usda.gov/wps/portal/nrcs/main/wa/snow/
- Washington Dept. of Ecology Water Resources - http://www.ecy.wa.gov/programs/wr/wrhome.html
- Washington Dept. of Transportation - http://www.wsdot.com/traffic/weather/weatherstation_list.aspx

National Resources Inventory for Washington State: Statistical survey of land use, natural resource conditions and trends in soil, water, and related resources on non-federal lands; see NRCS website.

APPENDIX H - HYDROLOGIC PROPERTIES OF SOILS

This adaptation from Koloski et al. 1989 relates geologic materials commonly found in Washington to the descriptive properties of permeability and storage capacity. A generalized explanation of the two terms is presented below, but is not intended to rigorously define either the geologic categories or the geotechnical properties. The information presented in the table is useful for indicating the general range of values for these properties. It should be considered representative, but is not a substitute for site-specific laboratory and field information.

Classification	Permeability (feet per minute)	Storage Capacity
Alluvial (High Energy)	0.01-10	0.1-0.3
Alluvial (Low Energy)	0.0001-0.1	0.05-0.2
Eolian (Loess)	0.001-0.01	0.05-0.1
Glacial Till	0-0.001	0-0.1
Glacial Outwash	0.01-10	0.01-0.3
Glaciolacustrine	0-0.1	0-0.1
Lacustrine (Inorganic)	0.0001-0.1	0.05-0.3
Lacustrine (Organic)	0.0001-1.0	0.05-0.8
Marine (High Energy)	0.001-1.0	0.1-0.3
Marine (Low Energy)	0.0001-0.1	0.05-0.3
Volcanic (Tephra)	0.0001-0.1	0.05-0.2
Volcanic (Lahar)	0.001-0.1	0.05-0.2

Permeability differences reflect variations in gradation between geologic materials. Very high permeability is associated with high-energy alluvial deposits or glacial outwash where coarse, open-work gravel is common. Permeability in these deposits can vary greatly over short horizontal and vertical distances. Extremely low permeability is associated with poorly to moderately sorted materials that are ice-consolidated and contain a substantial fraction of silt and clay.

Storage capacity reflects the volume of void space and the content of silt or clay within a soil deposit. Storage capacity is very low for poorly sorted or ice-consolidated, fine-grained materials such as till and glaciolacustrine deposits.

ATTACHMENT 2

Part 4.4 Complex or composite rotational deep-seated landslides

Cruden and Varnes (1996) define complex or composite landslides as a combination in time and space of two or more principal types of movement. Complex slides are the only category that is not differentiated by movement type (Table 1, Part2.1). The breadth of this catch-all category may have contributed to a lack of focus within the scientific literature on particular types of complex slide, such as composite rotational deep-seated landslides found in glaciated forested terrain in Washington State. The SR 530 landslide in Snohomish County, WA, an active rotational deep-seated failure that hosted both a debris flow/avalanche and a rotational slide (GEER Report: Keaton, Jeffrey R.; Wartman, Joseph; Anderson, Scott; Benoît, Jean; deLaChapelle, John; Gilbert, Robert; Montgomery, David R. (July 22, 2014), The 22 March 2014 Oso Landslide, Snohomish County, Washington, Geotechnical Extreme Events Reconnaissance; Iverson et al., 2015), demonstrated the need for a better understanding of the potential range of activity within large complex failures in areas underlain by glacial sediments. Large complex landslides also occur on bedrock slopes and from the flanks of composite volcanoes. The hazards associated with landslides in all of these settings, especially where they may generate rapid flows warrant careful attention. Unlike shallow (translational) landslides and debris flows that are known to occur repeatedly and are well understood, composite deep-seated slumps are less commonplace and have received less attention in hazard assessment. Rapid movement from such features represents a classic case of the hazard associated with events of low frequency but high consequence. This discussion focuses primarily on large failures in glacial sediments, although many of these comments would also apply to large failures in other geologic settings.

Purely rotational slumps in cohesive soils are rare in nature because the shape of the rupture surface usually departs from constant curvature (Hungr, 2014). Instead, as the host slump moves, internal deformation during transport may cause segmentation of the failure surfaces, resulting in the evolution of desegregated secondary landslides in hummocky terrain that may be more prone to saturation (Cronin, 1992). Complex or composite rotational landslides may fail sequentially, exhibiting multiple instabilities within a host deep-seated slide during a single event (Figure 23) or as multiple secondary movements over time (Figure 24), or both.

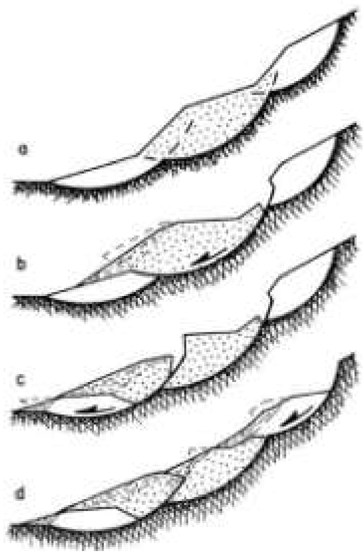

Figure 23. Schematic of a typical sequence of instability within a stacked rotational deep-seated slide over a single event. The original slope configuration a) initially at rest until sliding movement begins, at which time the b) middle (stippled) slump mass loads the lower slide, removing support from the upper scarp. As the lower landslide mass becomes active, c) it may rotate outward, causing the d) debutressed upper slide mass to fail onto the original slump feature (Cronin, 1992).

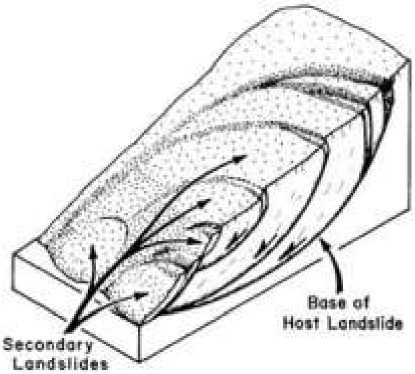

Figure 24. Rotational deep-seated slides can be sufficiently large to host multiple failures within the original slide mass (Cronin, 1992).

Fortunately, recent improvements in high-resolution LiDAR have proved to be a highly effective tool for identifying the footprint of dormant and active rotational deep-seated slumps. The topography generated as a digital terrain model (DTM) from LiDAR data has made possible the remote detection of these features, even in forested areas. Prior methods, such as the use of aerial photographs to identify the slide footprint were less effective as the forest canopy often obscured subtle topographic features on the ground surface. The usefulness of LiDAR to identify rotational deep-seated slides is demonstrated by the King County, WA *Preliminary Landslide Investigation in King County, WA, Phase 1*. The study found evidence of over 200 rotational deep-seated slumps in a countywide sample that was limited to large glaciated river valleys.

However, further research and analysis is necessary in order to identify those characteristics of large landslides that may predispose them to failure modes that include long rapid runout. Evidence of the presence of a past landslide of any type is thought to be a primary indicator of the possible location and type of future failures (Baum and Kean, 2015). LiDAR-based comparisons of a slump feature are useful to ascertain relative age because freshly activated scarp features produce a sharper image on high-resolution topography than those that are less clear (Figure 25). Visual inspection of LiDAR imagery is also useful for change detection. For example, to ascertain evidence of movement in the S.R. 530 landslide prior to and after the event, Iverson et al. (2015) compared the difference in two LiDAR DEM’s from 2013 and 2014. However, both image clarity and evidence of movement prior to a large event may not be sufficient to determine if a landform could become a composite slide. Additional methods used in conjunction with LiDAR imagery, such as field inspection and monitoring, local historical investigations, examination of historical aerial photography, detailed local geologic mapping, subsurface exploration, groundwater monitoring, and use of motion detection tools such as structure for motion (SfM) or INSTAR, provide important additional information. Combined use of these tools to investigate the relative age of the landform compared to other features, as well as indications of recent movement, evidence of weakness in a particular geologic context, and evidence of secondary landslide types such as flows may provide better predictions of the potential for composite instability (Table 1).

Table 1.

	Indicators using LiDAR images	**Indicators using field assessment and monitoring**	**Aerial photographs, Change Detection (SfM)**	**Geologic maps**
Indicators of recent or modern movement	Crisp, defined features such as steep, arcuate scarps, sharp trim lines, clearly visible hummocky terrain or well-defined internal slide blocks indicating more recent movement (Figure 25). Presence of closed depressions in the slide mass. Evidence of recent toe erosion or incision (Figure 26.)	Field evidence of extensional fractures on the ground surface. Differential movement interrupting surficial topography and bisecting woody vegetation	Evidence of movement such as increased channel incision at the toe of a rotational slide or a shift in channel location.	-
Evidence of geologic weakness	Multiple rotational slides clearly visible within a homogeneous geologic area such as the valley walls of a river corridor (Figure 27).	Failure-prone stratigraphy such as permeable glacial outwash immediately overlying glaciolacustrine deposits or evidence of contact discontinuities such as a distinct clay layer at the toe of a slide.	Evidence of repeated failures within homogeneous geologic terrain over time	Mapped weak or failure-prone geologic units
Deep-seated slump size and complexity	Large rotational slump landforms with signature features such as sag ponds and convoluted channels flowing on the surface of hummocky slump topography (Figure 28).	Unconsolidated hummocky surface with visible standing water or sag ponds, evidence of soil saturation, or tributary drainage capture.	-	-
Evidence of flow-type slides extending beyond the rotational slump mass.	Debris flow lobes that show evidence of travel distances beyond those normally associated with the toe of a simple rotational slump. These may be present on the subject failure or on nearby similar failures	-	-	-

Dormant slump features that exhibit no evidence of recent or ongoing movement are assumed to be less likely to become unstable again, but given the limited historical record (e.g. 100 years or less) and problems with assuming that past climate patterns will continue into the future, predictions of dormancy are difficult to make with confidence. Furthermore, evidence of rotational deep- seated slide movement alone does not provide information on the potential for composite instabilities. It is not documented how frequently single rotational slump failures become composite slides when unconsolidated deposits are reactivated by external factors such as precipitation, snowmelt, and earthquake. Known predictors of complex slides include evidence of geologic weakness prone to composite failure, large and complex deep- seated slump features, and evidence of landforms (e.g., debris flow lobes) associated with secondary or multiple types of movements such as flows.

In Western Washington, the likelihood of composite failures in rotational deep-seated slides may increase in the future due to projections of a rise in the magnitude and duration of precipitation caused by atmospheric rivers and diminished mid-elevation snow falling as rain during the winter months. In addition to atmospheric precipitation and overland flow, stream capture and interrupted groundwater flowpaths may also elevate pore pressures in the unconsolidated hummocky topography characteristic of large rotational slides (Hungr, 2011; 2014). For this reason we need methods that will improve our ability to predict if the topographical signature of a rotational slide indicates a landform that is likely to fail as a composite slide, especially where multiple or secondary movements might evolve into rapid flows. Meanwhile, due to the lack of published research in this area, the observations, conclusions and recommendations listed in this section should be considered preliminary.

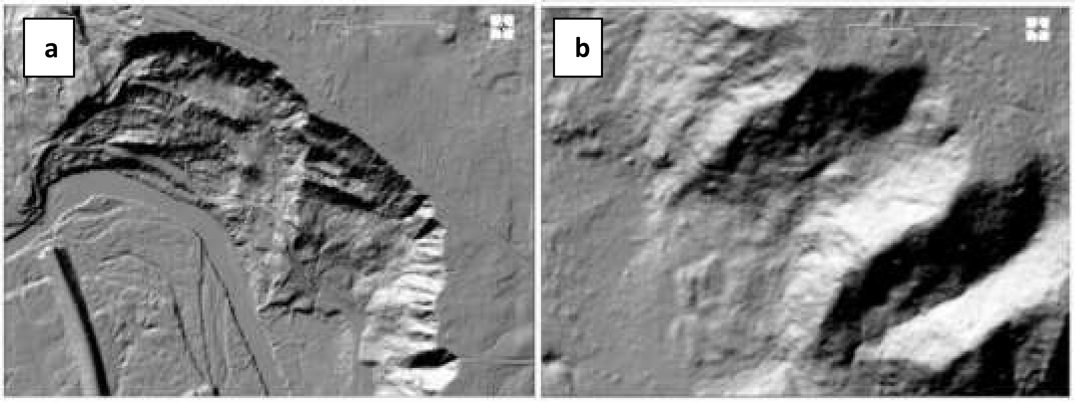

Figure 25. LiDAR comparison between two images with the same resolution data show the a) crisp topography of an active deep-seated rotational slide and b) landslide feature with subdued topography; the fuzzy image suggests greater age.

Figure 26. LiDAR image showing channel incision within a large deep-seated slump feature in the Tolt River valley, King County.

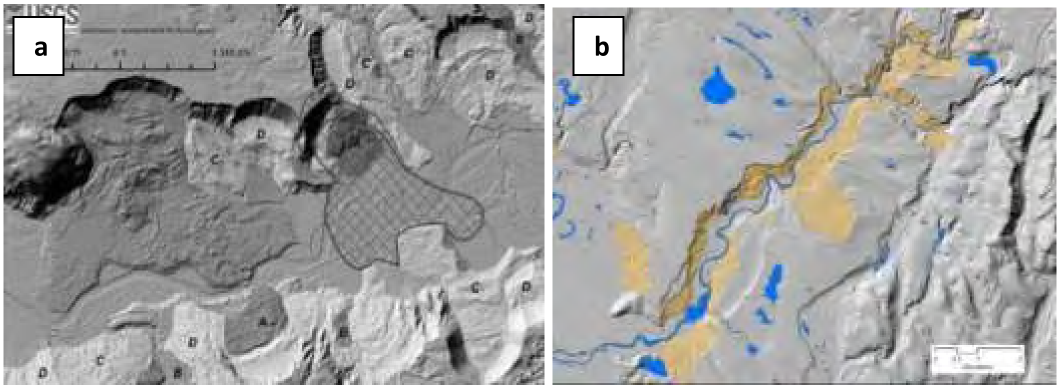

Figure 27. Western Washington topography is largely a product of the Quaternary glacial history and post glacial adjustment of the region. The valley walls of river corridors, such as a) a shaded relief image adapted from the 2013 LiDAR survey of the Stillaguamish (Snohomish County, WA) (Haugerud, 2014) and the b) Tolt (King County, WA) are associated with a weak geologic stratigraphy that results in similar clusters of complex rotational slides.

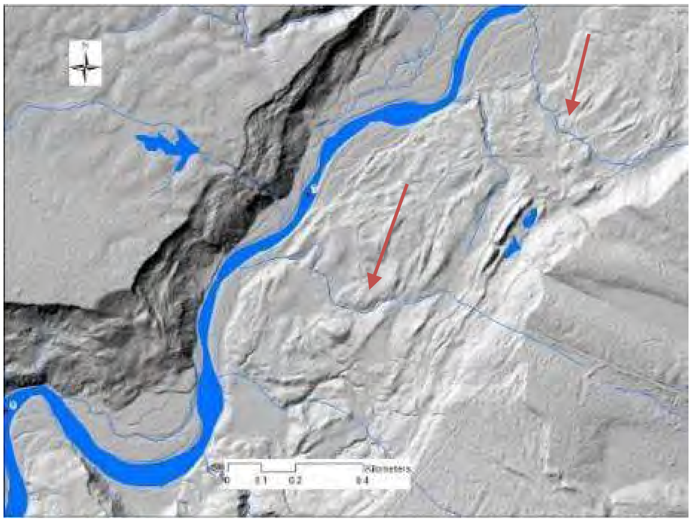

Figure 28. Evidence of more recent movement within a large slump including convoluted surface patterns deflected by slump debris and sag ponds (see red arrows).

ATTACHMENT 3

(Insert at end of Forest Practices Board Manual 16, Part 1. Introduction, p. 16-4)

1.1 Landslide Assessment Decision Pathway

The outcomes of the analyses described within Parts 5, 6, and 7 of this Board Manual are interrelated, and a framework which explicitly links them together is useful for properly classifying Forest Practices Applications (FPA) and determining whether or not a proposed forest practice will have a probable significant adverse impact. The following decision pathway provides a framework intended to help field practitioners, Qualified Experts (QE), and the DNR determine the appropriate methods for assessing the presence of Rule-Identified Landforms (RIL: WAC 222-16-050(1)(d)(i), Part 4) and the regulatory requirements for those forest practices proposed on or near potentially unstable slopes or landforms (WAC 222-10-030(1), Part 7.2, Figure 1). It integrates the methods described in this Board Manual into a repeatable, defensible decision making process while maintaining discretion based on professional judgement and site-specific factors. The overarching purpose of the decision pathway is to enable more effective and precautionary risk management decisions consistent with the intent of the Forest Practices Rules to avoid accelerating the rates and magnitudes of mass wasting that could deliver sediment or debris to a public resource or in a manner that would threaten public safety (WAC 222-10-030(4)). Is it appropriate to apply the precautionary principle to landslide hazard assessment, because in the face of scientific uncertainty, land management decisions that err on the side of caution will best protect the environment and public well-being[1]. Accordingly, when evaluating the likelihood that proposed forest practices will result in slope movement and/or delivery, the scope of analysis should be commensurate with the level of resource and/or public risk such that scientific certainty is maximized where the risk is greatest (Part 7.2).

The decision pathway involves a series of steps and decision points based on the presence or absence of RIL and whether or not forest practices are planned within RIL (Figure 1). The process begins with office and field reviews to screen for the presence of potential RIL on or near the proposed forest practices (Parts 4-5). Preliminary maps are revised with information gathered in the field for reporting with the FPA Slope Stability Informational Form and/or Geotechnical Report. If the office and field reviews indicate with a high level of certainty that a RIL is not present, then the FPA may be classified as a Class III (for the purposes of the unstable slopes regulations). The level of certainty is driven in part by the applicable assumptions, project limitations, and the weight of the evidence (Part 7.1). Because scientific certainty is not defined by Rule, DNR is ultimately responsible for determining whether or not the information submitted with a FPA provides sufficient certainty that a RIL is either present or absent.

Alternatively, if the presence of a RIL is possible or uncertain, the field practitioners and/or QE evaluate the likelihood of runout and delivery of sediment or debris to public structures and resources (Part 6.6). Delivery/threat assessment may be limited to coarse methods if they result in high certainty (Part 6.6.X), otherwise more technical methods should also be utilized (Part 6.6.Y-Z). If delivery/threat is unlikely (low likelihood with high certainty), then the feature is not considered a RIL and the FPA may be classified as a Class III (for the purposes of the unstable slopes regulations). If there is high or moderate delivery/threat potential or uncertainty is high or moderate, then the feature is treated as a RIL. Again, DNR is ultimately responsible for determining whether or not the information submitted with a FPA provides sufficient certainty that a RIL will or will not deliver and/or threaten public safety. If forest

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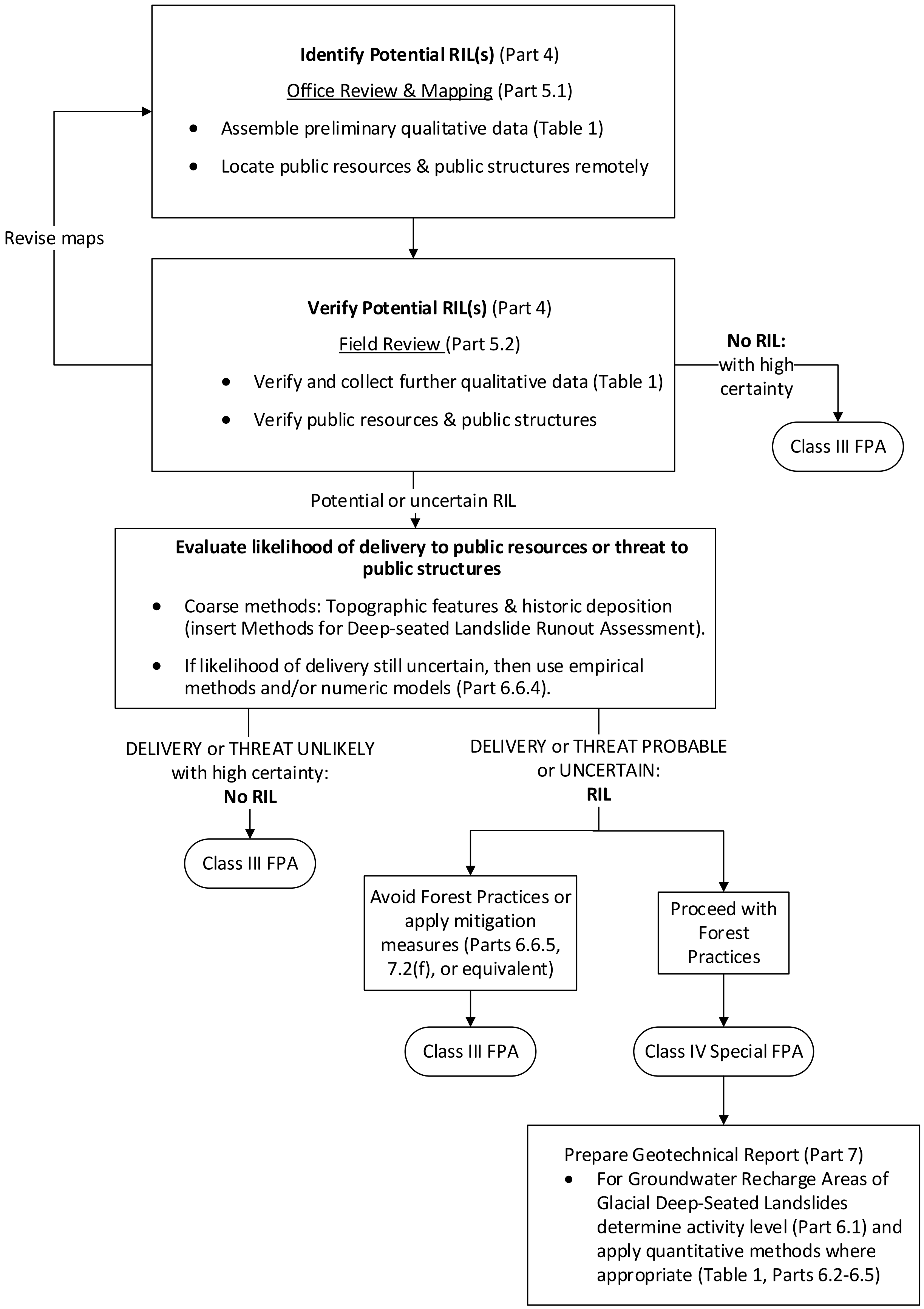
[1] Kriebel et al. 2001

practices are avoided or adequate mitigation measures are applied such that movement due to forest practices is unlikely (Parts 7.2, X.4), then the FPA may be classified as a Class III (for the purposes of the unstable slopes regulations). Mitigation measures must be designed to avoid accelerating the rates and magnitudes of mass wasting that could deliver sediment or debris to a public resource or in a manner that would threaten public safety (WAC 222-10-030(4)). If the applicant intends to proceed with forest practices on the RIL, then the FPA is classified as a Class IV Special and a Geotechnical Report must be prepared by a QE (WAC 222-10-030(1), Part 7). For Groundwater Recharge Areas of Glacial Deep-Seated Landslides, QE should determine the landslide activity level (Part 6.1) and apply quantitative methods where appropriate (Table 1, Parts 6.2-6.5). Finally, the DNR uses the information presented in the Geotechnical Report to make the appropriate SEPA threshold determination based on the likelihood the proposed forest practice will have a probable significant adverse impact (WAC 222-10-030(2)).

Kriebel, D., J. Tickner, P. Epstein, J. Lemons, R. Levins, E.L. Loechler, M. Quinn, R. Rudel, T. Schettler, and M. Stoto. 2001. The Precautionary Principle in Environmental Science. Environmental Health Perspectives 109(9):871-876.


Identify Potential RIL(s) (Part 4)
Office Review & Mapping (Part 5.1)
Assemble preliminary qualitative data (Table 1)
Locate public resources & public structures remotely
Revise maps
Verify Potential RIL(s) (Part 4)
Field Review (Part 5.2)
Verify and collect further qualitative data (Table 1)
Verify public resources & public structures
No RIL: with high certainty
Class III FPA
Potential or uncertain RIL
Evaluate likelihood of delivery to public resources or threat to public structures
Coarse methods: Topographic features & historic deposition (insert Methods for Deep-seated Landslide Runout Assessment).
If likelihood of delivery still uncertain, then use empirical methods and/or numeric models (Part 6.6.4).
DELIVERY or THREAT UNLIKELY with high certainty: No RIL
Class III FPA
DELIVERY or THREAT PROBABLE or UNCERTAIN: RIL
Avoid Forest Practices or apply mitigation measures (Parts 6.6.5, 7.2(f), or equivalent)
Class III FPA
Proceed with Forest Practices
Class IV Special FPA
Prepare Geotechnical Report (Part 7)
For Groundwater Recharge Areas of Glacial Deep-Seated Landslides determine activity level (Part 6.1) and apply quantitative methods where appropriate (Table 1, Parts 6.2-6.5)

(Previous page)

Figure 1. Landslide Assessment Decision Pathway and corresponding Board Manual Parts.

Table 1. Qualitative and Quantitative Methodologies for identifying Rule-Identified Landforms and evaluating Ground Water Recharge Areas (GWRA) of glacial deep-seated landslides (GDSL), with corresponding Board Manual Parts labeled.

Information type	Methodology	Examples	Limitations/ Specifications
Qualitative (Part 5)	Historic observations	Stereo air photos, landslide databases (LHZ, LSI, etc.)	Limited air photo record, forest canopy concealment of features, no subsurface information (GWRA)
	Surface observations	GDSL activity level, soil and geologic maps, surface water	No subsurface information (GWRA)
	Surface topography	30 m or LiDAR DEM, GPS, GDSL activity level	No subsurface information (GWRA)
	Geophysical: shallow (Part 6.3)	Test pits, hand augers, hand probes	Presence and depth of perched groundwater table may remain unknown (GWRA)
Quantitative (GWRA of GDSL only)	Geophysical: deep (Part 6.3)	Ground penetrating radar, electromagnetic, resistivity, and seismic methods, Carbon dating	Snapshot in time, regional data source
			Snapshot in time, site-specific data source
		Drill rig: single sample (borehole)	Snapshot in time
	Hydrologic (Part 6.3)	Groundwater monitoring wells, precipitation record	Multi-year, regional data source
			Multi-year, site-specific data source
	Hydrogeologic modeling (Parts 6.4-6.5)	Deep Percolation Model, Precipitation Runoff Modeling System, Variable Infiltration Capacity Model, Limit Equilibrium Analysis	Extrapolated regional data input and/or high margin of error
			Site-specific data input and/or low margin of error

ATTACHMENT 4

(insert before Part 6.6.4 Methods and Models for Predicting Shallow Rapid Landslide Runout and Delivery)

Shallow Rapid Landslide Coarse Screen

To determine the potential runout distances of landslides that start out as shallow rapid landslides, the following delivery guidelines are recommended. The runout distance is defined as the total distance landslide debris is transported and includes landslide deposition. In some cases, shallow rapid landslides can become debris flows or landslide dam-break floods. These guidelines accommodate these process transformations, and account for the associated increased runout distances.

As such, these guidelines may be used by general practitioners and qualified experts as a coarse screen to assess whether or not an open slope landslide, debris flow, or dam break flood is likely to deliver to a public resource or threaten public safety. The methods described below and summarized within the accompanying flow chart (Fig. Z), have been adapted from published methods synthesized by the Tolt River Watershed Analysis[1] as well as related science from Washington, Oregon and British Columbia[2].

Measurable topographic factors at the failure initiation site, along the transport path, and at the deposition zone for each hypothetical mass failure are used to determine the potential runout distance. If the transport and deposition steps show that a public resource will be impacted and/or there is a threat to public safety the failure is viewed as deliverable. If the failure becomes channelized, additional topographic variables are analyzed to determine if it becomes a debris flow, and/or a dam-break flood. The following guidelines do not apply to non-soil failures, such as rock fall (e.g., talus and scree slopes).

Landslide Runout: Transport and Deposition Potential

Initially, given an initiation hazard of a shallow landslide, the runout potential is assessed. If the landslide enters a channel, potential initiation of a secondary, channelized landslide is explored (e.g. does an open slope landslide turn into a debris flow or dam-break flood, after depositing in or entering a stream channel? Fig. Z). If it does, runout of the channelized landslide is analyzed. This process is repeated, as necessary, until final landslide deposition occurs.

Open slopes: Shallow Landslide Initiation

Initial runout potential of a shallow landslide, whether from a hillslope or a road, is based on the gradient just downslope from the landslide. If the hillslope gradient is ≤20 degrees (36%) the area is classified as minimal runout, with low delivery potential; if the slope is >20 degrees (36%) the area is classified as high delivery potential.

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[1] Ward 1993

[2] Benda and Cundy 1990, Fannin and Wise 2001, ODF 2003

If the hillslope or road-related failure slope is >20 degrees (36%) and ≤30 degrees (58%) and then the slope changes to ≤20 degrees for at least 150 feet, then add an additional 150 feet of runout to the deposition area for a total of 300 ft. If the hillslope is >30 degrees (58%) and changes to ≤20 degrees (36%) for at least 500 feet, then add an additional 500 feet of runout to the deposit area for a total of 1,000 feet.

If there are no public resources (e.g. water, fish, wildlife, or capital improvements of the state) or threats to public safety within the determined runout distance, then there is a low hazard and the runout analysis is complete. If there are public resources or threats to public safety within the determined runout distance, then the forest practice should be modified to eliminate the delivery potential, or a qualified expert should be consulted for further analysis.

Debris Flow Initiation and Runout

If an open slope landslide enters a stream channel (dry or wet at the time of analysis), debris flow initiation is considered next. The potential for transport and deposition (runout) from a channelized debris flow is based on channel gradient, channel confinement (the ratio of the valley width at the valley floor to the channel width), and receiving tributary junction angle if applicable.

If the channel gradient is ≤20 degrees, confinement is ≥5, *or* the tributary junction angle (if applicable) is ≥70 degrees, add 1000 feet to the runout distance, and test for dam-break flood potential. If threats to public safety or public resources exist within that distance, then the forest practice should be modified to eliminate the delivery potential, or consult a qualified expert, for further analysis.

If the channel gradient is > 20 degrees, confinement is <5, *and* the tributary junction angle (if applicable) is <70 degrees, there is a high debris flow initiation hazard. Proceed to the next step in order to determine potential runout distance. If the channel maintains a gradient ≥3.5 degrees (6.1%) and confinement of ≤5, assume the debris flow will continue traveling until the channel gradient decreases to <3.5 degrees and confinement increases to >5 for at least 500 feet. Add 500 feet for a total of 1,000 ft. runout distance (the debris flow is assumed to deposit). If at any point along the runout distance a potential threat to public safety or public resources exists, then the forest practice should be modified to eliminate the delivery potential, or consult a qualified expert, for further analysis.

Dam-Break Flood: Description and Process

Dam-break floods are common in confined mountain channels of the Pacific Northwest[3]. Dams may be composed of material deposited from landslides or debris flows, or they may be composed almost entirely of organic debris. For mass wasting generated dam-

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[3] Benda and Zhang, 1989

break floods, a landslide or debris-flow deposit dams in a low-order channel, and the dam breach sends a surge of water, sediment, and organic debris downstream[4].

If an open slope shallow landslide or a debris flow deposits in a channel, test for dam-break flood initiation. Apply only after debris avalanche or debris flow deposition.

Initiation potential of a dam-break flood is low hazard if any of the following apply:

- Channel gradient ≤2 degrees (3%), *or*
- Channel width >65 feet, *or*
- Channel wall ≤6 feet high, *or*
- Channel confinement ≥10

Dam-break flood initiation potential is high hazard if:

- Channel gradient is >2 degrees (3%) *and*
- Channel confinement is ≤10

If there is high dam-break flood *initiation* hazard, dam-break flood *runout* hazard is considered next.

Dam-break flood runout is based on channel gradient and confinement. If channel gradient is ≤2 degrees (3%) *or* channel confinement is ≥10, the dam-break flood deposits. If channel gradient is >2 degrees (3%) *and* channel confinement is <10, the flood continues to deliver downstream until it reaches the above conditions.

If at any point along the runout distance a potential threat to public safety or public resources exists, then the forest practice should be modified to eliminate the delivery potential, or consult with a qualified expert for further analysis.

References

Benda and Cundy 1990
Benda and Zhang 1989
Coho and Burges 1994
Johnson 1991
Kennard 1993
Ward 1993
Fannin and Wise 2001
ODF 2003

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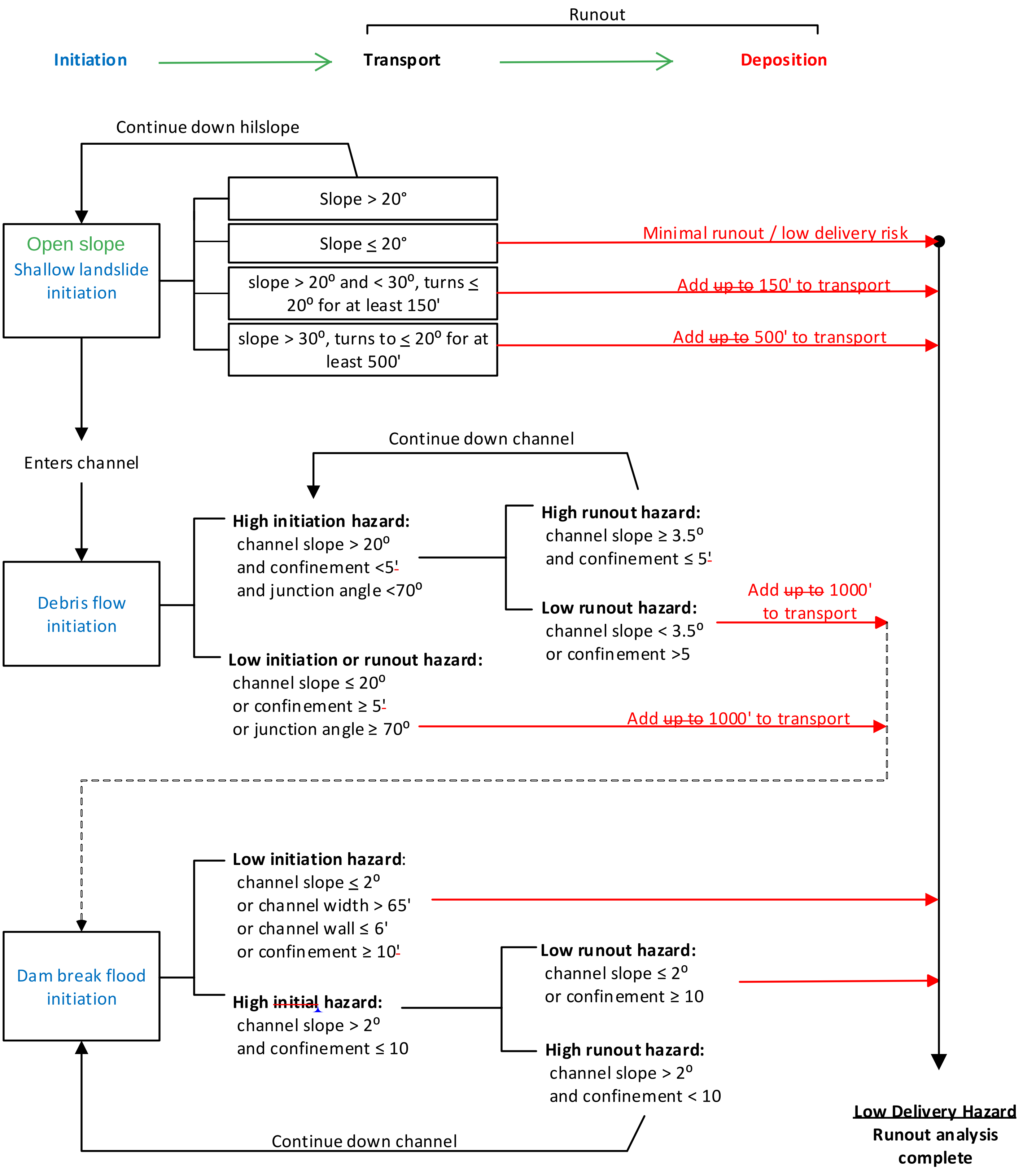
[4] Johnson 1991, Coho and Burges 1994

~~Course~~ Screen for Shallow-Rapid Landslide Runout and Delivery ~~9/8~~

Conservation Caucus edits in green plus red strike-through



ATTACHMENT 5

(insert between X.3 Coarse Screen for Shallow-Rapid Landslides and X.4 Methods and Models for Shallow Rapid Landslide Runout and Delivery Assessment)

Methods for Deep-seated Landslide Runout Assessment

The same tools used to identify deep-seated landslides can often be used to roughly estimate future runout distance. For example, past landslide deposits can be mapped with a fair amount of precision using geologic maps, topographic maps, field observations, landslide inventories, and especially high-resolution topographic data such as LiDAR bare earth digital elevation models (DEM). The extent of past landslide deposits at a given site, or in similar geologic materials in the vicinity, may indicate the extent of future landslide deposits. For instance, although the Oso/Hazel landslide traveled much farther in 2014 than it had historically, in 2014 it traveled a similar distance across the North Fork Stillaguamish River floodplain as the neighboring Rowan deep-seated landslide (Figure X). When assessing the potential runout distance of a deep-seated landslide, it is important to examine not only the immediate vicinity but also the larger landscape (at least at 1:24,000 scale) for evidence of past landslide deposits. In cases where more recent fluvial erosion or deposition has eroded or buried older landslide deposits, the true extent of the older deposits may be underestimated by current morphology. To better understand the potential for future failure and rapid movement, analyses of past landslide mechanics, stratigraphy, and chronology, and forecasts of climate change and river channel migration may be essential[1]. Where public safety may be impacted, it is most appropriate to apply the precautionary principle, and a more conservative (further) runout distance should be assumed.

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[1] Haugerud 2014

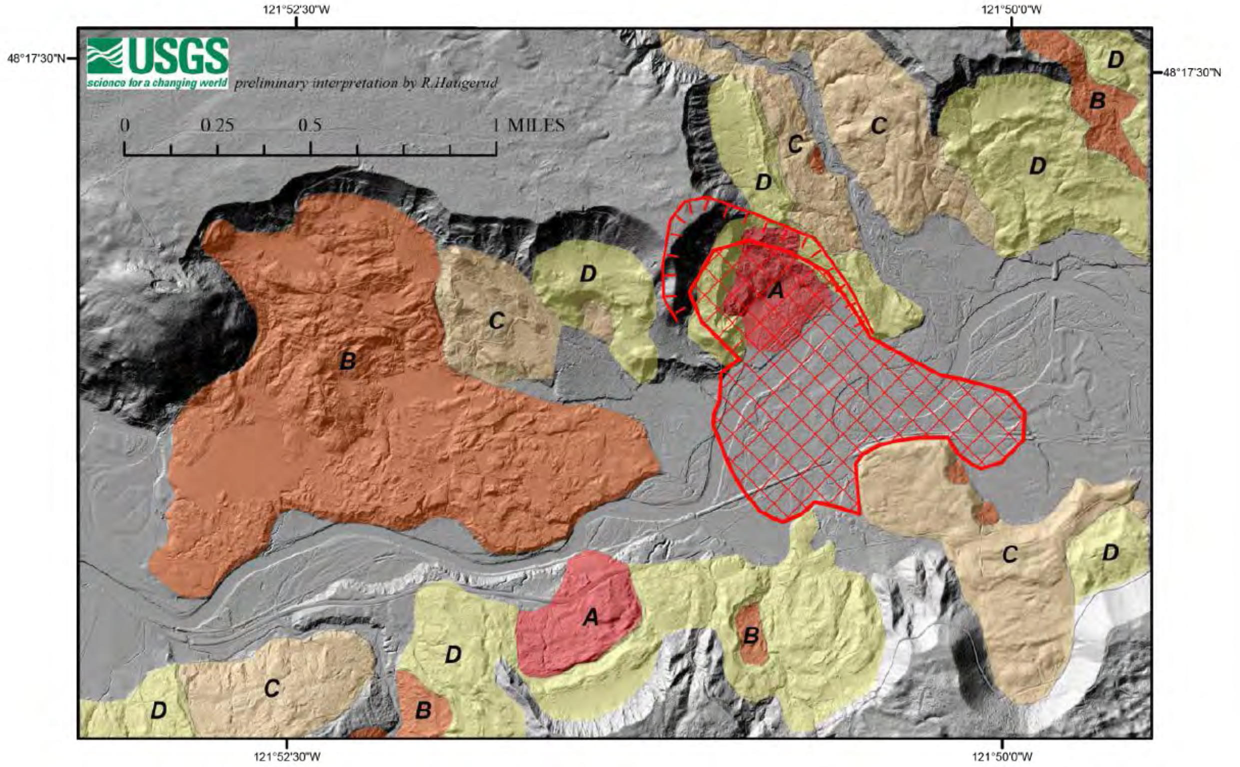


Figure X. LiDAR hillshade image revealing the extent of deep-seated landslide deposits in the vicinity of Oso, Washington as of 2013. Colored polygons indicate landslide deposits by relative age (A, youngest to D, oldest), the red cross-hatched polygon marks the approximate extent of the March 22, 2014 Oso/Hazel landslide deposits, and the large orange polygon depicts the deposits of the older Rowan landslide (from Haugerud 2014).

Haugerud, R.A., 2014, Preliminary interpretation of pre-2014 landslide deposits in the vicinity of Oso, Washington: U.S. Geological Survey Open-File Report 2014-1065, 4 p., http://dx.doi.org/10.3133/ofr20141065.

ATTACHMENT 4

November 9, 2015

Forest Practices Board

forest.practicesboard@dnr.wa.gov

RE: Revisions to Guidelines for Evaluating Potentially Unstable Slopes

Dear Forest Practices Board,

I respectfully submit the following comments in no other capacity than as a concerned citizen with extensive professional and academic experience in the science of landslides in the Pacific Northwest. I am a professor of Geomorphology at the University of Washington and my credentials are summarized below. I write to the Forest Practices Board (FPB) to express my concern that the proposed DNR Board Manual Section 16 (dated 11/15) governing forest practices on potentially unstable slopes contains omissions with respect to identifying and avoiding geologic hazards in relation to logging permit decisions. In my opinion, the Board Manual does not provide adequate technical guidance to agencies and forest landowners seeking to conduct forest practices on or near potentially unstable slopes. In addition, it assigns geologic screening and assessment tasks to personnel who may not have requisite training to practice geology in the State of Washington. These concerns lead me to believe the Board Manual guidance may lead to DNR approving forest practice applications (FPAs) that should not necessarily be approved if prioritizing protecting public safety and resources is a primary policy objective.

I am not receiving financial compensation from anyone for writing this letter. Nor do I have any financial stake in forestry practices, other than that, on occasion, I have worked as a consultant for both timber companies and environmental organizations.

I understand that the Board Manual is legally not a “rule” but offers guidance to assist in assessing forest practice-induced landslide hazard and risk. As such, however, it shapes the on-the-ground character and standard of practice. Based on my academic and professional experience, it is my opinion that the proposed Board Manual falls short for analyzing the potential hazards and risks of forest practices, particularly for deep-seated landslides. I will explain the basis for my concern below. I first describe my professional background and experience in the discipline of geomorphology in the Pacific Northwest. I will then explain the basis for why I consider the proposed Board Manual inadequate, and why reliance on its guidance will not adequately ensure public safety given the tools available to assess landslide hazards and their potential to threaten public safety or public resources.

Professional Background and Experience Relative to Landslide Assessment

I received my Ph.D. from the University of California, Berkeley, Department of Geology and Geophysics, and since 1991 have been a faculty member at the University of Washington, where I am presently the Dean's Professor of Geomorphology in the College of the Environment. I am a fellow of both the American Geophysical Union and the Geological Society of America. I co-authored the introductory geomorphology textbook *Key Concepts in Geomorphology* (2014), and have published several general-audience science books, edited several other technical books and published several hundred papers in the scientific literature. I have served on the editorial boards of the journals *Geomorphology*, *Geology*, *Quaternary Research*, *Earth Surface Processes & Landforms*, and *Basin Research*, as well as an associate editor of *Reviews of Geophysics* and *Water Resources Research*. Over the past several decades, I have engaged in numerous studies of landslides and landslide processes around the world and was an author of a widely cited physically-based model for identifying potentially unstable slopes prone to shallow landsliding.

After the devastating 2014 Oso landslide, I was invited to participate in two working groups that prompted me to take a fresh look at the regulatory, screening, and enforcement policies and processes governing land use practices on or near potentially unstable slopes in Washington State. First, I was a member of the Geotechnical Extreme Events Reconnaissance (GEER) team, funded by the National Science Foundation to study the Oso landslide. Second, Governor Inslee invited me to participate in the SR 530 Landslide Commission convened to examine responses to the Oso tragedy and to make recommendations on preventing and responding to such catastrophic geologic events in the future.

Inadequate Consideration of the Potential for Forest Practices to Reactivate Dormant Landslides

A primary concern of mine with the Board Manual is that the interpretation of the "rule-identified landforms" does not consider the potential for forest practices to reactivate dormant bedrock and glacial deep-seated landslides. As I read the definition for category E (*Any areas containing features indicating the presence of potential slope instability which cumulatively indicate the presence of unstable slopes*) all deep-seated landslides should be covered under the definition, and thus trigger class IV special status and the need for technical assessment by qualified experts. While not all "dormant" landslides will have a high reactivation potential, I see no justification for excluding them all from analysis of reactivation potential by simply relying instead on the indicators of whether there is ongoing movement, as it appears that the manual suggests and implementation allows (see more below).

Hence, in my opinion, the Board Manual needs language to the effect that lack of evidence of active movement is not adequate evidence for dismissing the potential for reactivation. As it is, the Board Manual provides no guidance for assessing reactivation potential and apparently adopts the presumption that a dormant state means no potential hazard from forest practices. I do not consider this technically defensible.

This major, in my view, oversight was brought to my attention when I reviewed the forest practice application (FPA) and associated geological report for the proposed, approved, and now apparently withdrawn Zender timber sale. As I recall, a box was checked on this FPA to indicate that no potentially unstable slopes were present—despite the harvest occurring on a dormant landslide. I further recall from reading the geological report that this interpretation was based on the finding of a field reconnaissance that reported the landslide had no visible evidence of indicators of existing activity. I have not visited this site and do not question or challenge the observations presented in the geologic review of this site or the interpretation that the landslide is dormant (not actively moving). But I question why no other analysis was done to consider potential reactivation of this landslide when even a cursory inspection of a lidar image of the terrain reveals that the body of the slide had, when it failed some time in the past, pulled away from the upper portion of the slope—which displays prominent topographic cracks that outline a block that looks like it potentially could be destabilized should the lower portion of the landslide, where the proposed logging was to occur, reactivate and mobilize.

After I read the Board Manual I realized that no analysis was done to assess the reactivation potential at Zender because the manual does not suggest, let alone require, such analyses for dormant landslides. The methods recommended for assessing the presence of potential slope instability in section 4.5 of the Board Manual are primarily geared toward recognizing the extent and assessing the state of activity of deep-seated landslides (top bullet point on page 16-30). Reading this section one is left with the impression that if a slide is indeed dormant, the recommended procedure is to conclude that the hazard is minimal or non-existent. That appears to have been the case in the geologic assessment for the Zender landslide as the report concluded that it was "stable" based on the lack of evidence for "historic, recent, or on-going movement" and the "lack of apparent response to past harvest and road construction." This particularly bothered me for the Zender FPA because an elementary school was immediately downslope of a deep-seated landslide on which the proposed timber sale sat, indisputably in the slide's groundwater recharge zone. What was the potential for the proposed harvest to reactivate the landslide? No analysis was done beyond an assessment of whether it had moved in recent decades. In following the Board Manual guidance this assessment concluded that there was no risk of failure based on the argument that it wasn't active at present and didn't fail the last time it was cut. This does not really address the potential for reactivation as it boils down to the argument that if it was logged before and it didn't fail, logging can safely be done again.

For years I have read opinions by, and heard directly from DNR personnel and industry foresters that if a slope had been cut before and didn't fail that it was not at risk of doing so again—that the failure to fail last time was assurance that it would not fail if harvested again. I consider this ludicrous. It is akin to arguing that if you managed to survive crossing I-5 blindfolded then you could conclude that you could safely do so again. In the case of harvesting on dormant landslides the potential for reactivation depends not only on the forest practice but on the weather in the decades after harvest. It is well established that slope instability reflects both the state of the landscape (e.g., vegetation cover, root strength, etc…) as well as the variability in processes driving instability (e.g., precipitation, earthquake shaking, slope undercutting). The argument that future harvests are risk free because prior cutting did not lead to landsliding is not, in my view, technically defensible.

The manual provides no guidance for how to evaluate the potential for reactivation of dormant or relict landslides as a result of forest practices. Instead, the procedure appears to be to look for indicators of active movement and if a slide has not moved in recent decades it is determined to be safe to operate on. I consider it a serious, and potentially dangerous, oversight to simply dismiss the potential for instability because a landslide is dormant.

In my opinion, to be scientifically and technically-correct the Board Manual must analyze whether forest practices conducted on dormant deep-seated landslides have the potential to alter or increase groundwater inputs into the landslide and whether this additional groundwater has the potential to reactivate the landslide. While it would be challenging to estimate how past forest practices altered the hydrologic regime and quantify the likelihood that future forest practices will reactivate a deep-seated landslide without some analysis of groundwater conditions and potential for harvest-related change, a deep-seated landslide's age or historic activity level is not necessarily a reliable predictor of the future potential to reactivate, even if past forest practices appear not to have triggered slope movement. This is true for the simple reason that weather matters to whether landslides happen following timber harvest.

In the Board Manual, no analysis appears to be required, or even recommended, for forest practices in the groundwater recharge zone of dormant landslides (i.e., those that have failed previously failed but not presently moving and appear not to have moved in recent decades). Yet such landslides potentially may be reactivated by changes in their hydrological balance or alterations such as grading from road construction. While the risk of such reactivation may be low in many if not most cases, it is widely recognized that altering the hydrology of dormant slides can lead to their reactivation. I do not understand why no consideration is given in the Board Manual to identifying recharge areas for dormant landslides and for assessing their reactivation potential.

Based on these considerations, when tools like Light Detection and Ranging (LiDAR) or other mapping resources indicate the presence of a deep-seated landslide under or adjacent to a proposed logging site it is my opinion that the Board Manual should require estimating the potential increase or alteration in groundwater recharge from timber harvest and assessment of how this will potentially affect the stability of dormant landslides, especially sites that could pose a potential threat to public safety if reactivated.

The proposed Board Manual, however, makes groundwater analysis an optional requirement to assess landslide danger and suggests that such groundwater analysis is "rarely" used in the forested environment and that although such analysis "can" better assess landslide risk, hydrologic analysis is not required to make a fully-informed assessment. Indeed, no methodology or analysis considerations are offered for assessing the potential for hydrologic changes to reactivate dormant landslides.

Another problem I see with the Board Manual is that it only points to delineation of groundwater recharge zones for deep-seated glacial landslides. Yet both glacial and non-glacial deep-seated landslides in the Pacific Northwest are activated, and potentially reactivated by groundwater. While the board manual addresses the delineation of groundwater recharge areas for glacial deep-seated landslides it makes an unwarranted distinction in neglecting the potential for hydrologic changes to influence non-glacial deep-seated landslides. If the goal is to prevent or minimize the impacts of forest practices on landsliding, and thereby public resources and safety, I can think of no reason why there is no analysis required of the potential impacts of timber harvest in groundwater recharge zones of non-glacial deep-seated landslides.

The Board Manual Does Not Include a Landslide Susceptibility Model to Identify Potentially Unstable Ground, Despite Widespread Use of Such Models.

The proposed Board Manual guidance does little more than list the existing tools available for identifying slopes susceptible to shallow landsliding. More emphasis is needed in the guidance on the utility of LiDAR and other simple models in predicting where forest practices should avoid triggering shallow landslides. For example, numerous studies have documented how various existing landslide hazard screening tools perform well for predicting locations susceptible to shallow landsliding. There are many such models that could be run to provide an objective, quantitative tool for assessing zones of potential instability. The widespread availability of lidar data and the new state program to dramatically increase coverage should allow for even better screening performance using such models. For example, physically-based models for the topographic control on shallow landslide initiation and runout could be implemented and used to define zones where geological expertise should be applied, at least for assessing shallow landslide potential. The Board Manual should provide more than a cursory reference to these widely used tools.

The Board Manual Does Not Include a Method for Assessing Potential Deep-seated Landslide Runout.

While physically-based predictive models for runout of deep-seated landslides are still under development, qualitative and empirical methods are available for estimating deep-seated landslide runout, yet these are not mentioned in the proposed Board Manual. To estimate the runout of a deep-seated landslide where forest practices are being proposed, field practitioners should at least be directed to examine the extent of past landslide deposits in comparable geologic materials in the vicinity as an indicator of potential future runout distances. For example, lidar images reveal to even the untrained eye that the Rowan landslide directly to the west of the Oso landslide ran out a similar distance across the valley as the 2014 Oso landslide. In addition, several empirical methods for estimating the runout length of deep-seated landslides were reviewed in the GEER report; these relate potential runout lengths to landslide volumes. Such approaches could be assessed as to whether they could provide an interim way to estimate potential runout lengths for existing deep-seated landslides, for which rough volume estimates would not be difficult to determine. Such empirical "models" are of a similar spirit to a number of empirical methods listed in the Board Manual for analyzing shallow landslide runout, in so much as they are based on experience with other slides rather than physics-based predictions using the particular attributes and context of specific slides.

The Board Manual Assigns Geologic Screening to Personnel That May Not Have Credentials to Practice Geology.

The Board Manual states that "*The objective of the general practitioner's field assessment is to determine the presence or absence of rule-identified landforms*" (p. 16-34). The listed "rule-identified landforms" include category E, which again are defined as "*Any areas containing features indicating the presence of potential slope instability which cumulatively indicate the presence of unstable slopes*." Hence the general practitioners are expected to be able to apply professional judgment to assess the presence of and potential for slope instability. Taking the definition of Class E at face value, evaluating whether landforms present at a site fall into category E requires professional judgment that goes beyond the proscriptive list of features laid out in A through D of the "rule-identified landforms." Thus, the Board Manual is tasking general practitioners to formulate geological opinions and to make decisions based on those opinions—in other words to practice geology. The manual goes on to state that when the conditions are beyond the general practitioner's expertise (a call that this person presumably would make) that "*the landowner may wish to have a qualified expert complete a further assessment.*" Thus, not only are apparently unqualified non-experts making the call as to whether there are geological conditions that indicate the presence or potential for slope instability but they are tasked with assessing the adequacy of their own expertise to do so.

It is my understanding that Washington law provides that only licensed geologists may practice the profession of geology. Yet the Board Manual assigns crucial first-level screening tasks to persons who may not be licensed geologists including judging the presence of a category E rule-identified landform, and, it seems, whether a forest practice is being proposed in the groundwater recharge area of a glacial deep-seated landslide. In so much as the Board Manual thus explicitly allows unlicensed personnel to evaluate evidence of existing or potential slope instability and determine whether geological analyses are warranted, it expects and requires persons who are not licensed geologists to practice geology.

WAC 18.220.020 states that a license is required to practice "**any branch of the profession of geology**." In my view, the geomorphological assessment of slope stability through landform interpretation certainly qualifies as practicing a branch of the geological profession. Under WAC 18.220.190 the following text describes permitted activities for which a certificate of licensing is not required; bold-faced and underlined text shows wording pertinent to my concern.

> *(1) Geological work performed by an employee or a subordinate of a geologist or specialty geologist licensed under this chapter,* **<u>provided that the work does not include responsible charge of geological work as covered by this section</u>***, and is performed under the direct supervision of a geologist licensed under this chapter, who shall be and remains responsible for such work; ...*

> *(7) General scientific work customarily performed by such physical or natural scientists as chemists, archaeologists, geographers, hydrologists, oceanographers, pedologists, and soil scientists,* ***providing such work does not include*** *the design and execution of geological investigations, being in responsible charge of geological or specialty geological work, or* ***the drawing of geological conclusions and recommendations in a way that affects the public health, safety, or welfare****…*

In my view, making the call as to whether landforms fit under class E of WAC 222.16.050 inherently involves forming geological opinions and would therefore seem to require geological expertise under WAC 18.220.020 that might not be held by the personnel now permitted to make the call. When regulations and board manual guidance assign geologic screening tasks to non-geologists who may underestimate landslide hazard, public safety and public resources are potentially put at risk.

Proscriptive Versus Permissive Language

Finally, the edits that were shown on the 11/15 version of the proposed Board Manual included a number of places where language was changed from proscriptive (shall) to permissive (may). These changes obviously weaken the language in regard to protecting public safety and resources with no proffered technical justification. If something is necessary for a credible technical assessment then "shall" is appropriate for a guidance document, as "may" suggests that the thing need not necessarily be done. Of particular concern to me therefore is that the revisions of this nature appear to have been made after the technical group formulated and agreed upon their recommendations.

Conclusion

In summary it is my opinion that, as written, certain aspects of the proposed Board Manual (version of 11/15) provide insufficient and potentially misleading guidance to forest landowners, agencies, and the public for assessing the potential impacts of forest practices on potentially unstable landforms, public safety, and public resources. Thank you for considering my comments.

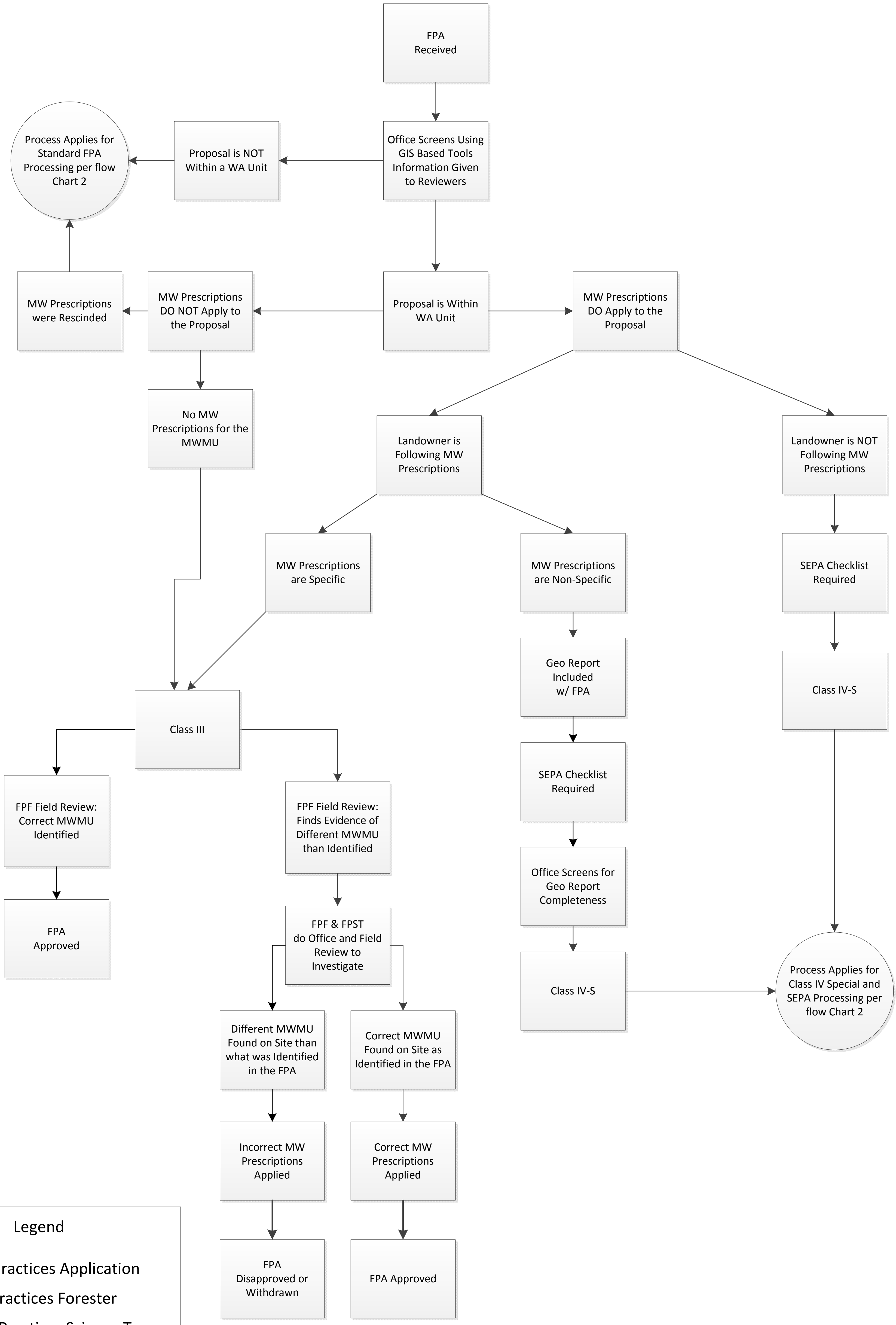
Sincerely,

David R. Montgomery

WA State Licensed Geologist #520

Attachment B

FPA Processing for the Protection of
Potentially Unstable Slopes within Watershed Analysis Units (flow chart 1)



Legend

FPA = Forest Practices Application

FPF = Forest Practices Forester

FPST = Forest Practices Science Team

SEPA = State Environmental Policy Act

GIS = Geographic Information Systems

Geo Report = Geo-Technical Report

WA = Watershed Analysis

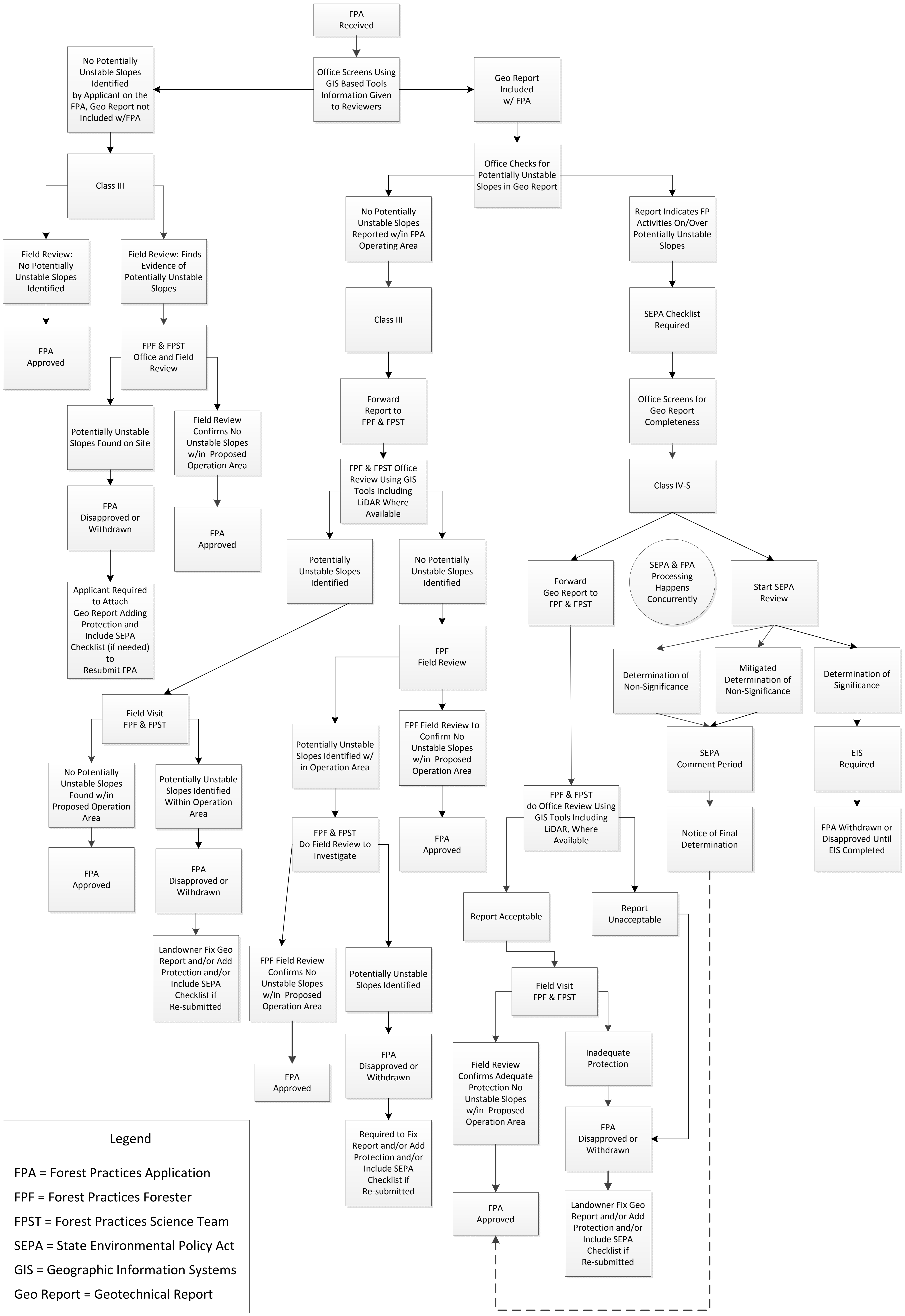
MW = Mass Wasting

MWMU = Watershed Analysis Mass Wasting Map Unit

Attachment B

FPA Processing for the Protection of

Potentially Unstable Slopes (flow chart 2)



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