STATE OF WASHINGTON
FOREST PRACTICES BOARD

PO Box 47012
Olympia, WA 98504-7012

Regular Board Meeting – May 11, 2016
Natural Resources Building, Room 172, Olympia

Please note: All times are estimates to assist in scheduling and may be changed subject to the business of the day and at the Chair's discretion. The meeting will be recorded.

DRAFT AGENDA

9:00 a.m. - 9:05 a.m.	**Welcome and Introductions** Safety Briefing – Patricia Anderson, Department of Natural Resources (DNR)
9:05 a.m. - 9:15 a.m.	**Approval of Minutes** *Action: Approve February 10, 2016, meeting minutes*
9:15 a.m. – 9:25 a.m.	**Report from Chair**
9:25 a.m. – 9:40 a.m.	**Public Comment** – This time is for public comment on general Board topics. Comments on any Board action item that will occur later in the meeting will be allowed prior to each action taken.
9:40 a.m. – 11:00 a.m.	**Cultural Resources** • Tribal introduction • What is a cultural resource and why is it important – David Powell, Yakama Nation and David Merrill, Hancock Forest Management • Current practices – Marc Engel, DNR and Allison Brooks, Department of Archaeology and Historic Preservation • Tribal Perspective - Panel • Landowner Perspective - Panel
11:00 a.m. – 11:15 a.m.	**Break**
11:15 a.m. – 11:35 a.m.	**Western Gray Squirrel Annual Report –** Brandon Austin, DNR and Terry Jackson, WDFW
11:35 a.m. – 11:45 a.m.	**Western Gray Squirrel Petition for Rule Making** – Marc Engel, DNR
11:45 a.m. – 11:55 a.m.	**Public Comment on Petition for Rule Making**
11:55 a.m. – 12:10 p.m.	**Western Gray Squirrel Petition for Rule Making** – Marc Engel, DNR *Action: Consider action on petition for rule making.*
12:10 p.m. – 1:10 p.m.	**Lunch**
1:10 p.m. – 1:25 p.m.	**Public Comment** – This time is for public comment on general Board topics. Comments on any Board action item that will occur later in the meeting will be allowed prior to each action taken.
1:25 p.m. – 1:35 p.m.	**Board Manual Section 16 Unstable Slopes -** Marc Ratcliff, DNR
1:35 p.m. – 1:45 p.m.	**Public Comment on Board Manual Section 16 Unstable Slopes**
1:45 p.m. – 2:00 p.m.	**Board Manual Section 16 Unstable Slopes -** Marc Ratcliff, DNR *Action: Consider approval of amended board manual section.*
2:00 p.m. – 2:15 p.m.	**Unstable Slopes Proposal Initiation Update** – Hans Berge, DNR

Future FPB Meetings

Next Meeting: August 11 and November 10, 2016
Check the FPB Web site for latest information: http://www.dnr.wa.gov/
E-Mail Address: forest.practicesboard@dnr.wa.gov Contact: Patricia Anderson at 360.902.1413

2:15 p.m. – 2:30 p.m.	**2016-2017 CMER Budget Adjustments**
2:30 p.m. – 2:40 p.m.	**Public Comment on 2016-2017 CMER Budget**
2:40 p.m. – 2:50 p.m.	**2016-2017 CMER Budget** – Hans Berge, DNR *Action: Consider approval of 2016-2017 amended CMER budget.*
2:50 p.m. – 3:10 p.m.	**2017-2019 CMER Master Project Schedule and Proposed Budget**
3:10 p.m. – 3:20 p.m.	**Public Comment on 2017-2019 CMER Master Project Schedule and Proposed Budget**
3:20 p.m. – 3:35 p.m.	**2017-2019 CMER Master Project Schedule and Proposed Budget** – Hans Berge, DNR *Action: Consider approval of CMER Master Project Schedule and associated budget.*
3:35 p.m. – 3:50 p.m.	**Break**
3:50 p.m. – 4:05 p.m.	**Board's Practices and Procedures Rule Making** – Marc Ratcliff, DNR
4:05 p.m. – 4:15 p.m.	**Public Comment on Board's Practices and Procedures Rule Making**
4:15 p.m. – 4:30 p.m.	**Board's Practices and Procedures Rule Making –** Marc Ratcliff, DNR *Action: Consider approval of draft rule language and file a CR-102.*
4:30 p.m. – 4:45 p.m.	**Small Forest Landowner Westside Template Update** – Marc Engel
4:45 p.m. – 4:55 p.m.	**Staff Reports** A. **Adaptive Management** – Hans Berge, DNR B. **Board Manual Development** - Marc Ratcliff, DNR C. **Compliance Monitoring** – Garren Andrews, DNR D. **Rule Making Activity** - Marc Engel, DNR E. **Small Forest Landowner Advisory Committee and Small Forest Landowner Office** -Tami Miketa, DNR F. **Upland Wildlife Working Group** - Terry Jackson, Washington Department of Fish and Wildlife (WDFW) G. **Northern Spotted Owl Implementation Team and Safe Harbor Agreement** - Lauren Burnes H. **TFW Cultural Resources Roundtable** – Jeffrey Thomas and Karen Terwilleger, Co-chairs I. **Clean Water Act Assurances** – Mark Hicks, Department of Ecology **Annual Reports** A. **Taylor's Checkerspot Butterfly Annual Report** - Sherri Felix, DNR and Gary Bell, WDFW
4:55 p.m. – 5:05 p.m.	**TFW Policy Committee's Work Priorities** – Adrian Miller, Chair
5:05 p.m. – 5:15 p.m.	**2016 Work Planning** - Marc Engel, DNR *Action: Consider changes.*
	Executive Session **To discuss anticipated litigation, pending litigation, or any other matter suitable for Executive Session under RCW 42.30.110**

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FOREST PRACTICES BOARD
Regular Board Meeting
February 10, 2016
Natural Resources Building, Room 172
Olympia, Washington

Members Present
Stephen Bernath, Chair, Department of Natural Resources
Bill Little, Timber Products Union Representative
Bob Guenther, General Public Member/Small Forest Landowner
Brent Davies, General Public Member
Carmen Smith, General Public Member/Independent Logging Contractor
Court Stanley, General Public Member
Dave Herrera, General Public Member
Heather Ballash, Designee for Director, Department of Commerce
Joe Stohr, Designee for Director, Department of Fish and Wildlife
Patrick Capper, Designee for Director, Department of Agriculture
Paula Swedeen, General Public Member,
Tom Laurie, Designee for Director, Department of Ecology

Members Absent
Vacant, Elected County Official

Staff
Joe Shramek, Forest Practices Division Manager
Marc Engel, Forest Practices Assistant Division Manager
Patricia Anderson, Rules Coordinator
Phil Ferester, Senior Counsel

WELCOME AND INTRODUCTIONS
Stephen Bernath called the Forest Practices Board (FPB or Board) meeting to order at 9:00 a.m. Introductions of Board and staff were made.

APPROVAL OF MINUTES
MOTION: Bill Little moved the Forest Practices Board approve the November 10, 2015 meeting minutes.

SECONDED: Bob Guenther

ACTION: Motion passed unanimously.

REPORT FROM CHAIR
Stephen Bernath acknowledged Dave Somers' service as a Board Member and introduced Joe Shramek as the new Forest Practices Division Manager.

He provided an update on the following:
- DNR's Proposed Budget

- Legislation including 29 bills on wildfire and several on public safety, cultural resources and pesticides
- Unstable slopes training conducted through regional TFW groups

PUBLIC COMMENT (AM)
Bruce Barnes, Elk Hunters, shared his concerns regarding the application of herbicides and the effects on fish and wildlife and their habitat. He asked the Board to revisit the spraying process used in forest practices.

Mark Smith, Eco Park Resort, shared his concerns on the lack of oversight and administration of aerial herbicide spraying and the permitting process. He asked the Board to conduct an audit on the current aerial herbicide application process and conduct a study on the effects to native wildlife habitat.

Ken Miller, Washington Farm Forestry Association, invited the Board to conduct a field tour on his property to better visualize the prescriptions identified in the alternate plan template being reviewed through the adaptive management process. He also shared concerns that because the process is already overburdened, the small landowner community may not see any recommendations on the alternate plan template coming soon. He asked the Board to request a partial recommendation from Timber, Fish and Wildlife (TFW) Policy Committee (Policy) by the end of the year to show the Board's intent of a review which will demonstrate a good faith effort to small landowners.

Chris Mendoza, Conservation Caucus, commented on the Board's operations and procedures rule making. He said that he takes responsibility for submitting late comments to the Board last November and prefers not to do that; however, he said that timely release of documents from staff will result in a more timely response from the public. He recommended rule language be developed that ensures timely release of documents that is standardized, transparent and consistent.

Peter Goldman, Conservation Caucus, provided an explanation of the Board Manual Section 16 process that resulted in the timing of their submitted comments in November 2015. He also said that it is time for a Type F permanent rule, and encouraged the Board to be ready to move forward in November with rule making regardless of Policy's recommendations.

Karen Terwilleger, Washington Forest Protection Association (WFPA), provided a brief history of the water typing rules stating that it has been ten years since the Board decided to not move forward with the model and even longer since the first emergency rule was adopted by the Board in 1996. She said while it has taken a long time, there needs to be scientific justification for a change and she believes that Policy is getting close. She also said they support the approval of Dr. Jenny Knoth as a Cooperative Monitoring, Evaluation and Research Committee (CMER) member.

BOARD MANUAL SECTION 16 UPDATE AND PROPOSAL INITIATION FOR UNSTABLE SLOPES
Marc Ratcliff, DNR, provided a status update on the revisions to the board manual. He reminded the Board that their November motion directed DNR to convene a qualified expert group to address the items near resolution contained in the Conservation Caucus memo.

He said the qualified expert group has incorporated additional information regarding 'complex and composite' landslides, and how LiDAR can be used for identifying potentially unstable features on

complex landslides. He mentioned that most of the material pertaining to the deep-seated landslide runout coarse screen document is being considered for inclusion in the runout and delivery section of the manual.

He concluded by sharing that the group will reconvene after the Board meeting to continue the review of these two documents.

Marc Engel, DNR, presented the Unstable Slopes Proposal Initiation for Board approval. He described the proposal initiation process outlined in WAC 222-12-045 and Board Manual Section 22. He said once the Unstable Slopes Proposal Initiation is approved it will be sent to the Adaptive Management Program Administrator (AMPA) who will make recommendations to the Policy Committee on whether it is a policy or science track. Policy will then prepare a work plan that includes timelines for completion for Board approval.

He then reviewed the Unstable Slopes Proposal Initiation contents which includes four items identified in the Conservation Caucus' letter dated November 9, 2015, needing additional review by the adaptive management program. The four items are: non-glacial deep-seated landslides; deep-seated landslides reactivation; shallow rapid landslide coarse screen; and landslide risk decision pathway.

He concluded by recommending the Board:

- Accept the Unstable Slopes Proposal Initiation;
- Direct staff to send the packet to the AMPA to prepare recommendations for either a policy or science track; and
- Direct Policy to develop a work plan and timeline by the Board's May 2016 meeting.

PUBLIC COMMENT ON PROPOSAL INITIATION

Chris Mendoza, Conservation Caucus, expressed concern that the Conservation Caucus did not have input on the Unstable Slope Proposal Initiation regarding the emphasis language that has not been resolved with the current work of the stakeholder group. He also cautioned the Board on conducting additional science as proposed in the Unstable Slopes Proposal Initiation as it may not be useful or necessary because it may not be possible to conduct such studies.

Kara Whittaker, Washington Forest Law Center (WFLC), said she met with DNR to discuss the Conservation Caucus' seven items of concern and agreed to the Unstable Slopes Proposal Initiation approach under the condition that the Conservation Caucus would have an opportunity to help draft the proposal with DNR staff. Unfortunately, she said, that did not occur and for these reasons she asked the Board to direct the AMPA to consider their input when reviewing the proposal. Under this condition, the Conservation Caucus finds it acceptable for the Board to approve the Unstable Slopes Proposal Initiation process moving forward and to complete the proposal review recommendations at the May meeting.

Karen Terwilleger, WFPA, said they support the Unstable Slopes Proposal Initiation moving forward. She also said they feel strongly that the board manual should be guidance and not rule.

Peter Goldman, Washington Forest Law Center, said they support the Unstable Slopes Proposal Initiation moving forward in order to inform whether new rules or additional guidance is needed. He also asked the Board to request an update at their May meeting and keep it moving forward.

PROPOSAL INITIATION FOR UNSTABLE SLOPES
Marc Engel, DNR, asked the Board to approve the Unstable Slopes Proposal Initiation for the Adaptive Management process.

Joe Stohr asked how the evaluation of the emphasis language occurred. Bernath responded the Board directed staff in August 2015 to work on this along with other amendments that were brought forward to the Board in November and subsequently approved.

Swedeen acknowledged the issue of the emphasis language and asked if feedback can be solicited from practitioners which could then inform any necessary changes to the board manual. Bernath concurred with Swedeen and said as the Department trains staff on the board manual, feedback should be available within a year or so. Engel also responded that it was part of the Board's motion in November 2015 to review how the board manual is doing in November 2016.

Tom Laurie asked whether the AMPA could include input from the Conservation Caucus when reviewing the Proposal Initiation. Berge replied yes.

MOTION: Carmen Smith moved the Forest Practices Board forward the Proposal Initiation for Unstable Slopes to the Adaptive Management Program Administrator to initiate Adaptive Management Program review. She further moved the Board direct TFW Policy Committee to provide to the Board at their May 2016 meeting an Adaptive Management Program work plan and timeline for review of the items in the Proposal Initiation and completion of recommendations for further actions to the Board.

SECONDED: Heather Ballash

Board Discussion:
Court Stanley asked Policy to be mindful of the Proposal Initiation for the Small Forest Landowner Alternate Plan Template that is currently within Policy.

ACTION: Motion passed unanimously.

ADAPTIVE MANAGEMENT PROGRAM BUDGET
Hans Berge, DNR, provided an update on the budget and highlighted savings within the Administrative Support staff fund due to vacancies. He also provided a progress report on some of the projects. He indicated that there is a larger surplus of funds than previously identified and since the funding source is from the General Fund instead of Forests and Fish Support Account, any unspent funds within a fiscal year cannot be carried over into the next fiscal year. He asked the Board to allow CMER to spend up to 10 percent of the annual budget during the 2015-2017 biennium towards priorities within the Adaptive Management Program.

Carmen Smith asked what the money he referred to will be used for. Berge responded that he has some ideas, however it will need to be vetted through the program.

PUBLIC COMMENT ON MASTER PROJECT SCHEDULE
Mark Smith, Eco Park Resort, advocated for monies to be spent on auditing the application of herbicide spray within forest practices.

Ken Miller, WFPA, said they are working on proposing an eastside template at the May 2016 Board meeting. He asked that the Board members and stakeholders be receptive to meet with them prior to the May meeting to review their proposal.

Bruce Barnes, Elk Hunters, encouraged the Board to provide additional monies to Department of Fish and Wildlife to research the cause of the hoof rot disease within the elk population.

Doug Hooks, WFPA, said he supports the proposed spending flexibility within the Adaptive Management Program.

2015-2017 BIENNIAL MASTER PROJECT SCHEDULE CHECK-IN
Hans Berge, DNR, requested the Board approve the authorization for CMER to spend General Fund-State money on priority projects.

MOTION: Carmen Smith moved the Forest Practices Board authorize the Adaptive Management Program Administrator the flexibility within the Master Project Schedule to spend up to 10% of each fiscal year's budget to fund priorities within the Adaptive Management Program as approved by the TFW Policy Committee. Any additional spending must be recommended by the TFW Policy Committee and approved by the Board.

SECONDED: Bob Guenther

Board Discussion:
Bob Guenther asked if monies could be spent to address wildlife concerns brought up by the public and whether there are any projects in the que to address wildlife. Berge responded that the program is focused on the riparian and aquatic habitat conservation not wildlife.

Guenther then asked how the public would go about getting these wildlife concerns addressed. Bernath responded that he would send out DNR's testimony presented to the Senate Natural Resources and Parks Committee on how the Department deals with aerial application of pesticide. He said perhaps at the next meeting the Board could have more discussions on wildlife issues.

Bob Guenther concurs with the wildlife issues brought forward today and would like the Board to address it somehow.

Brent Davies asked if there are any CMER projects that focus on the pesticide spraying. Berge responded that there are some proposals related to researching herbicide spraying.

ACTION: Motion passed unanimously (Laurie not available for vote.)

TFW POLICY COMMITTEE'S TYPE F UPDATE
Adrian Miller, Co-chair, provided an update on Policy's progress with Type F. He indicated that electrofishing and off-channel habitat are both moving along and recommendations should be ready

to be presented to the Board at the November 2016 meeting. He also said that Policy is working on other components, such as the Type F physicals, however this is not moving along as quickly.

COMPLIANCE MONITORING 2014 INTERIM REPORT

Garren Andrews, DNR, provided a brief review of the 2014 interim results and highlighted the program design updates. The new program study design objectives included:

- Increase statistical precision
- More quantitative estimate of compliance
- Better determine specific rule noncompliance
- Flexibility to add, remove, or combine prescription types

The 2014 interim results included:

- Desired future condition
- Water typing
- No inner zone harvest
- Non-fish bearing perennial and seasonal streams
- Type A and B and forested wetland management zones
- Roads
- Haul routes

The final report will be presented to the Board in August 2016.

PUBLIC COMMENT (PM)

Steve Barnowe-Meyer, Washington Farm Forestry Association, said he recommends the Compliance Monitoring Program be directed to include root cause analysis as a critically important step in the future methodology and work of the program. He then explained root cause analysis.

Kara Whitaker, WFLC, said she likes having the presentation before the public comment on the agenda as it helps solicit comments from the public. She also said they support Department of Fish and Wildlife's recommendation to maintain the status of threatened and endangered for the Northern spotted owl.

Chris Mendoza, Conservation Caucus, shared some of his concerns with the Compliance Monitoring Program design and the average compliance rating. He said the current way the rating is rolled up does not provide an accurate reflection of compliance.

SELECTION PROCESS FOR COMMITTEE CO-CHAIRS

<u>TFW Policy Committee</u>

Policy has a process and description for selection of co-chairs.

Bernath suggested Policy develop a permanent rotation schedule for the other caucuses to fill in as co-chair to see what the workload is like until a permanent co-chair is selected.

<u>CMER</u>

CMER has a process in place for co-chair nominations and selection.

<u>TFW Cultural Resources Roundtable</u>

TFW Cultural Resources Roundtable has strategies in place for co-chair selection.

Tom Laurie asked whether the strategies list is part of a broader description of duties or is it guidance.

Karen Terwilleger, Co-chair, said they developed the list of strategies over a period of two meetings since they did not have a process in place.

Stephen Bernath asked if the assignment is complete as it appears the duties are not defined and the strategies seem to be characteristics of a co-chair.

Jeffrey Thomas, Co-chair, said they have fulfilled the direction stated in the Board's motion by providing the information they have on selecting co-chairs.

NORTHERN SPOTTED OWL STATUS REVIEW UPDATE

Joe Buchanan, Washington Department of Fish and Wildlife, provided a status update on the Northern spotted owl (NSO) which included historical listing status, general distribution in Washington, limiting factors and population status.

He concluded by stating the NSO population continues to decline in Washington and recovery requires a continued focus from all conservation partners on minimizing threats and implementing conservation actions including incentive-based programs.

Joe Stohr said next steps include moving forward on:

- barred owl pilot projects;
- safe harbor agreements;
- incentives;
- modeling; and
- looking at minor rule changes

SAFE HARBOR AGREEMENT UPDATE

Lauren Burnes, DNR, updated the Board on the project plan for the NSO programmatic safe harbor agreement process. She said the goal is to deliver to USFWS a draft Safe Harbor Agreement with a draft NEPA environmental assessment.

Paula Swedeen acknowledged the substantial gains that have been made, but mentioned that the modeling identified potential habitat outside the SOSEAs and would like to see the pace of action increase in order to identify additional habitat. Bernath committed to reenergizing the Northern Spotted Owl Implementation Team (NSOIT) but not the analysis at this time. An update will be provided at the May meeting on the NSOIT's progress.

STAFF REPORTS

Small Forest Landowner Advisory Committee and Small Forest Landowner Office

Tami Miketa, DNR, said on January 21, Commissioner Goldmark, the Washington Tree Farm Program, and the Washington Farm Forestry Association celebrated 75 years of sustainable forestry in Washington State at a special ceremony in the Capitol rotunda. The ceremony honored the key role of the American Tree Farm System in nurturing sustainable forestry since the establishment of Clemons Tree Farm near Montesano in 1941.

TFW Cultural Resources Roundtable

Karen Terwilleger, Co-chair, asked if they could provide the Board with a cultural resources 101 at their May 2016 meeting. The Board welcomed the idea and requested that enough time be allotted for this topic.

No questions on the following reports.

- Adaptive Management
- Board Manual Development
- Compliance Monitoring
- Upland Wildlife

LEGISLATIVE UPDATE

Joe Shramek, DNR, provided an update on three bills that could impact the Board and the Forest Practices Program.

- SB 6396 changing rule making requirements to require preadoption review by the attorney general and a yearly expiration.
- SB 6287 concerning the definition of hydraulic project in relation to the Forest Practices Hydraulic Project approval permits.
- HB 2856 establishing the office of Chehalis River Basin flood risk reduction.

PUBLIC COMMENT ON CMER MEMBERSHIP

None.

CMER MEMBERSHIP

Hans Berge, DNR, requested the Board approve Dr. Jenny Knoth as a CMER member.

MOTION: Patrick Capper moved the Forest Practices Board approve the CMER roster dated February 2016 that reflects Dr. Jenny Knoth as a member of CMER.

SECONDED: Heather Ballash

ACTION: Motion passed unanimously.

OVERVIEW OF BOARD'S OPERATIONS AND PROCEDURES RULES MAKING

Marc Engel, DNR, requested the Board consider rule making to develop a process to receive information from the public on action before the Board. He said the intent is not to restrict any information given to the Board. It is to ensure that the Board has enough time to process the information received and prepare for the decision making at the meeting.

PUBLIC COMMENT ON THE BOARD'S OPERATIONS AND PROCEDURES RULE MAKING

None.

BOARD'S OPERATONS AND PROCEDURES RULE MAKING

MOTION: Heather Ballash moved the Forest Practices Board approve the filing of a CR101 Preproposal of Inquiry to begin rule development relating to the Board's administrative process for submittal of documents to the Board for consideration on action items.

SECONDED: Bob Guenther

Board Discussion:
Paula Swedeen said she is not opposed to a rule but questioned whether a rule is actually necessary or if guidelines could be developed.

Court Stanley asked whether there is a mechanism in place in the event a large document was received just prior to Board action and whether the Board had to consider it before taking action. Engel responded that the rule making process does have a method.

Tom Laurie said he is not opposed to the motion; however he acknowledged that in order for the public to provide comments, the Department needs to make the information available in a timely manner.

Stanley said he would prefer a commitment of all parties versus a rule.

ACTION: Motion passed. 2 opposed (Stanley and Stohr)

BOARD'S 2016 WORK PLAN
Marc Engel, DNR, reviewed the changes to the work plan as a result of today's meeting.

The following was added or adjusted to the Work Plan:
- Proposal Initiation to review Unstable Slopes-Recommendations and Timeline - May
- Board's administrative process rule making - November

MOTION: Tom Laurie moved to approve the work plan presented today with the additional items.

SECONDED: Brent Davies

ACTION: Motion passed unanimously.

EXECUTIVE SESSION
None.

Meeting adjourned at 3:30 p.m.

WASHINGTON STATE DEPARTMENT OF
Natural Resources

Washington Department of FISH and WILDLIFE

April 18, 2016

MEMORANDUM

TO: Forest Practices Board

FROM: Terry Jackson, Forest Habitats Section Manager
Washington State Department of Fish and Wildlife

Donelle Mahan, Forest Practices Operations Assistant Division Manager
Washington State Department of Natural Resources

SUBJECT: 2015 Annual Report on the Voluntary Protection Approach for Western Gray Squirrel

On November 12, 2013, the Board directed the Washington Department of Natural Resources (DNR) and Washington Department of Fish and Wildlife (WDFW) to annually report on the status of management plans and the success of the voluntary protection approach. DNR and WDFW will present this report at the May 11, 2016 board meeting.

This report is the second annual report to the Board and covers the period from January 1, 2015 through December 31, 2015. It includes the results of WDFW's tracking data for FPAs and voluntary management plans, which help us to evaluate how well the voluntary protection approach is working. The report also includes an update on WDFW's periodic status review for the WGS, WDFW's current and planned surveys for informing us on the population and habitat status of the squirrel, and some other forest landowner efforts to help in conservation of the WGS.

We look forward to discussing the 2015 report with you at your May 2016 meeting. In the meantime, please do not hesitate to contact us: terry.jackson@dfw.wa.gov at 360.902.2609 or donelle.mahan@dnr.wa.gov at 360.902.1405.

Attachment

cc. Hannah Anderson
Brandon Austin
Penny Becker
Gary Bell
Marc Engel
Joe Shramek
Amy Windrope

2015 Annual Report to the Forest Practices Board

The Status of a Voluntary Protection Approach for the Western Gray Squirrel May 11, 2016

SPECIES BACKGROUND

The western gray squirrel (WGS) was listed by the Washington Fish and Wildlife Commission as State Threatened effective November 14, 1993.

In Washington State, the species occurs in three highly localized areas in the oak woodlands and conifer forests of Klickitat and southern Yakima counties; low to mid-elevation conifer forests in Okanogan and Chelan counties; and the oak woodlands and conifer forests on Joint Base Lewis-McChord in Pierce and Thurston counties.

The WGS inhabits transitional forests of mature Oregon white oak, ponderosa pine, Douglas-fir, and various riparian tree species (Linders and Stinson 2007). Habitat quality in Washington is assumed to be relatively poor compared to other parts of the species' range due to the lower number of oak species and degradation of pine and oak habitats. The cumulative effects of land conversion, logging, sheep grazing, and fire suppression largely eliminated the open-grown stands of mature and old growth pine and have degraded oak woodlands (Linders and Stinson 2007). The most recent population estimate for Washington was based on data gathered over ten years ago (1994 to 2005 by Linders and Stinson, 2007). At that time the population was between 468 and 1,405 squirrels. Population size can fluctuate dramatically with disease and changes in food supply. WDFW is currently involved in conducting multi-year surveys on population and habitat status for the WGS.

HISTORY OF FOREST PRACTICES BOARD ACTIONS

In 2013 staff from the Department of Natural Resources (DNR) and Washington Department of Fish and Wildlife (WDFW) worked together to explore administrative and operational improvements to provide WGS protection measures as part of approved forest practices applications. DNR staff then incorporated these improvements into Forest Practice Application (FPA) processing guidance that have been applied to all FPAs containing WGS habitat. Key components of this guidance include:

- Noting the presence of WGS or their habitat on the DNR *Office Checklist* page which becomes part of the FPA.
- Providing WDFW a courtesy email that an FPA has triggered a "hit" for potential WGS presence within the vicinity of the FPA. This provides notification on all new

FPAs sent out for review to DNR forest practices foresters, WDFW biologists, and interested stakeholders that WGS or their habitat may be present within the proposed forest practices activity areas.

- DNR includes a "note" on the FPA *Notice of Decision* page acknowledging the presence of WGS or their habitat in the harvest vicinity, and refers them to WDFW staff for assistance. Though this note is not a condition of the application, it is expected to inform the FPA proponent of the potential occurrence of WGS or their habitat and to provide WDFW contact information, further improving communications and increasing the likelihood of voluntary WGS protection.

On November 12, 2013, the Board directed DNR and WDFW to annually report on the status of management plans and the success of the voluntary protection approach. At the May 2015 Board meeting, DNR and WDFW staff presented the 2014 WGS Annual Report. A public rule petition was submitted to the Board at the November 10, 2015 meeting. The Board moved that the petition be denied at that time; however, the Board moved that they would revisit the status and possible next steps for protection of the WGS at their May 2016 meeting. At this meeting, the 2015 WGS Annual Report to the Board would be presented, including an update from WDFW on the results of the periodic status review for the squirrel. This 2015 report is the second annual report to the Board.

2015 FOREST PRACTICES APPLICATIONS/NOTIFICATIONS (FPA/NS)

The process changes for screening FPA/Ns with the potential to impact WGSs (mentioned above) began in November of 2013. Using WDFW's GIS location data for documented WGS presence, nests, and/or potentially suitable habitat, WDFW and DNR both screen FPA/Ns for potential WGS impacts. DNR also notifies WDFW of all FPA/Ns within ¼-mile of these locations via email. WDFW then further evaluates the FPA/Ns for potential WGS conflicts, working with the landowner/land manager to conduct WGS nest surveys (as needed), discussing forest management goals and options, and developing voluntary WGS management plans. These management plans incorporate conservation measures identified in WDFW's Priority Habitats and Species (PHS) Management Recommendations for WGSs.

In order to better evaluate the effectiveness of the voluntary WGS protection approach, in December 2013, WDFW began actively tracking more detailed FPA/N information for potential WGS conflicts. Information collected includes FPA/N number, date of posting in the Forest Practice Application Review System (FPARS), applicant name, whether they are a large or small landowner, if a WGS nest survey was needed or completed, if a WGS Management Plan was necessary or developed, and any additional notes or pertinent information. This report covers the calendar year for 2015.

The following provides a summary of FPA/Ns that triggered a WGS "hit" from January 1, 2015 through December 31, 2015:

- A total of 73 FPA/Ns were identified as potentially being associated with WGS.
- Of these 73 WGS-related FPA/Ns, 56 FPA/Ns were located in Klickitat County, 16 were located in Okanogan County, and one was located in Clark County.
    - One FPA/N was a renewal of existing FPA.
    - One FPA/N was a resubmittal of a previously withdrawn FPA.

- Of the 73 total FPA/Ns, 25 were associated with large/industrial landowners, and 48 were associated with small forest landowners.

WESTERN GRAY SQUIRREL SITE MANAGEMENT PLANS

Throughout 2015, WDFW continued its WGS conservation efforts with landowners, conducting WGS nest surveys and coordinating with landowners to develop and implement WGS management plans. The following is a summary of management plan development and implementation activity for the time period of January 1 through December 31, 2015:

Of the 73 WGS-related FPA/Ns requiring evaluation or action of some kind:

- All FPA/Ns involved the need for further review, including such tasks as confirming WGS presence or absence, conducting a WGS nest survey, and/or confirming appropriate WGS protection measures to be implemented during forest practice activities:
    - 36 FPA/Ns resulted in no WGS nests and no need for WGS management plans.
    - 16 FPA/Ns were for salvage activities associated with the "Carlton Complex Fire" in the Okanogan region, requiring no WGS management plans.
- 21 FPA/Ns required development or implementation of WGS management plan:
        - 10 FPA/Ns were associated with small landowners.
        - 11 were associated with large or industrial landowners.
    - Of the 21 WGS management plans, 2 included less than ideal WGS protection measures (e.g. leaving nest trees only, etc.). These 2 were associated with small landowners in Klickitat County.
    - Due to limited staffing and resources, WDFW has not been able to conduct compliance and/or effectiveness monitoring.

OTHER LANDOWNER EFFORTS

Beginning in the fall of 2010, Hancock Forest Management began leading research, along with other cooperators, pertaining to WGSs in Klickitat County. Objectives of the research include: (1) developing a detection probability model for nests, (2) quantifying the relationship between nest counts and squirrel abundance, and (3) evaluating the efficacy of using GPS telemetry to quantify squirrel use in response to forest management. As of December 2015, 28 different forest stands have been evaluated for nest detection probability. Efforts to evaluate the relationship between nest density and animal abundance were completed in 2015. Efforts are on-going to analyze and summarize the trapping mark / recapture data.

In 2015, WDFW began collaborative discussions with SDS Lumber Company about development of a landscape-level management approach for SDS ownership in the Klickitat region. The goal of this landscape plan would be to formally incorporate WDFW's *Priority Habitats and Species Management Recommendations for Western Gray Squirrel (August 2010)* into a Habitat Management Plan (HMP) for SDS lands. Due to workload factors for SDS and WDFW, progress has been slow, but both are committed to continuing development of the HMP in 2016.

PROTECTION BY COUNTIES

Washington's Growth Management Act (RCW 36.70A) requires that local jurisdictions protect critical areas, including fish and wildlife habitat conservation areas. Regulations (WAC 365-190-130(4)(a)) specify that counties should identify and classify habitat for federal and state listed and sensitive species and should utilize WDFW's Priority Habitats and Species (PHS) database when doing so. The PHS database contains GIS location data for Western Gray Squirrels and is routinely requested by counties to support their land use planning. This is the same data that WDFW biologists use to screen FPA/Ns and other proposals going through the State Environmental Policy Act process for potential project impacts to the Western Gray Squirrel.

WDFW PERIODIC STATUS REVIEW FOR WESTERN GRAY SQUIRREL

In January 2016, WDFW's periodic status review for the WGS was presented to the Fish and Wildlife Commission for action. Because of the species' relatively small total population size, continuing threats, and a lack of information suggesting that any of the three populations have either reached the downlisting goals of the recovery plan or substantially declined since 2005, the Commission's decision was that the WGS remain a state threatened species in the state of Washington. Ongoing surveys will provide information to better clarify current population levels and to assess the status of the species and their habitat for the next scheduled periodic status review.

2015 WDFW SURVEYS AND CONSERVATION EFFORTS

Population/Habitat Surveys

Several population monitoring and research efforts have been recently initiated for WGS in Washington. These include: (1) A state-wide, three-year (2015-2017) monitoring project using hair-sampling tubes to detect the distribution of the WGS and to factor into estimates of their abundance; and (2) Research pertaining to the effects of forestry practices on WGS populations at Joint Base Lewis McChord (JBLM). Within the next three years, WDFW also intends to: (1) conduct an evaluation of habitat change in Klickitat County, and (2) conduct an evaluation of the impacts of recent wildfires on WGS habitat in the North Cascades (along with other partners).

Conservation Actions

WGS recovery and management actions by WDFW include: (1) the review of FPAs that may impact the species and its habitat, and preparation of management plans for willing landowners, including *WDFW's Western Gray Squirrel PHS Management Recommendations* on a site-specific basis; (2) the thinning of forest understory vegetation on the Klickitat Wildlife Area to enhance WGS habitat and reduce the threat of large wildfires; (3) advising DNR staff on measures for enhancing WGS habitat on DNR lands; (4) advising JBLM forest land management staff on habitat management activities affecting the species; and 5) the preparation of professional scientific manuscripts describing the ecology and conservation of WGSs, competition with eastern gray squirrels, and population modeling.

SUMMARY

All proposed forest practice activities identified as potentially having an impact to WGS were screened by WDFW and DNR. WDFW staff conducted nest surveys and worked with

all landowners, having presence of squirrels or nests on their land or harvest unit, to develop voluntary management plans. In January of 2016, WDFW completed a formal periodic status review of the species. Because of the species' relatively small total population size, continuing threats, and a lack of information suggesting that any of the three populations have either reached the downlisting goals of the recovery plan or substantially declined since 2005, the Washington State Fish and Wildlife Commission took action that the WGS remain a state threatened species in the state of Washington. Ongoing surveys will provide information to better clarify current population levels and to assess the status of the species and their habitat for the next scheduled periodic status review. These data and continued tracking of FPAs and management plans will allow WDFW and DNR to monitor and evaluate the effectiveness of the voluntary protection approach and to provide recommendations, as needed, on possible changes or improvements to forest practices protection strategies.

William Weiler Stewardship
[redacted]

April 20, 2016

Patricia Anderson Forest Practice Board Rules Coordinator
1111 Washington St., SE
PO Box 47012
Olympia, WA 98504-7012

Dear Ms. Anderson:

Subject: **Petition to the Forest Practices Board for New Rules for the Conservation of the State Threatened Western Gray Squirrel**

Under WAC 222-08-100, (RCW 34.05) Washington citizens are allowed to petition the Forest Practice Board to consider new rules. This petition specifically requests adding the western gray squirrel conservation measures to rules to 222-10-040 (1) and (2) and to re-instate former western gray squirrel guidelines into (3) in order to conserve the state threatened western gray squirrel.

The western gray squirrel was listed as state threatened species in 1993. Even before the listing, according to WDFW, "Beginning in the mid-1980s, western gray squirrel habitat in south-central Washington has been logged at an accelerated rate due to a strong timber market and attempts to salvage beetle and drought-killed ponderosa pine (Pinus ponderosa). To address this threat, in 1996 the Washington Forest Practices Board established guidelines for commercial harvest within areas occupied by western grey squirrels. These guidelines were designed to protect existing nest trees and provide for retention of mast-producing trees and corridors to water sources within sites used by squirrels." (Surveys for Western Gray squirrel Nests on Sites Harvested under Approved Forest Practice Guidelines, WDFW. 2004).

From documents obtained from WDFW, it is clear that when individuals and timber companies followed the guidelines, western gray squirrel habitat was successfully protected. (Attachment 1 WDFW Habitat Biologist letter), and that "damage to public resource" was threatened when the former Western Gray Squirrel Guidelines were not implemented (Attachments 2 and 3 WDFW Habitat Biologist letters).

In addition, WDFW research undertaken in 1999 determined the following research results: "In the spring of 1999 we began revisiting sites that had been harvested under approved forest practice applications for the purpose of documenting post-harvest nesting activity by western gray squirrels. Our objective was to address two questions of direct relevance to current nest protection guidelines: 1) does timber harvest affect nesting activity of western gray squirrels?,

and 2) are operators complying with the current voluntary guidelines? Our approach was to resurvey sites that had been surveyed in prior years and document change in number of active nests. We resurveyed 10 sites that had been surveyed for western gray squirrels and subsequently harvested for timber, and 10 sites that had been surveyed but not harvested. All nest trees on post-harvest sites were evaluated for quality of protection according to nest protection guidelines. All sites were located within the Klickitat River drainage.

Examination of nests marked during pre-harvest surveys revealed that operators **frequently were not complying** with nest protection guidelines specified in individual forest practice permits. In some cases the violations appeared to represent disregard for the nest protection measures (e.g., removal of large pine trees in close proximity to nests), whereas in others the violations were less obvious. For example, fair or poor ratings for many of the nest trees on one site resulted from understory thinning of young trees within the 50-ft buffer (Surveys for Western Gray Squirrel Nests on Sites Harvested Under Approved Forest Practice Guidelines. WDFW, 2004).

This petition asks the Forest Practices Board to re-instate the former WDFW Recommended Western Gray Squirrels Management Guidelines (Table 1) that (when enforced) were shown to be effective in protecting western gray squirrel nests and habitat. These guidelines were applied to all harvest units with documented squirrel occurrences. Before harvesting, surveys must be completed and reported to WDFW personnel who are trained in identifying squirrel habitat. Management includes maintenance of nesting areas, providing minimum caopy requirements around nest areas, and retaining connectivity among nest areas. Management guidelines also include seasonal activity restrictions.

Since the release of the WDFW Survey Report in 2004, western gray squirrel populations have been negatively impacted by a series of deleterious events and actions:

1. Boise Cascade Corporation liquidation and subsequent sale of 60,000 acres of western gray squirrel habitat in Klickitat County.
2. Numerous Klickitat County wildfires including the (7,000 acres near Satus Pass), and in the past week, the fires in Okanogan County that destroyed prime habitat in Black and Squaw Canyons for the only western gray squirrel population in northern Washington.
3. Confirmed existence and expansion of eastern gray squirrels in Klickitat County.
4. Extensive forest practices by the Yakama Nation within western gray squirrel habitat in northern Klickitat County/southern Yakima County.
5. No implementation of the former Western Gray Squirrel Management Guidelines also since 2009.

We recommend the Forest Practices Board add the former Western Gray Squirrel Management Guidelines into its rule package in order to ensure conservation of one of the largest squirrels in North America.

Sincerely,

William J. Weiler
Wildlife Biologist

Cc: Tahoma Audubon
Portland Audubon
Conservation Northwest and
Distribution List A

Table 1. Standard guidelines for protecting western gray squirrel habitat in Washington (WDNR 1996).

1) Protect all squirrel nests and nest trees
2) Maintain a no-cut buffer within 50 feet of each nest tree
3) Retain at least 50% canopy coverage
within 400 feet of each nest tree
4) Maintain arboreal "stringers" of trees between nests and other important resources (nearby water sources,
foraging habitat, and other nest trees).
5) Retain all oaks whenever possible
6) Avoid logging, road building, or other noisy activities within
400 ft of all nest trees during the western gray
squirrel breeding season (1 March – 30 September)

STATE OF WASHINGTON
DEPARTMENT OF FISH AND WILDLIFE
5405 NE Hazel Dell Avenue • Vancouver, Washington 98663 • (360) 696-6211 FAX (360) 690-7238

Soda Springs Site 1

November 27, 1996

Pete Stocks, Forester
Department of Natural Resources
P.O. Box 185
Husum, WA 98623

SUBJECT: Forest Practices Application #FP-01-08881, Boise Cascade, 60% cut on 185 acres in western gray squirrel nesting and foraging habitat, Pts. S 1/2 of Section 21, T05N, R14E, near Canyon Creek, WRIA 30.0069

Dear Pete:

Boise has reported that there are approximately 61 western gray squirrel nests on this property, and you have also reported nest presence.

We concur with your recommendation to apply the standard gray squirrel protection rules to this forest practice, including maintenance the 50 foot no entry buffer around the nest trees, maintenance of at least 50% canopy coverage within the next 350 feet of the nests, etc. These provisions will help to prevent the local extirpation of the species.

Please call me at (360) 835-8831 if you have any questions.

Sincerely,

Carl Dugger
Area Habitat Biologist

cc: Bryan Cowan
Dan Guy
F:FPA/Klickitat

None of the sample plots had trees with an average DBH in excess of 20 inches or less than 15 inches.

The formula assumes minimal damage to the remaining trees during harvest. Also, we did not measure trees less than 12 inches in diameter, because of the company's intent to retain the largest trees. These small trees did contribute to canopy coverage, but the degree of their contribution is nearly impossible to estimate. As stated in the FPA, no harvest should occur within 50 feet of any nest, in order to protect the integrity of the nest tree.

The FPA requires that all leave trees be marked on the bole and root collar with paint for inspection by WDFW prior to harvest. However, we would be willing to accept a flagged, no entry perimeter around a group of nests, as was proposed previously, provided that the perimeter is at least 50 feet from any individual nest. The previously flagged perimeter does not always meet that standard. With such a flagged perimeter, individual leave trees within it would not have to be painted. We will also recommend to DNR that trees within the 50% retention zone (50 to 400 feet from a nest or group of nests) would not have to be individually painted, provided we have written assurance from the company that the operators would be following the spacing guidelines recommended in this letter.

The guidelines that we have developed have been based on experience gained in managing western gray squirrel habitat over the past 5 years, and are designed to provide the minimum level of protection necessary to prevent local extirpation of the species. We appreciate SDS's willingness to work with us to accomplish that goal. Please call me at (360) 835-8831 if you have any questions.

Sincerely,

Carl Dugger

Carl Dugger
Area Habitat Biologist

Enclosure

cc: Pete Stocks, DNR-SE
Frank Backus, SDS Lumber Company
Rich Costello
Timothy Quinn
Jeff Lewis
F:FPA/Klickitat

State of Washington
Department of Fish and Wildlife
2108 Grand Blvd. • Vancouver WA 98661 • (360) 696-6211

October 15, 1998

Eric Keller, Forester
Boise Cascade Corporation
P.O. Box 106
Goldendale, WA 98620

SUBJECT: FPA #2700728, and western gray squirrel management considerations, Canyon Creek, WRIA 30.0069, Section 3, T5N, R14E

Dear Eric:

As we discussed during our recent field visit, it is critical that your surveyors more carefully check for western gray squirrel nests during your field surveys. Two nests, #518 and #519, (see enclosed map) were recently missed by one of your surveyors. We can understand how easy it is to miss these nests, as our own surveyor missed some also, but the species can ill afford such mistakes.

We are also concerned that so many take trees had been marked. Per our agreement, Boise is to maintain 65% canopy coverage within 50 feet of any nest tree, and **50% canopy coverage** within 50 and 400 feet of each nest tree. However, your crew had marked so many take trees that well under 50% canopy coverage would be left following harvest. This could have resulted in a take of a threatened species.

As we discussed, we have developed tree spacing recommendations based on DBH of mixed fir/pine stands similar to the stand at Canyon Creek. The recommendations are as follows:

Average DBH of Trees over 12"	Recommended Average Spacing to Retain 50% Canopy Coverage
14" or less	15'x15'
15"	15'x15'
16"	15'x15'
17"	16'x16'
18"	16'x16'
19"	18'x18'
20"	18'x18'
21" or greater	20'x20'

Letter from WDFW to DNR

average 11 acre home range, within an average of 50% canopy coverage. 400 feet is the approximate radius of a circular 11 acre range. As an alternative, we have recommended in the past that the **best 11 acres of habitat** around a nest be protected by an area containing 50% canopy coverage, but that requires a judgement call that most loggers are not qualified to make, so we haven't pressed the concept.

4. Regarding the comment to retain large mast producing trees, usually live trees do not present an L&I safety hazard if the logging is carefully conducted. Over-emphasis of "hazard trees" may result in unnecessary destruction of valuable forage habitat.

5. The timing requirement normally applies within **400 feet of all nests**, not just 200 feet of **active** nests (It is very difficult to determine just what nests are or are not active, with the exception of remnant nests.). The 400 feet was a minimum standard, based on observations by Susan Foster and other individuals. We have also recommended a minimum 1/4 mile buffer for unusually loud activities such as blasting. In addition, we recommend staying with the current Options A and B, which allow the logger greater flexibility. Option A is the one you described. Option B prohibits operations from February 1 to April 30 and from July 1 to September 15, but allows operations during the month of June, which is sometimes a critical month for operations. It shortens protection during the second breeding season, but offers protection during the early breeding season.

6. As noted above, remnant nests should be protected for three years. Intact, old nests should be protected permanently, since it is nearly impossible to determine whether or not they are being used from time to time. Nests that are not being used will usually deteriorate and turn into remnants over time, and their lack of use usually becomes obvious.

7. All nest locations, including those of remnant nests, should be reported to WDFW using the enclosed data forms.

We are now conducting studies that will help determine, in part, whether our current nest protective standards are adequate, or even over protective. However, it has been my experience in the field that current standards represent the bare minimum necessary to prevent local extirpation of the species. I am particularly uncomfortable with the size of the no entry area. It should probably be expanded to 80 or 100 feet. If DNR wants to provide a higher level of protection, that might be a good place to start.

Sometimes we can reach an equal or higher level of protection with an "alternate plan," but those

WASHINGTON STATE DEPARTMENT OF
Natural Resources

PETER GOLDMARK
Commissioner of Public Lands

MEMORANDUM

April 7, 2016

TO: Forest Practices Board

FROM: Marc Ratcliff
Forest Practices Policy Section Manager

SUBJECT: Board Manual Section 16, *Guidelines for Evaluating Potentially Unstable Slopes and Landforms*

On May 11, I will request the Board's approval of revisions to Board Manual Section 16. These revisions include the work done by the DNR convened qualified expert stakeholder group to address 'items near resolution' for possible inclusion into this section; and staff recommendations for minor clarifications. All amendments are shown as underline strikeout text.

DNR convened the group to review and discuss the information in two of the documents submitted to the Board on 9th November, 2015. In the review of these documents, titled *Complex or Composite Rotational Deep-Seated Landslides* and *Methods for Deep-seated Landslide Runout Assessment*, the group identified three elements for inclusion:

- expanded descriptions on the complexity of movement within deep-seated landslides (DSL);
- LiDAR examples showing DSL features for estimating relative age; and
- the use of LiDAR for identifying past landslide deposits.

The Board accepted the remaining material in these documents for inclusion in the Unstable Slopes Proposal Initiation under review by the Adaptive Management Program.

All TFW Policy Committee representatives were invited to provide a qualified expert to participate in these discussions. Regardless of participation, revised drafts were distributed to committee representatives as progress continued.

I will be available to provide further information at the May meeting. Should you have any question in advance of the meeting, I can be reached at 360.902.1414 or marc.ratcliff@dnr.wa.gov.

MR

Section 16
Guidelines for Evaluating
Potentially Unstable Slopes and Landforms

PART 1. INTRODUCTION 3
PART 2. LANDSLIDE TYPES IN WASHINGTON....4
2.1 Landslide Types and Effects 5
Table 1. Landslide Classification 6
Figure 1. Illustrations of the major types of landslide movement (all from Highland and Bobrowsky 2008, except the earth flows illustration is from U.S. Geological Survey 2004). 7
2.2 Shallow Landslide Types 8
Figure 2. Debris flow (DNR 2000). 8
Figure 3. Impounded water caused by landslide dam. 9
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). 10
2.3 Deep-Seated Landslides 10
Figure 5. Rotational deep-seated landslide. Rotational displacement of blocks of soil commonly occur at the head of the landslide (adapted from USGS 2004)....11
Figure 6. Left: Schematic of sequential instability within a rotational slide. 12
PART 3. SLOPE FORM 13
Figure 7a. Slope configurations as observed in map view....14
Figure 7b. Slope configurations as observed in profile: convex, planar, and concave. 14
PART 4. CHARACTERISTICS OF UNSTABLE AND POTENTIALLY UNSTABLE SLOPES AND LANDFORMS....15
4.1 Bedrock Hollows, Convergent Headwalls, Inner Gorges 15
Figure 8. Typical hillslope relationships between bedrock hollows, convergent headwalls, and inner gorges (drawing by Jack Powell, DNR 2003). 15
Figure 9. Common hillslope relationship: bedrock hollows in convergent headwalls draining to inner gorges (photo and drawing by Jack Powell, DNR 2003). 16
Figure 10. Bedrock hollow and relationship to inner gorges (drawing by Jack Powell, DNR 2003). 17
Figure 11. Evolution of a bedrock hollow following a landslide (adapted from Dietrich et al. 1988; drawing by Jack Powell, DNR 2004). 17
Figure 12. Bedrock hollow slopes are measured at the steepest part of the slope, rather than along the axis (drawing by Jack Powell, DNR 2004). 18
Figure 13. Example of leave tree strips protecting unstable slopes 19
(photo by Venice Goetz, DNR 2004)....19
Figure 14a. Stereo pair of a clearcut convergent headwall in Pistol Creek basin, North Fork Calawah River, Washington. 19
Figure 14b. Rotated topographic map and outline of convergent headwall displayed in the stereo pair of Figure 14a (Hunger Mountain and Snider Peak USGS 7.5' quadrangles). 20
Figure 15. Convergent headwall in North Fork Calawah River, Washington. 20
Figure 16. Cross-section of an inner gorge. This view emphasizes the abrupt steepening below the break-in-slope (drawing from Benda et al. 1998). 21
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 by Laura Vaugeois, DNR 2004). 22

4.2 Toes of Deep-Seated Landslides 23
Figure 18. Deep-seated landslide showing the head scarp, side-scarps, body, and toe. 23
4.3 Groundwater Recharge Areas for Glacial Deep-Seated Landslides 24
Figure 19a. Extent of continental ice sheet in the Pacific Northwest (DNR 2014). 24
Figure 19b. Continental and alpine glaciation in western Washington (DNR 2014). 25
Figure 20. Hydrologic budget of a hillslope (University of Colorado). 26
Figure 21. Diagram illustrating failure surface resulting from groundwater recharge to a glacial deep-seated landslide (DNR 2014). 27
4.4 Outer Edges of Meander Bends 28
Figure 22. 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). 28
4.5 Areas Containing Features Indicating the Presence of Potential Slope Instability 28
PART 5. IDENTIFYING POTENTIALLY UNSTABLE SLOPES AND LANDFORMS 30
5.1 Office Review 31
5.1.1 General Practitioner's Office Review 31
5.1.2 Qualified Expert's Office Review 32
5.1.3 Remote Sensing Tools Available for Office Reviews 33
5.1.4 LiDAR Use in Identifying Potentially Unstable Landforms 33
Figure 23. Example of a dormant glacial deep-seated landslide as seen in different types of remotely sensed data and in varying resolution quality: 35
Figure 24. LiDAR image comparison between two deep-seated landslide scarps with the same resolution showing (a) subdued topography and (b) crisp topography. 36
Figure 25. Large slump feature showing displaced (deflected) streams within the landslide mass and sag ponds impounded by ridges (DNR 2016). 37
Figure 26. LiDAR image showing channel incision within a large deep-seated slump feature in the Tolt River valley, King County (DNR 2016) 37
5.2 Field Assessment 37
5.2.1 General Practitioner's Field Assessment 37
5.2.2 Qualified Expert's Field Assessment 38
5.3 Delineating Groundwater Recharge Areas for Glacial Deep-Seated Landslides 40
Figure 27a. Glacial deep-seated landslide. The dash-lined polygon is an approximate delineation of a groundwater recharge area based on LiDAR data (DNR 2014). 41
Figure 27b. Hillslope cross-section (A-A' in figure 27a) derived from 2-meter DEM of a glacial deep-seated landslide showing the groundwater recharge area, geologic units, and generalized groundwater flow paths (DNR 2014) 41
5.3.1 Office Review for Groundwater Recharge Areas 42
5.3.2 Field Assessment for Groundwater Recharge Areas 42
PART 6. ADDITIONAL ANALYSES FOR UNSTABLE SLOPES 43
6.1 Deep-Seated Landslide Activity Assessment 44
Table 2. Guidelines for estimating deep-seated landslide activity level based on vegetation and morphology 45
6.1.1 Glacial Deep-Seated Landslide Assessment 45
6.2 Quantitative Field Assessment Methods for the Qualified Expert's Subsurface Investigations 46
6.3 Water Budget and Hydrologic Contribution to Glacial Deep-Seated Landslides 47
6.3.1 Modeling Evapotranspiration 48
6.3.2 Groundwater Recharge and Groundwater Flow Modeling 49
6.4 Computational Slope Stability Assessment Methods 49
6.5 Runout and Delivery Assessment 50

6.5.1 Landslide Types Associated with Rule-Identified Landforms 52
Table 3. Landslide types associated with rule-identified landforms. 52
6.5.2 Factors Influencing Debris Flow Runout 53
Figure 28. Debris flow characteristics relative to channel slope (adapted from Benda et al. 1998). 53
Figure 29. Slope distributions for depositional zones (discrete and gradual), transitional zones, erosional zones (incised and bedrock), and initiation sites for debris flows (from May 2002). 54
6.5.3 Debris Fan Formation 56
Figure 30. Relation between average fan slope (S_f) and Melton number (M_E) for European landslide datasets. 57
6.5.4 Methods and Models for Predicting Shallow-Rapid Landslide Runout and Delivery 57
Figure 31. Cross section showing travel distance, travel distance angle, and slope geometry (Hunter and Fell 2003). 59
Figure 32. From USGS 7.5' Deadmans Hill Topographic Quadrangle. 62
6.5.5 Runout Mitigation Strategy: Barrier Trees 62
Figure 33. Debris flow path (from bottom to top of the photo) showing width changes from traveling through an older forest stand (Guthrie 2010) 63
6.5.6 Deep-Seated Landslide Runout Evaluation 63
Figure 34. LiDAR derived image revealing past glacial deep-seated landslide deposits in the Stillaguamish River valley. The crosshatch polygon marks the approximate extent of the 2014 SR 530 landslide. (DNR 2016). 64
PART 7. SYNTHESIS OF RESULTS, EVALUATION, AND GEOTECHNICAL REPORTS 64
7.1 Synthesis and Evaluation 64
7.2. Geotechnical Reports 65
GLOSSARY 68
REFERENCES 71
APPENDIX A – MEASUREMENTS OF SLOPE GRADIENTS 83
APPENDIX B – LANDSLIDE PROVINCES IN WASHINGTON 85
APPENDIX C – MAPS AND SURVEYS 87
APPENDIX D – EARTH IMAGERY AND PHOTOGRAMMETRY 89
APPENDIX E – LiDAR: PROCESSING, APPLICATIONS, AND DATA SOURCES 90
APPENDIX F – TECHNICAL REPORTS AND RESOURCES 92
APPENDIX G – PHYSICAL DATABASES 93
APPENDIX H – HYDROLOGIC PROPERTIES OF SOILS 94

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~~serves as 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. 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, and potential runout distance.

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~~, plus 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 affects slope stability (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~~5 will be useful to both general practitioners and qualified experts for landslide runout assessments. The remainder of Parts 5 and 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~~ The manual ends with a glossary of terms that may not be familiar to many readers, 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

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

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 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~~ Diverting streams from one basin to another 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.

[2] Robison 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		
		Bedrock	Soils	
			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		

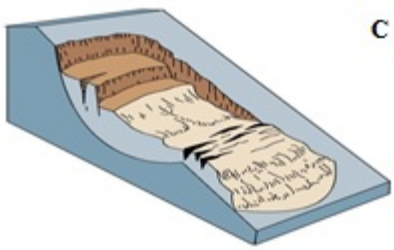
~~Thus, l~~Landslides are described with two terms that refer to the type of material and method of movement (rock fall, debris flow, and so forth).Materials in a landslide mass are either rock or soil (or both) and may include organic debris. In this context, soil is composed of sand-sized or finer particles and debris is composed of coarser fragments. The types of movement describe the actual internal mechanics of how the landslide mass is displaced: fall, topple, slide, spread, or flow. The types of landslides commonly found in forested areas in Washington are slides~~,~~ and 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 (rock fall, 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.

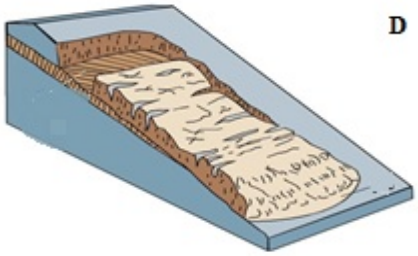
[3] The terms used in the "Predominately Fine" column are seldom used in the forest environment where coarse materials including wood are common.

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.

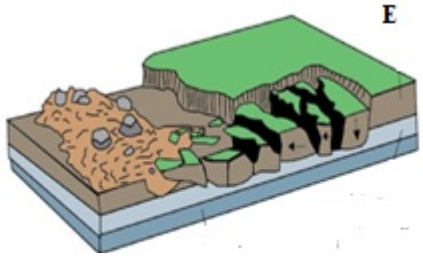
Topples: Landslides where the forward rotation of a mass of rock or soil breaks away or 'topples' from the slope. Their failure rates range from extremely slow to extremely fast.



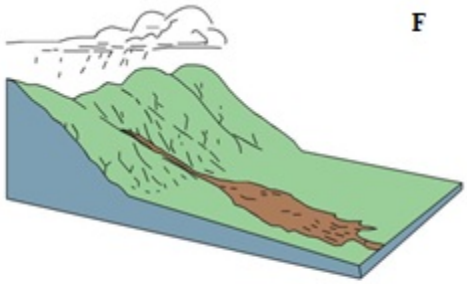
Rotational slides: Landslides where the surface of rupture is concave-up and the slide movement is rotational about an axis that is parallel to the contour of the slope



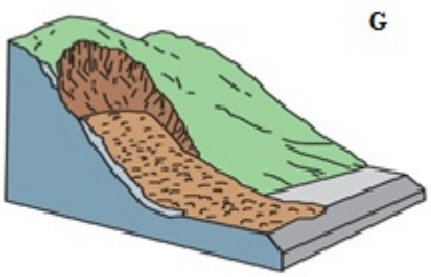
Translational slides: Landslides where the surface of the rupture is roughly planar with a surface roughly parallel to the ground surface. These are called rock slides, block glides, slab slides, or debris slides.



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 unconfined slopes.

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 Bobrowsky 2008, 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. Reduced root strength in slide prone areas resulting from timber harvest, fire and other natural processes can contribute to slope failure. Additionally, t~~T~~he amount of water and the materials contained within shallow landslides can 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 by sliding or rolling forward. The results are irregular hummocky deposits that are typically poorly sorted and non-stratified. 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 (6%), or the valley bottom becomes wider and allows the flow to spread out. Hyper-concentrated floods may travel greater distances and on lower gradient 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) described a debris avalanche as morphologically similar to a snow avalanche. Debris avalanches may enter steep drainage channels and become debris flows.

[4] Pierson and Scott 1985.
[5] Iverson and Reid 1992.

Therefore, the term debris avalanche ~~should be~~ is reserved for events that remain poorly channeled without a defined recurrent path or 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, or the active floodplain if present.

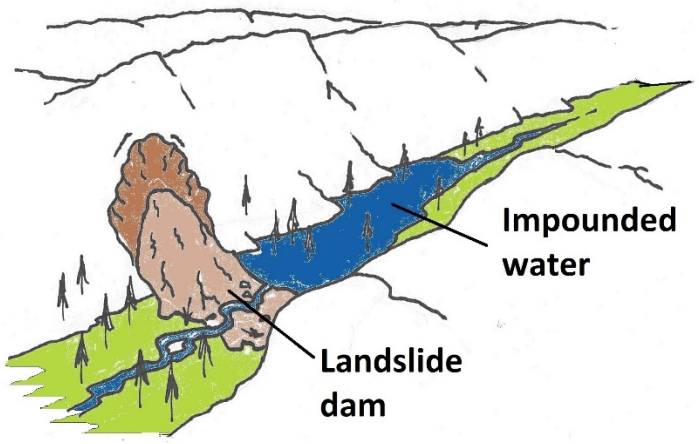


Figure 3. Impounded water caused by landslide dam.

Debris flows and dam break floods can occur in any 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 areas, deposit debris onto salmonid spawning areas, elevate turbidity, adversely affect water quality downstream, and threaten public safety.

[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~~slope, spread into 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~~slope and the river, the debris flow affected a county road, residential~~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~~ trees ~~areas~~ left in the ~~slide-prone~~ bedrock hollows and 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). 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 slides may respond to rainfall events over periods of days to weeks, or weather patterns over months to years or even decades.[9]

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 lack connectivity 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. Larger 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.~~

[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 sideslopes) and toe edges.

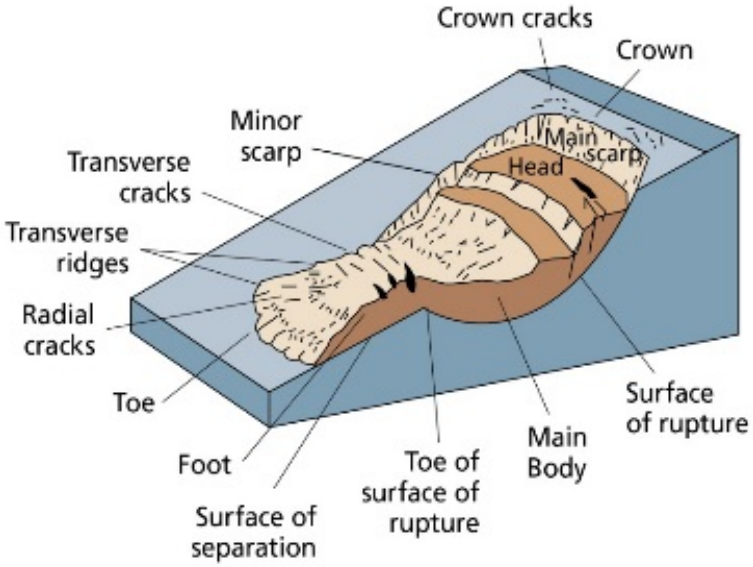


Figure 5. Rotational deep-seated landslide. Rotational displacement of blocks of soil commonly occur at the head of the landslide (adapted from USGS 2004).

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, parts of which ~~that may~~ can be intermittently active for hundreds of years or more.[11] The bodies and toes of deep-seated landslides and earth flows ~~are made up~~consist of incoherent collapsed materials ~~that were~~ weakened from previous movement. ~~of the materials~~ Because the original mass experienced movement, the disrupted portions of a landslide ~~and therefore~~ may be subject to secondary deep landsliding or 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 sideslopes along marginal stream channels within the bodies of deep-seated landslides.

Purely rotational slumps (Figure 5) in cohesive soils are rare in nature because the shape of the rupture surface usually departs from constant curvature.[12] Instead, as the host slump moves, internal deformation during transport may cause segmentation of the failure surfaces, resulting in the

[10] Roering et al. 2005.
[11] Bovis 1985; Keefer and Johnson 1983.
[12] Hungr 2014.

evolution of secondary landslides in hummocky terrain, which are more prone to saturation and movement.[13] Landslides may fail sequentially, exhibiting multiple instabilities containing smaller secondary landslides within a host landslide during a single event, from secondary movements over time, or a combination of both. The term compound is used by Cronin (1992) to describe large host landslides that encompass smaller secondary slides.

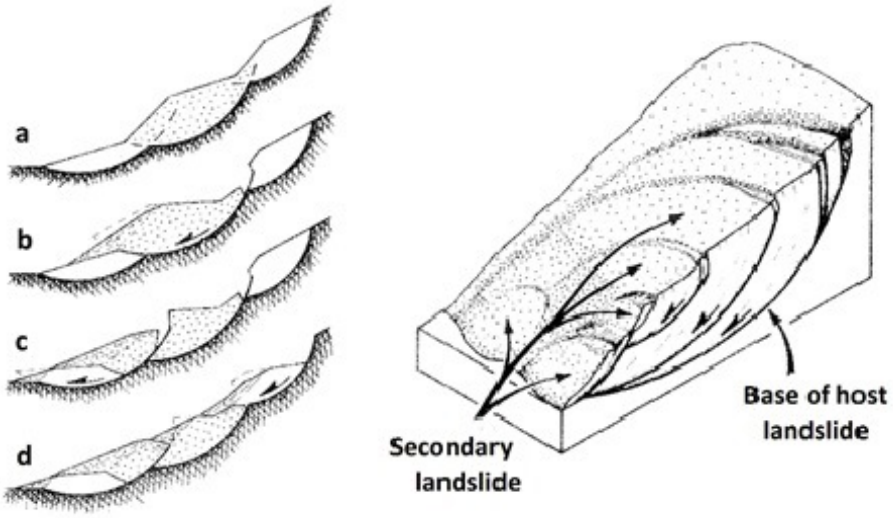


Figure 6. Left: Schematic of sequential instability within a rotational slide. The original slope configuration a) initially at rest until sliding movement begins, at which time the b) middle (stippled) slump mass loads the lower slide, removing support from the upper scarp. As the lower landslide mass becomes active, c) it may rotate outward, causing the d) unsupported upper slide mass to fail. Right: Block diagram of a compound landslide, showing a variety of secondary landslides within the host landslide (adapted from Cronin, 1992).

Compound deep-seated landslides are found in glaciated and non-glaciated terrain and some have the potential to become highly mobile failures. The SR 530 landslide in the Stillaguamish River valley is an active rotational glacial deep-seated failure that hosted both a debris flow/avalanche and a rotational slide[14] and raised awareness regarding the potential range of activity within large failures particularly in areas underlain by glacial sediments. Unlike shallow (translational) landslides and debris flows that may occur repeatedly and are better understood, secondary failures within compound landslides are less commonplace and present an unrecognized hazard potential.

Triggering mechanisms of deep-seated landslides can result from over-steepening of the toe by natural means such as glacial erosion or fluvial undercutting (channel incision), earthquakes, or anthropogenic activities such as excavating for land development.[15] 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.[16] Initiation or re-initiation of such landslides has also been associated with increases in groundwater levels[17] from individual storms or in response to seasonal accumulation from rainfall or snowmelt,

[13] Cronin 1992.
[14] Keaton et al. 2014.
[15] Schuster and Wieczoreck 2002.
[16] Cronin 1992.
[17] van Asch et al. 2005.

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 process used to identify how groundwater 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, deep-seated landslide movement can be diverse and influenced by geomorphic and hydrologic factors, and is not always associated with up-gradient groundwater sources.[18] Generally, avoiding the following practices will minimize human-caused re-initiation or 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.

Recent improvements in high-resolution LiDAR (Light Detection and Ranging) have proved to be a highly effective tool for identifying the footprint of dormant and active deep-seated landslides. Larger 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. For information on how LiDAR is used for identifying potentially unstable landforms see Parts 5.1.4 and 6.5.6.

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 identifying 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 ~~6~~7a). 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 ~~6~~7b).

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.

[18] van Asch et al. 2009.

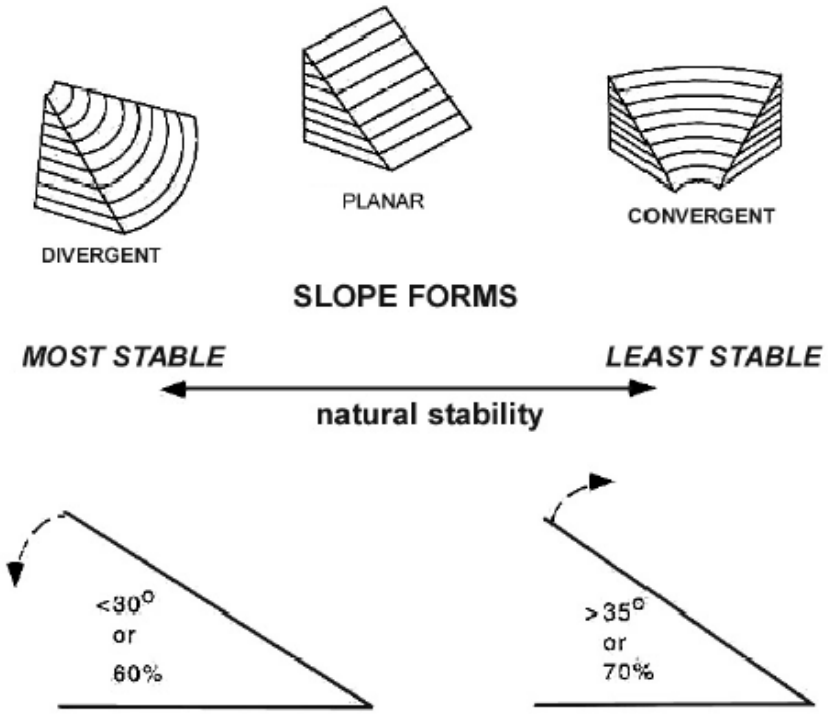


Figure ~~6~~7a. Slope configurations as observed in map view.

Figure ~~6~~7a 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.[19]

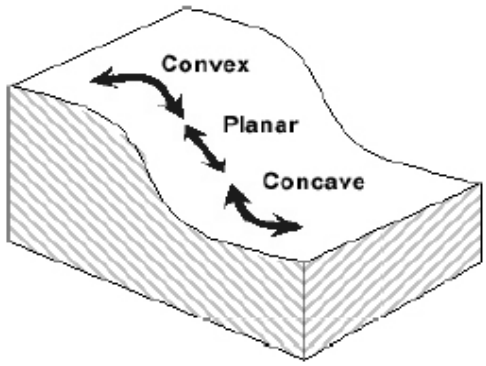


Figure ~~6~~7b. Slope configurations as observed in profile: convex, planar, and concave. These terms are used in reference to up and down directions on a slope (drawing by Jack Powell, DNR 2004).

[19] 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 (degrees and percent) are specifically provided. 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~~8 and ~~8~~9.

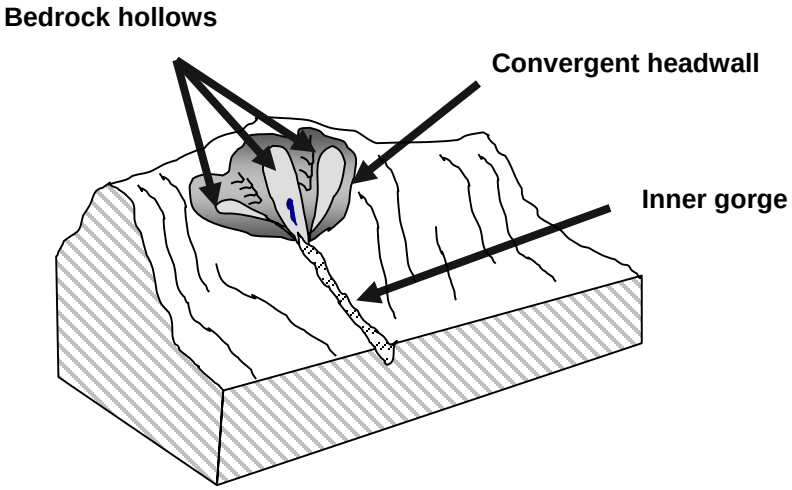


Figure ~~7~~8. Typical hillslope relationships between bedrock hollows, convergent headwalls, and inner gorges (drawing by Jack Powell, DNR 2003).

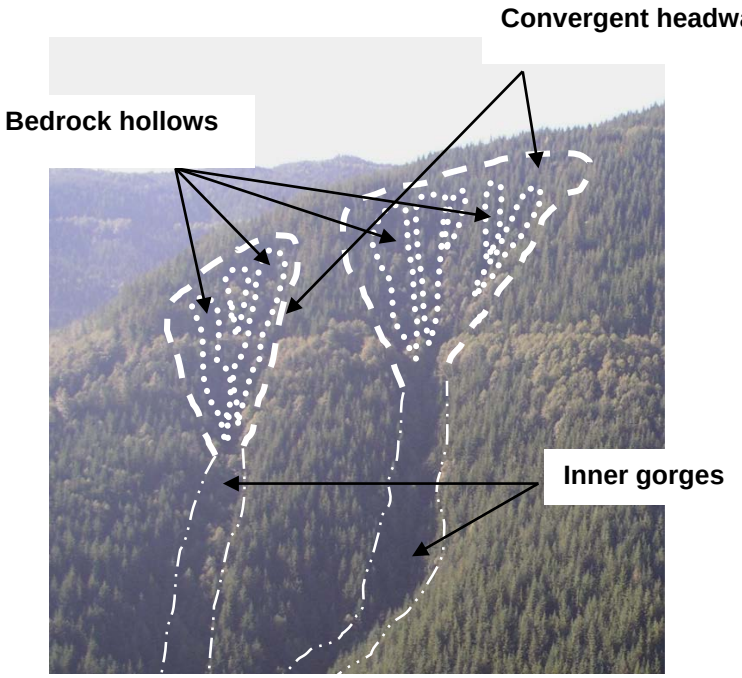


Figure ~~8~~9. Common hillslope relationship: bedrock hollows in convergent headwalls draining to inner gorges (photo and drawing by Jack Powell, DNR 2003).

Bedrock hollows are also called colluvium-filled bedrock hollows, zero-order basins, swales, bedrock depressions, or simply hollows.[20] 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 ridgeline. 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~~10).

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

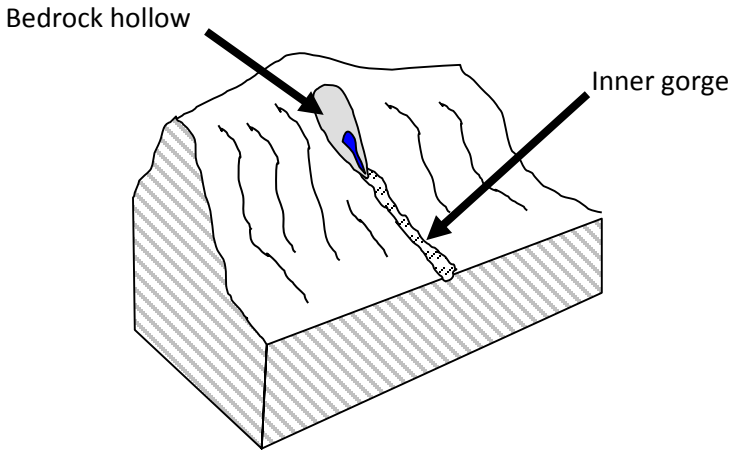


Figure ~~9~~10. Bedrock hollow and relationship to inner gorges (drawing by Jack Powell, DNR 2003).

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 adjacent 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~~ 11 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 6 feet, 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.

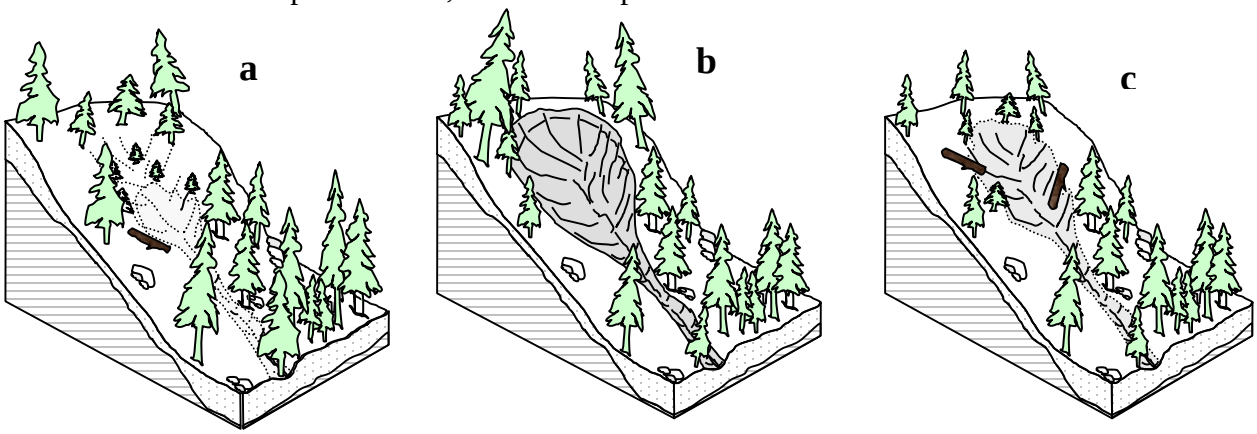


Figure ~~10~~11. Evolution of a bedrock hollow following a landslide (adapted from Dietrich et al. 1988; drawing by Jack Powell, DNR 2004).

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~~12).

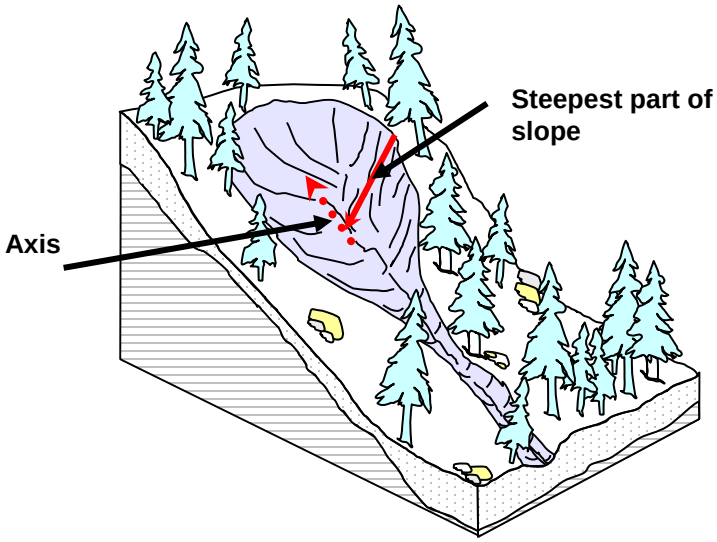


Figure ~~11~~12. Bedrock hollow slopes are measured at the steepest part of the slope, rather than along the axis (drawing by Jack Powell, DNR 2004).

Vegetation can provide 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[21] (Figures 4 and 1~~2~~3). 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.

[21] Montgomery et al. 2000.

Figure 1~~2~~3. Example of leave tree strips protecting unstable slopes (photo by 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 1~~3~~4a and 14b).

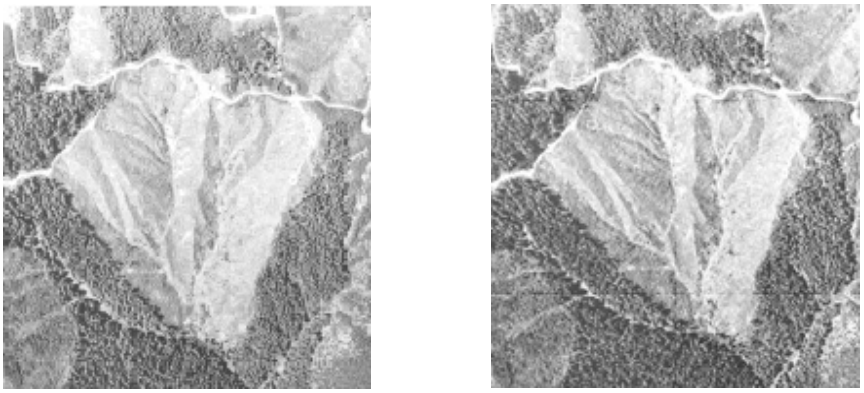


Figure 1~~3~~4a. Stereo pair of a clearcut convergent headwall in Pistol Creek basin, North Fork Calawah River, Washington.

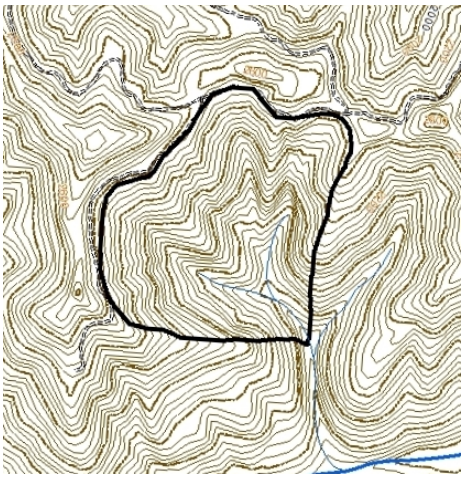


Figure 14b. Rotated topographic map and outline of convergent headwall displayed in the stereo pair of Figure 1~~3~~4a (Hunger Mountain and Snider Peak USGS 7.5' quadrangles).

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. The convergent headwall in Figure 15 contains approximately 25 bedrock hollows ~~today~~ (not visible through the canopy), and eons of high erosion 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 form below headwalls are formed by repeated debris flow erosion. Debris fans are commonly found at the base of their slopes.

Inner gorges are canyons created by a combination of stream down-cutting and mass movement on slope walls.[22] Inner gorges are characterized by steep, straight, or concave sideslope walls that commonly have a distinctive break in slope (Figure 16). Debris flows shape inner gorges by scouring the stream, undercutting sideslopes, and/or depositing material within or adjacent to the channel (Figure 17). Inner gorge sideslopes 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.

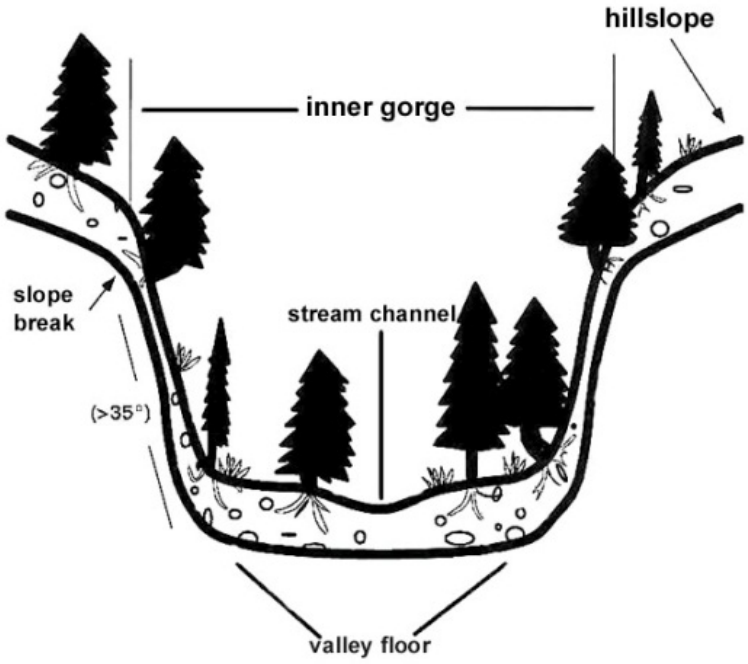


Figure 16. Cross-section of an inner gorge. This view emphasizes the abrupt steepening below the break-in-slope (drawing from Benda et al. 1998).

[22] Kelsey 1988.

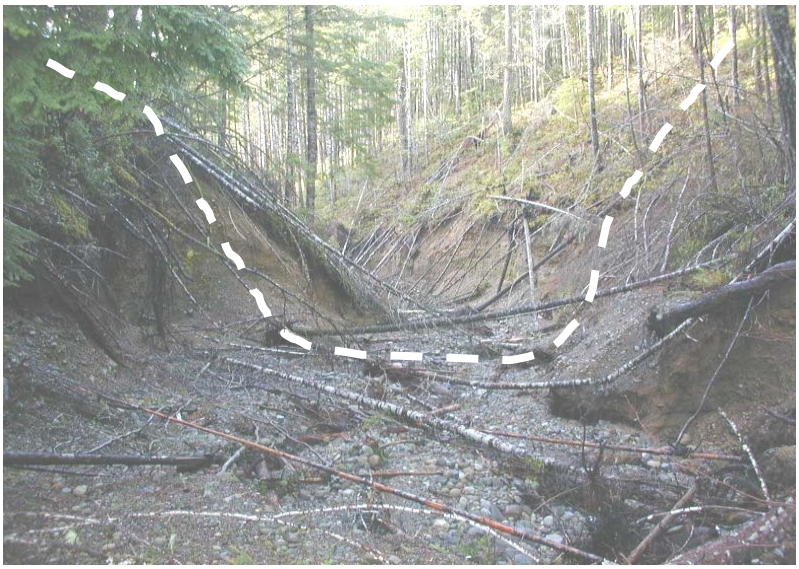
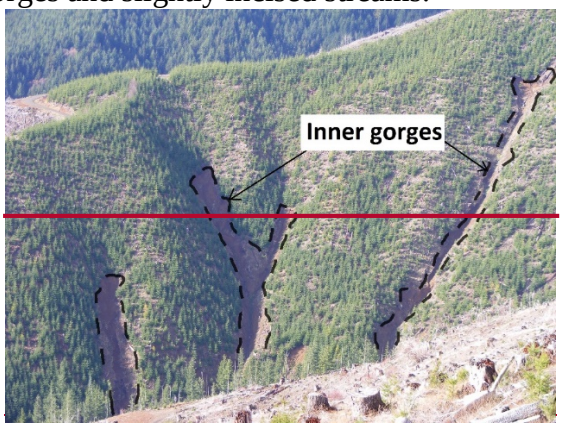


Figure 17. Photograph showing how debris flows help shape features related to inner gorges: over-steepened canyon wall; U-shaped profile; buried wood; and distinctive break-in-slope along margins of inner gorge (photo by Laura Vaugeois, DNR 2004).

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 side. 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 by 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 1~~1~~2).

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 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 provides soil stability and lessens 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

The toe of a landslide is the lower, displaced material most distant from the place or origin or main scarp. 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 1~~9~~8 show the toe in relation to other landslide features.

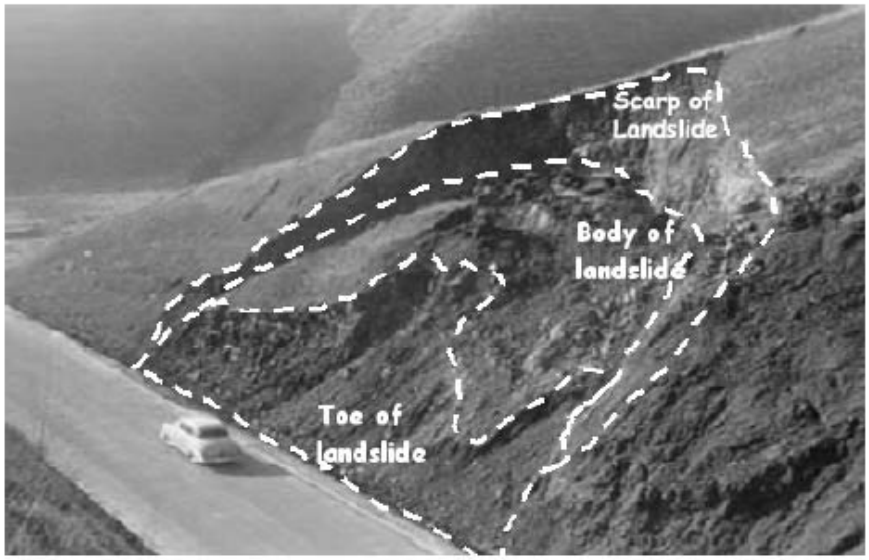


Figure 1~~9~~8. Deep-seated landslide showing the head scarp, side-scarps, body, and toe. Some of the toe has been removed in building and maintaining the highway (adapted from a USGS photo).

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 1~~9~~8 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 landslide. Because deep-seated landslides occur 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.

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 are 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.[23]

Glacial deep-seated landslides 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 ~~20~~19a), and the alpine glacial deposits (Figure ~~20~~19b) are found in mid-to-high elevation mountain ranges.[24]

Figure ~~20~~19a. Extent of continental ice sheet in the Pacific Northwest (DNR 2014).

[23] Terzhagi 1951.
[24] Booth et al. 2003; Booth et al. 1994; Thorsen, R.M. 1980; Barnosky 1984; Heusser 1973; Crandall 1965.

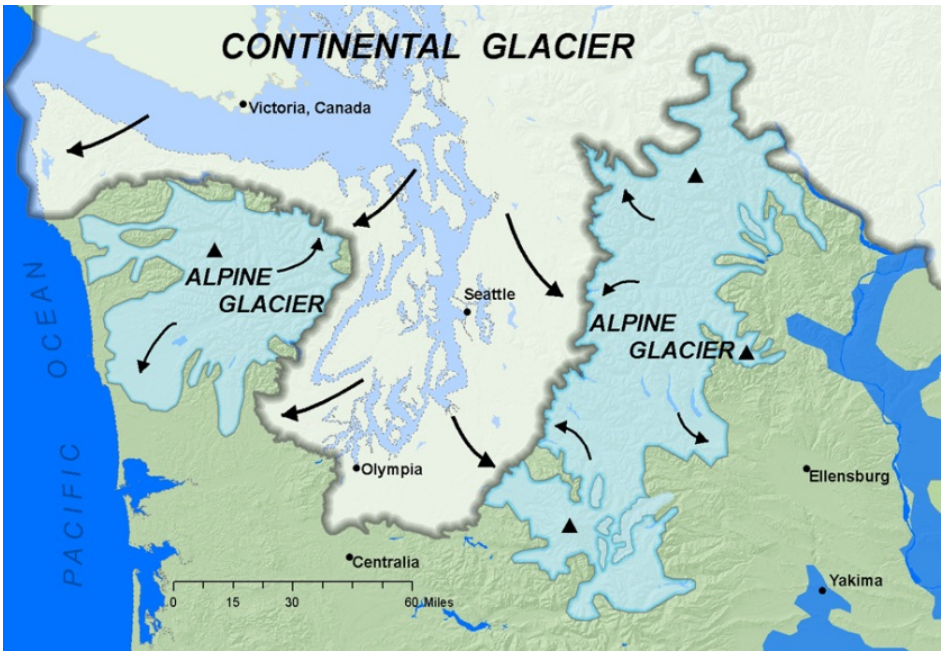


Figure ~~20~~19b. Continental and alpine glaciation in western Washington (DNR 2014).

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 were deposited on the surface of glacial deposits or became 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) deposited or 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 2~~1~~0). 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.

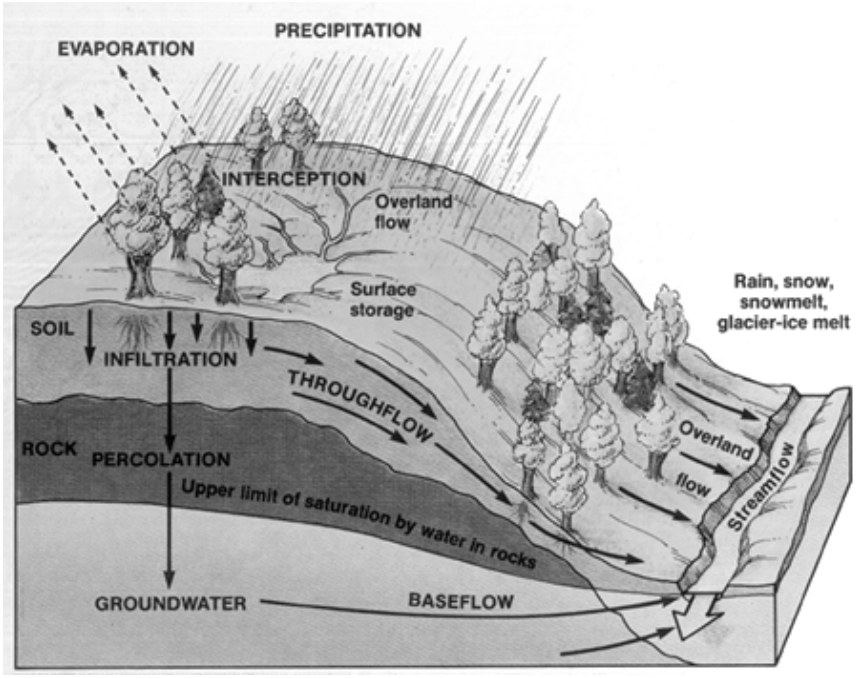


Figure 2~~1~~0. Hydrologic budget of a hillslope (University of Colorado).

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.[25] 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 2~~2~~1). This is a common configuration of the glacial deposits in much of the Puget Lowlands (e.g., landslides in Seattle)[26] and in the North Cascades foothill river valleys (e.g., the Stillaguamish River valley)[27], 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)

[25] Bauer and Mastin 1997; Vaccaro et al. 1998.
[26] Gerstel et al. 1997.
[27] Benda et al. 1988.

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. Saturated conditions can increase soil pore water pressure and reduce the soil strength causing landslide failure planes to 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.

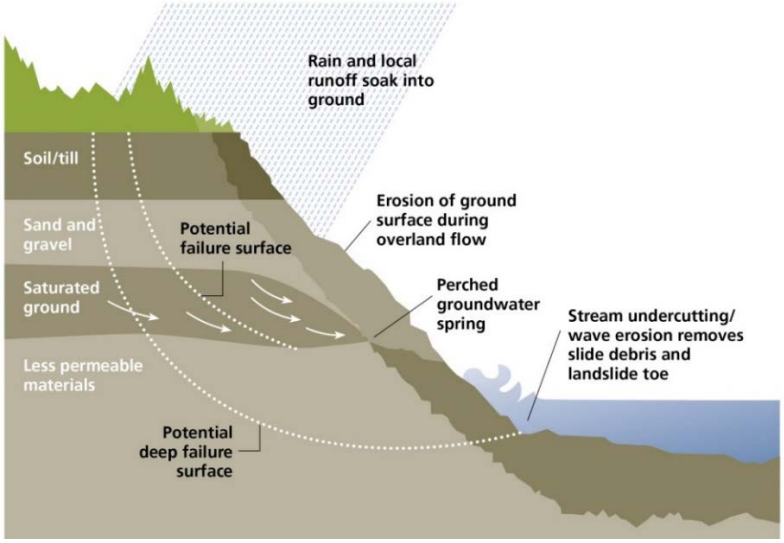


Figure 2~~2~~1. Diagram illustrating failure surface resulting from groundwater recharge to a glacial deep-seated landslide (DNR 2014).

A classic example of a geologic setting where glacial deep-seated landslides are common is in the Puget Sound lowlands where Esperance Sand or Vashon advance outwash overlies Lawton Clay. In this setting, groundwater recharge from precipitation infiltrates downward within the 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.[28]

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 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.

[28] Tubbs 1974.

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 LiDAR data, 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.[29] 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.

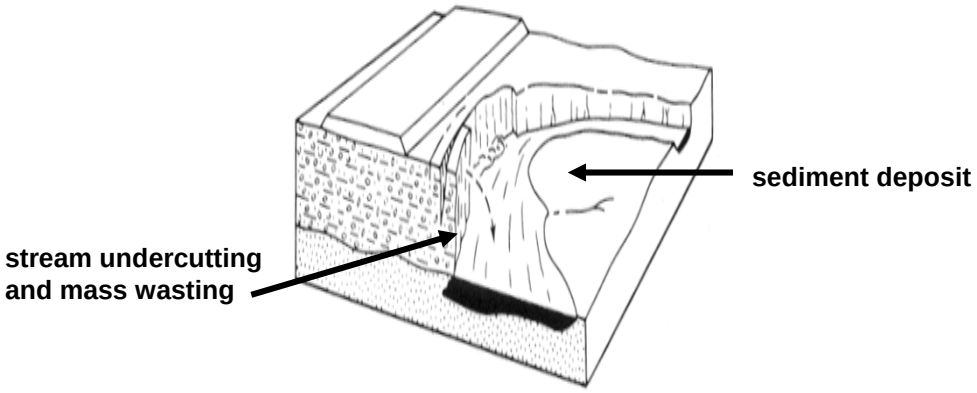


Figure 2~~3~~2. Outer edge of a meander bend showing mass wasting on the outside of the bend and deposition on the inside of the bend (adapted from Varnes 1978).

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 that 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 33 degrees (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 35 degrees (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

[29] Schuster and Wieczorek 2002.

watershed analyses and landslide hazard ~~zonation~~ projects have demonstrated that these features are unstable ~~-~~and routinely recognized and protected as ~~under~~ category E landforms.

Relatively large and recent topographic indicators of such features can be observed from 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 steep slopes. This condition may mark the location of a debris flow, or the headwall or sidewall of a slide or evidence of active movement.
- Benched or back tilted surfaces, especially below crescent-shaped headwalls, indicative of ~~a~~ rotational movement within the slide.
- Hummocky topography at the base of steep slopes. This may mark the accumulation zone (runout area) for a flow or slide.
- Boulder piles or 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.
- Presence of debris fans at the mouths of canyons indicating past runout events.

Hydrologic indicators

- Sag ponds (ponded water) in ~~a~~ tension cracks or low depressions ~~on a landslide body).~~ ~~Ponding of water in irregular depressions in undrained swampy or~~ in poorly drained areas on the hillslope ~~above the valley floor~~or landslide body. 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 landsliding, 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.
- Patterns of disturbed vegetation such as 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[30]; Hillslope Stability and Land Use[31]; Landslides, Processes, Prediction and Land Use[32]; and Slope Stability Reference Guide for National Forests in the United States[33].

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.

The steps in the investigation process typically include an office ~~screening~~review (5.1) and field assessments (5.2 and 5.3). If desired by the landowner or required by rule, further geotechnical assessments may include those described in Parts 6 and 7 as follows:

- deep-seated landslide activity assessment (6.1);
- glacial deep-seated landslide assessment (6.~~2~~1.1);
- quantitative field assessment methods for qualified experts' subsurface investigations (6.~~3~~2);
- water budget and slope stability modeling assessments for glacial deep seated landslides (6.~~4~~3);
- slope stability sensitivity assessment (6.~~5~~4);
- runout and delivery assessment (6.~~6~~5);
- 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.[34] The following is a general overview of the typical sequence and elements of a slope-stability assessment:

[30] Chatwin et al. 1994.
[31] Sidle et al. 1985.
[32] Sidle and 2006.
[33] Hall et al. 1994.
[34] Turner and McGuffy 1996.

1. Preliminary fact-finding to answer: What actions do the proposed forest practices activities include (e.g., partial cut, clearcut, 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 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~~ involves compiling and evaluating all pertinent site-specific and regional data to help identify, delineate, and interpret potentially unstable slopes and landforms (e.g., aerial imagery, LiDAR, GIS-based model predictions of 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. See ~~appendices C through E for data sources, and~~ Parts 5.1.3 and 5.1.4 for information regarding remote sensing tools and topographic data, and appendices C through E for data sources.

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

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 for a list of online sources).
- 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.

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 a qualified expert, especially where potentially unstable slopes and landforms are identified 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. 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 are 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 2~~4~~3).[35] However, LiDAR is not a panacea; rather it complements traditional aerial photo interpretation and the analysis of both information sources are useful. Aside from the information provided in 5.1.4, see Appendix E for more information about LiDAR processing, applications, and data sources.

5.1.4 LiDAR Use in Identifying Potentially Unstable Landforms
Hillshade, contour, and slope class maps derived from bare earth LiDAR digital elevation models (DEMs) are 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. A slope map shows the magnitude of the topographic gradient estimated by differencing the elevations of

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

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.

LiDAR-derived maps can reveal key topographic features indicating potential instability (like the visual indicators listed in 4.5) that are not always identifiable using other remote sensing data. Hummocky topography, benched surfaces, tension cracks, scarps, horst and graben features, pressure or transverse ridges, and irregular drainage patterns (Figures 25 and 26) 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 Figure 2~~4~~3. In Figure 2~~4~~3f, a hillshade map derived from 3-foot LiDAR data 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).

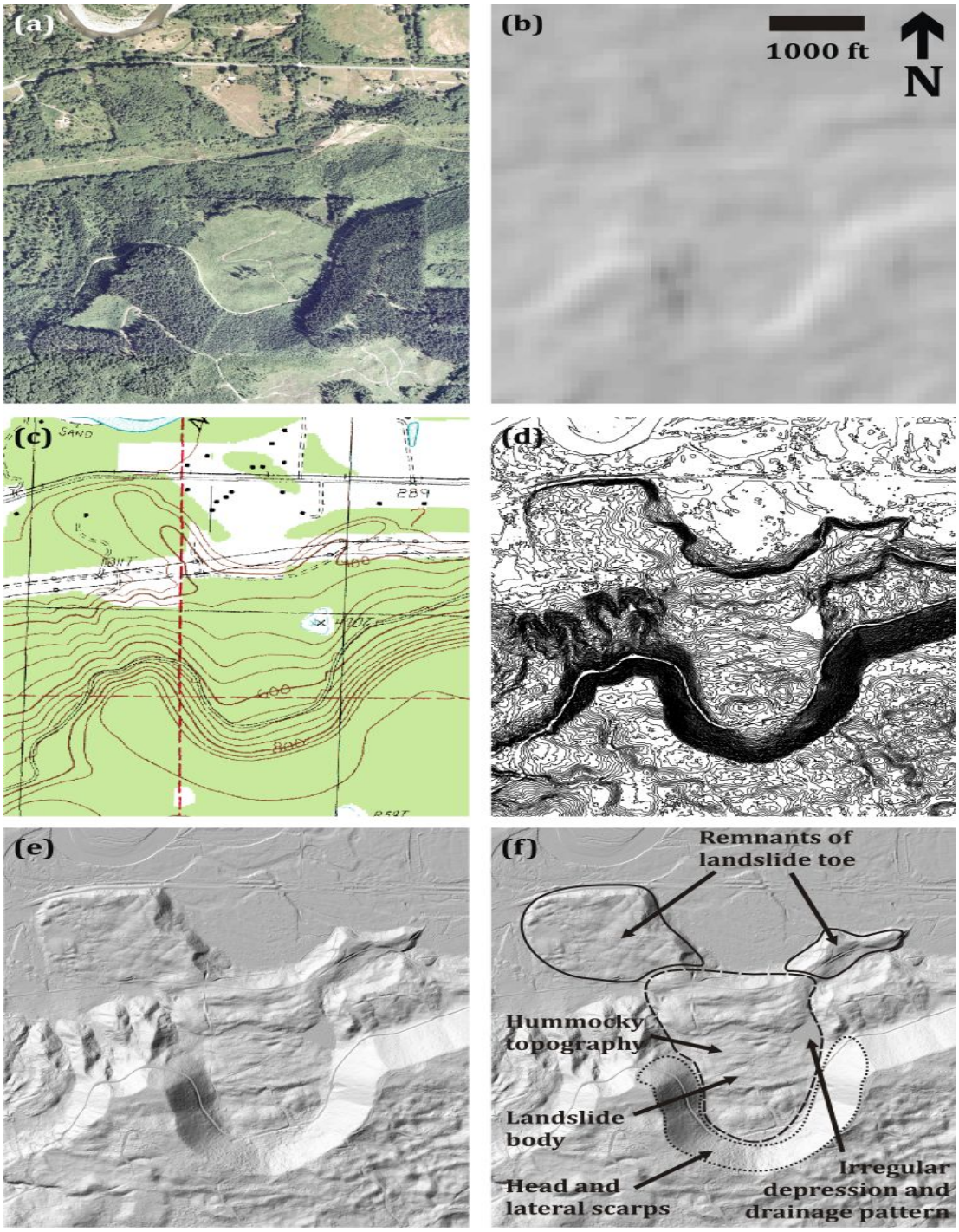


Figure 2~~4~~3. Example of a dormant glacial deep-seated landslide as seen in different types of remotely sensed data and in varying resolution quality:
(a) Digital Orthophoto Quadrangle, (b) hillshade map derived from 30-meter resolution ASTER Global Digital Elevation Model, (c) topographic map, (d) 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).

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.[36] Recent regional examples of deep-seated landslide mapping that used LiDAR-based protocols include Burns and Madin (2009), Schulz (2005 and 2007), and Haugerud (2014).

LiDAR-based comparisons of landslide features are useful to ascertain relative age because younger scarp features generally produce a sharper image on high-resolution topography (i.e., 2-meter pixels) than older, more eroded features that are less clear (Figure 24). It is important to consider DEM raster resolution to avoid misrepresenting landslide age from lower-resolution images. Visual inspection of LiDAR imagery is also useful for change detection to ascertain evidence of movement prior to and after an event[37].

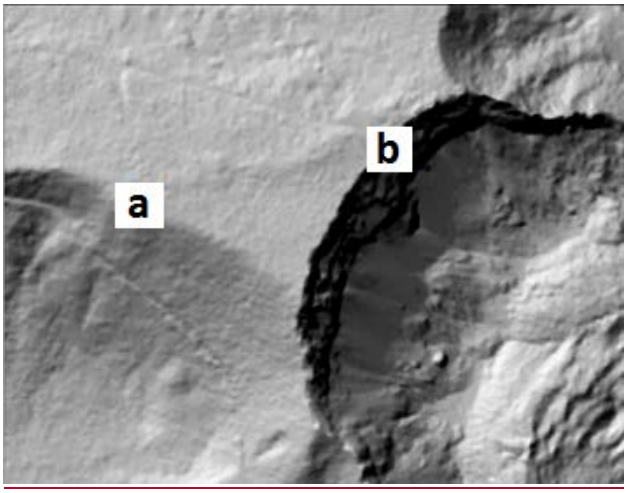


Figure 24. LiDAR image comparison between two deep-seated landslide scarps with the same resolution showing (a) subdued topography and (b) crisp topography. The less defined topography (a) suggests a greater relative age (DNR 2016).

[36] McKean and Roering 2004; Glenn et al. 2006; Booth et al. 2009; Berti et al. 2013.
[37] Iverson et al. 2015.

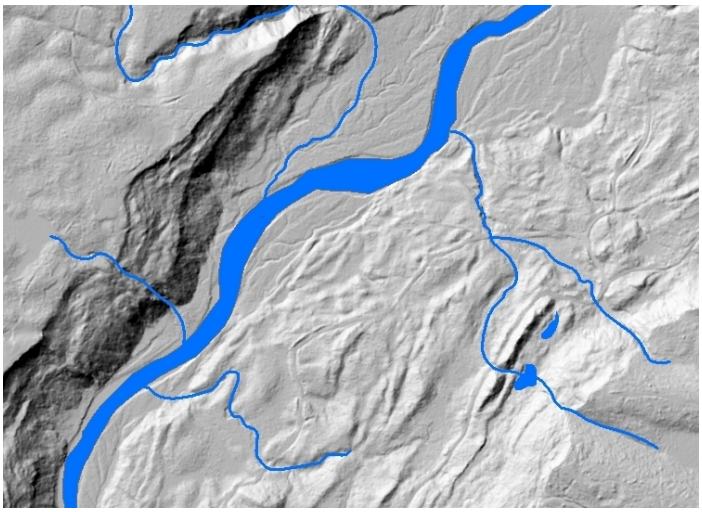


Figure 25. Large slump feature showing displaced (deflected) streams within the landslide mass and sag ponds impounded by ridges (DNR 2016).

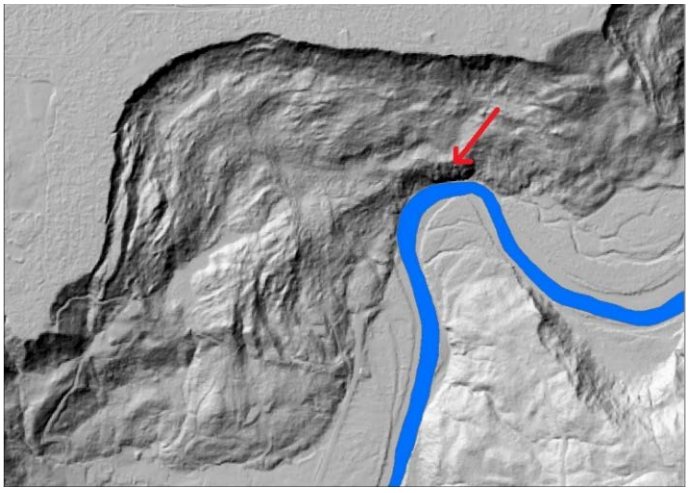


Figure 26. LiDAR image showing channel incision within a large deep-seated slump feature in the Tolt River valley, King County (DNR 2016).

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 surface indicators 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 the 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 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 ask a qualified expert to complete a further assessment.

The practitioner should refer to 4.5 for indicators of slope instability and 5.3.2 for field review of 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.
- 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).[38] 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 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~~ and 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~~, including 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).

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 may involve an interdisciplinary team meeting if required by DNR. Depending on the analyst's level of confidence in potentially unstable landform

[38] 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.

identifications, delineations, and interpretations for any given site, the field assessment might range from qualitative to 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.[39] To facilitate the review, geologic reports can include GPS locations of landforms and other relevant features for reviewers to locate in the field. It is also helpful 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 vegetative indicators described in 4.5.

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. 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).

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

  - 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. 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 includes the report ~~in~~with 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. This landform 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 determination 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 ~~25~~27a shows the approximate groundwater recharge area for a landslide based on upslope topographical delineation. The cross section shown in Figure ~~25~~27b 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.

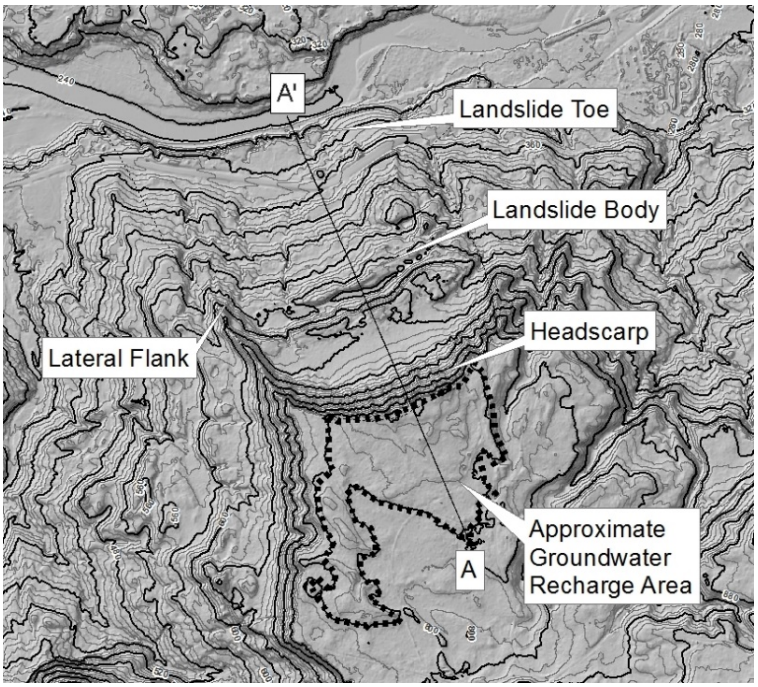


Figure ~~25~~27a. Glacial deep-seated landslide. The dash-lined polygon is an approximate delineation of a groundwater recharge area based on LiDAR data (DNR 2014).

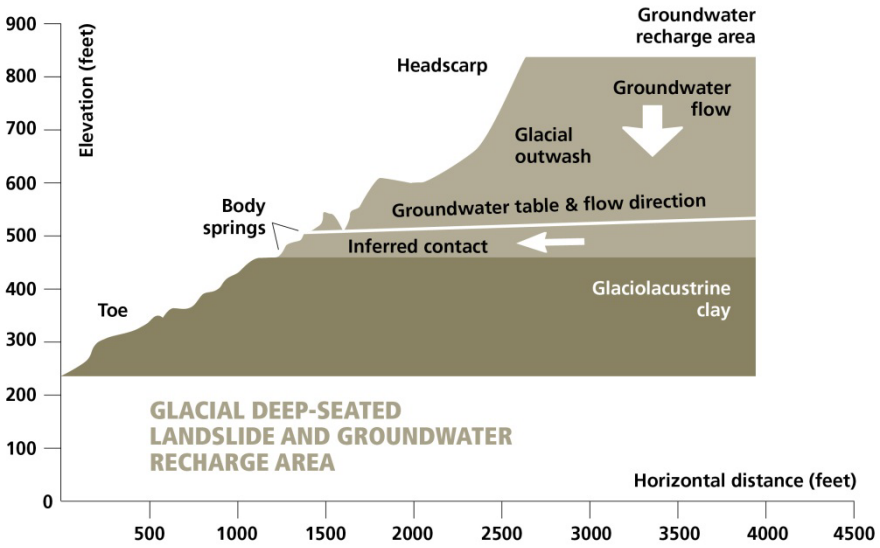


Figure ~~25~~27b. Hillslope cross-section (A-A' in figure ~~25~~27a) derived from 2-meter DEM of a glacial deep-seated landslide showing the groundwater recharge area, geologic units, and generalized groundwater flow paths (DNR 2014).

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 when uncertainties remain as to the accuracy of the recharge area boundary. DNR uses the results of these analyses provided by qualified experts in geotechnical reports to determine FPA classifications and other decisions based on applicants' proposed activities.

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 higher altitude areas of recharge to lower altitude areas of discharge.[40] 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:

- 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.
- 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[41] and the Columbia Plateau[42]. 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 accurately reflects the recharge area topography, including the topography up-gradient of the

[40] Freeze and Cherry 1979.
[41] Vacarro et al. 1998.
[42] Bauer and Hansen 2000.

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 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 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 maps 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, excavating test pits, driving soil probes, drilling monitoring wells, or using geophysical techniques such as seismic or electric resistivity methods 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:

- Deep-Seated Landslide Activity Assessment (6.1);
- Glacial Deep-Seated Landslide Assessment (6.~~2~~1.1);
- Quantitative Field Assessment Methods for the Qualified Expert's Subsurface Investigations (6.~~3~~2);
- Water Budget and Hydrologic Contribution to Glacial Deep-Seated Landslides (6.~~4~~3);
- Computational Slope Stability Assessment Methods (6.~~5~~4); and

- Runout and Delivery Assessment (6.~~6~~5).

6.1 Deep-Seated Landslide Activity Assessment

A landslide activity assessment is an important component of evaluating potential landslide hazard and risk~~,~~. Assessing past geomorphologic features and current landslide conditions ~~and~~ can contribute to a qualified expert's 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.[43]

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 all aid in determining the state of activity based on local knowledge of typical rates of biologic and geomorphic processes.[44] 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. 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 can enlarge or diminish if its total volume is increasing or decreasing.

The *style of landslide activity* ~~will be one of the movement types~~ refers to the type of movement as shown in Table 1, Landslide Classification. Landslides may also occur as complex failures encompassing more than one type of movement. Deep-seated landslides may reactivate or develop successive or secondary landslides over time as compound failures. ~~Many landslides involve different styles of landslide activity. Movements are 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 previously displaced material, or "successive" if the same style of activity affects previously stable material in the immediate vicinity of the previous landslide.~~

[43] Cruden and Varnes 1996.
[44] Keaton and DeGraff 1996, Table 2.

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 forest vegetation 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~~1.1 Glacial Deep-Seated Landslide Assessment

Following on the information in Part 6.1, ~~B~~below is a list of basic steps appropriate for ~~the~~a landslide activity 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~~3 will help the qualified expert determine if the next step should be ~~5~~4, ~~6~~5, or ~~7~~6. Where it is appropriate to follow step ~~5~~4, ~~6~~5, or ~~7~~6, step ~~8~~7 may need to be accomplished as well.

1. Identify and map 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~~3. 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~~4. 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~~5. 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.

~~7~~6. 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 such as assessing whether a potential increase in groundwater recharge from timber harvest will affect the stability of the landslide.

~~8~~7. Design appropriate landslide mitigation measures commensurate with delivery potential and hazard.

6.~~3~~2 Quantitative Field Assessment Methods for the Qualified Expert's Subsurface Investigations

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. 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 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.[45] 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) and summarized in the following paragraphs.

Test Pits. Shallow test pits can be dug by hand with a shovel. Trackhoes or excavators can 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 identifying 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.

[45] McGuffy et al. 1996.

Drive Probe. A simple hand probe can be used to estimate soil density and the depth to dense soil. The Williamson Drive Probe (WDP)[46] was developed as an inexpensive and portable alternative to other more expensive and less portable methods 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).[47] 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..

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~~3 Water Budget and Hydrologic Contribution to Glacial Deep-Seated Landslides

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 or unconfined groundwater sources. Not all precipitation, however, becomes groundwater; some is intercepted by vegetation or surface duff and debris and evaporates before reaching the ground or sublimates from the snowpack (see 6.~~4~~3.1). 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.

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 activity increases the potential for contributing to movement of unstable landforms. The extent of the analysis depends on site-specific geological and hydrogeological conditions. The following discussions of evapotranspiration and groundwater flow may be useful to the qualified expert.

[46] Williamson 1994.
[47] Adams et al. 2007.

6.~~4~~3.1 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.[48] 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. The various vegetation covers provide for varying balances of these fundamental water loss processes. The effects of evaporation on soil water budgets are relatively small compared to canopy evapotranspiration and interception.[49]

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.[50]

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.[51]

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 snowfall collects in the tree crowns facilitating an accumulation of snow over large surface areas of the canopy. Interception and subsequent evaporation of water from vegetation cover is particularly significant in coniferous forests[52]; snow or rain losses from these dense canopies can account for up to 50% of gross annual precipitation[53]. Moore and Wondzell (2005) estimated that interception loss in Pacific Northwest conifer forests ranged from 10% to 30%. Dingman (2002) reported similar values for Pacific Northwest plant communities, ranging from 21% to 35%, based on canopy characteristics and climate conditions. Hanell (2011) reported hydrologic modeling[54] that predicts a 27% decrease

[48] Jassal et al. 2009.
[49] Bosch and Hewlett 1982.
[50] Campbell 1986.
[51] Hanks and Ashcroft 1980.
[52] Link et al. 2004.
[53] Dingman 1994.
[54] DHSVM; Wigmosta, Njssena and Stork 2002.

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% of precipitation during intense winter storms.[55]

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~~3.2 Groundwater Recharge and Groundwater Flow Modeling

Groundwater recharge is difficult to measure directly, but several empirical and numerical methods exist for estimating recharge within unsaturated and saturated zones, including physical, tracer, and numerical-modeling techniques.[56] 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[57], the Precipitation Runoff Modeling System[58], and the Variable Infiltration Capacity Model[59]. 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.[60] 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 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~~4 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.

[55] Ramirez and Senarath 2000.
[56] Scanlon et al. 2002.
[57] Bauer and Vaccaro 1987.
[58] Leavesley et al. 1983.
[59] Liang et al. 1994.
[60] Harbaugh et al. 2000.

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.[61] 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 and 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 from 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 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 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~~5 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.

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

The following information is provided in 6.~~6~~5:

- 6.~~6~~5.1 provides an overview of the common landslide types associated with rule-identified landforms.
- 6.~~6~~5.2 and 6.~~6~~5.3 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~~5.4 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~~5.5 provides a brief overview of the use of barrier trees for mitigating potential landslide delivery.
- 6.5.6. provides an overview on how LiDAR can be used to evaluate potential runout based on past deep-seated landslide deposits.

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;
- 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% 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~~5.1 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.[62] Failures are commonly translational, move very rapidly, and accumulate additional 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

[62] Dietrich et al. 2007

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~~5.2 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.[63] 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.[64] Predictive models based on simple height and gradient parameters have been developed, and several are described in 6.~~6~~5.4.

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 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~~28 is a generalized illustration of debris flow processes.

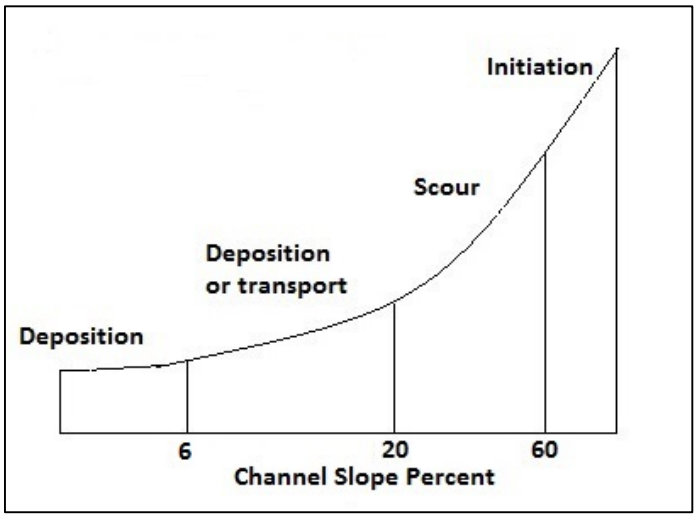


Figure ~~26~~28. Debris flow characteristics relative to channel slope (adapted from Benda et al. 1998).

[63] e.g., Benda and Cundy 1990; Robison et al. 1999; May 2002; Guthrie et al. 2010.
[64] e.g., Melton 1965; Scheidl and Rickenmann 2010.

Initiation and Gradient

Initiation typically occurs on hillsides steeper than 70% but sometimes occurs on slopes as low as 60%.[65] 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%).[66] Figure ~~27~~29 displays detailed field data that demonstrates both the real differences and the large overlap.[67] Two of the larger data sets show that net deposition generally occurs from 14% to 21% [68] and from 21% to 27%[69]. 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%.

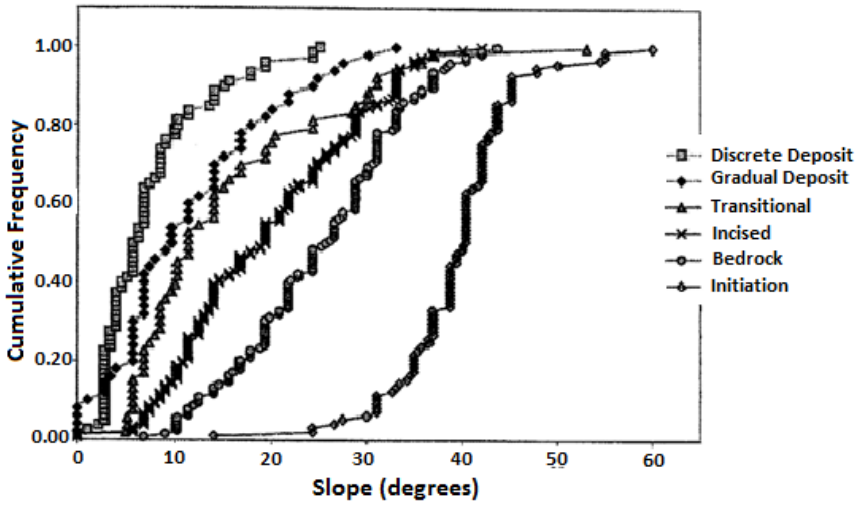


Figure ~~27~~29. Slope distributions for depositional zones (discrete and gradual), transitional zones, erosional zones (incised and bedrock), and initiation sites for debris flows (from May 2002).

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

[65] Robison et al. 1999.
[66] e.g., May 2002; Guthrie et al. 2010.
[67] May 2002.
[68] Hungr et al. 1984.
[69] Guthrie et al. 2010.

studies[70], but not all[71], 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.

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.[72] 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~~5.5 for further information on influence of trees along the runout path.

[70] e.g., May 2002; Sheidl and Rickmann 2010.
[71] Prochaska et al. 2008.
[72] May 2002; Lancaster et al. 2003; Robison et al. 1999.

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.[73] 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~~5.3 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.

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~~In addition, 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.

[73] Beverage and Culbertson 1964; Pierson and Scott 1985.

Figure ~~28~~30 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.

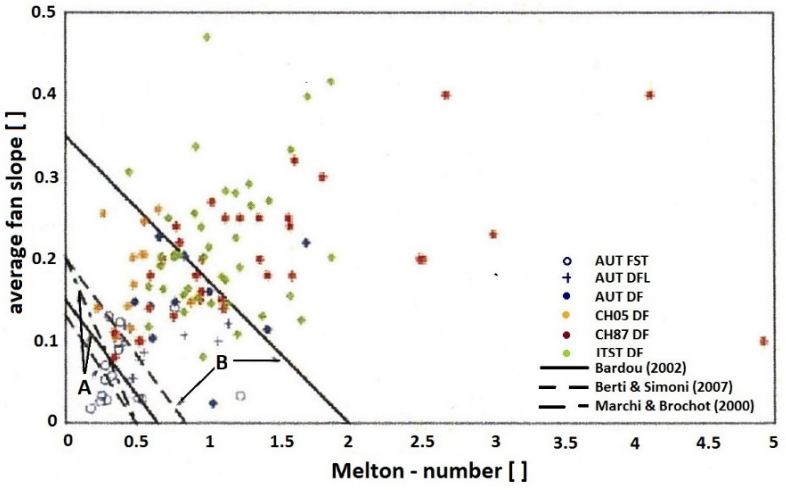


Figure ~~28~~30. Relation between average fan slope (S_f) and Melton number (M_E) for European landslide datasets.
Threshold lines (A and B) distinguish zones with dominant process types, and symbols represent three process types: DF = debris flow, DFL = debris flood, FST = fluvial sediment transport (Scheidl and Rickenmann 2010).

6.~~6~~5.4 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~~derived from 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[74] and the Oregon Department of Forestry's Technical Notes 2 and 6[75].

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[76] 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[77] 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 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.

[74] Weyerhaeuser Timber Company 1993.
[75] ODF Technical Note 2, 2003 and ODF Technical Note 6, 2003.
[76] Robison et al. 1999.
[77] Weyerhaeuser Timber Company 1993.

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[78] and has been improved over several years.[79] 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.[80] 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~~31).

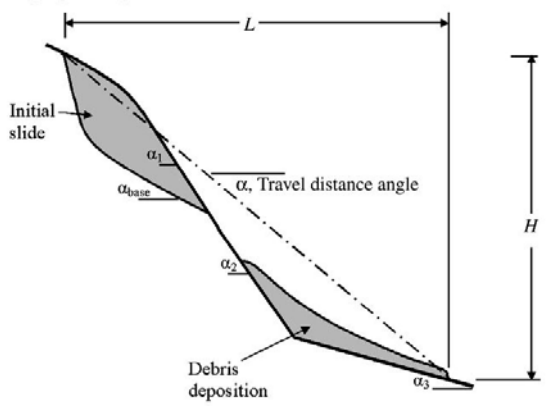


Figure ~~29~~31. Cross section showing travel distance, travel distance angle, and slope geometry (Hunter and Fell 2003).
The equation above could be applied to unconfined shallow-rapid landslides.

Acme Watershed Analysis 1999

A sediment delivery model for open slopes was developed for the Acme Watershed in Washington.[81] It is based on empirical observations that debris flows can develop a coulomb-

[78] Pirulli et al. 2003, Revellino et al. 2004.
[79] Shu et al. 2014.
[80] Oldrich Hungr, personal communication, June 2015.
[81] Crown Pacific Limited Partnership 1999.

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.[82] Four sites in coastal British Columbia with 449 events were used to develop the model for predicting debris flow travel distance in confined and unconfined (open) slopes. 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."[83] 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[84] to guide forest practices activities where shallow landslide hazards exist, and is based on published empirical data from the Pacific Northwest and British Columbia.

- 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; i.e., to determine if an operation is subject to shallow rapid landslides and Oregon's public safety rules. Part B provides guidance on how to determine the downslope extent of regulatory Further Review Areas for proposed operations. It provides gradient, confinement, and runout metrics for channelized and open slope topography.
- 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 guidance draws upon Benda and Cundy (1990), Robison (1999), and Benda (1999). Although it is intended for use within the context of Oregon's regulations, it can be applied throughout the Pacific Northwest for predicting shallow-rapid landslide runout and delivery potential.

[82] Fannin and Wise 2001.
[83] Ibid.
[84] ODF Technical Notes 2 and 6, 2003.

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.[85] Using historic landslide inventory data is appropriate because it is based on field observations of past landslide runout behavior.[86] 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.[87] 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.[88] Because 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 %

[85] Hungr et al. 2005.
[86] Corominas et al. 2014.
[87] Corominas et al. 2014.
[88] Ibid.

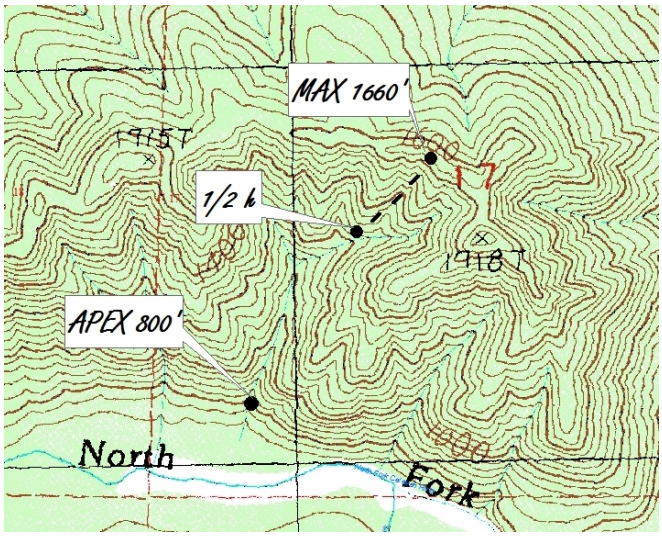


Figure 3~~0~~2. From USGS 7.5' Deadmans Hill Topographic Quadrangle. Maximum elevation of the small watershed is 1660 feet. Fan apex is 800 feet. The variable 1/2h (labeled) equals 1230 feet. B% is 0.243 (calculated from topo sheet); f% is 0.10 (field measured). Runout is 163 feet as estimated by the 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 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.[89] 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~~5.5 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[90] and dam-break floods.[91]

Riparian forests adjacent to larger channelized streams add woody debris and act as natural barriers to debris flows, independent of management practices. Furthermore, standing trees in mature forests may promote more rapid deposition, which can minimize landslide size.[92] Therefore, leaving mature trees where forest practices rules do not require RMZs (i.e., portions of Type N waters) may reduce landslide impacts. Large trees near the areas of debris flow deposition (such as on fans at the

[89] Hungr et al. 1984: Fannin and Wise 2001; Horel 2007.
[90] VanDine 1996, Benda et al. 1998, Guthrie et al. 2010.
[91] Coho et al. 1994.
[92] Guthrie et al. 2010.

mouths of steep tributaries) may be the most effective in inhibiting movement and protecting structures and highways.[93] 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.[94]

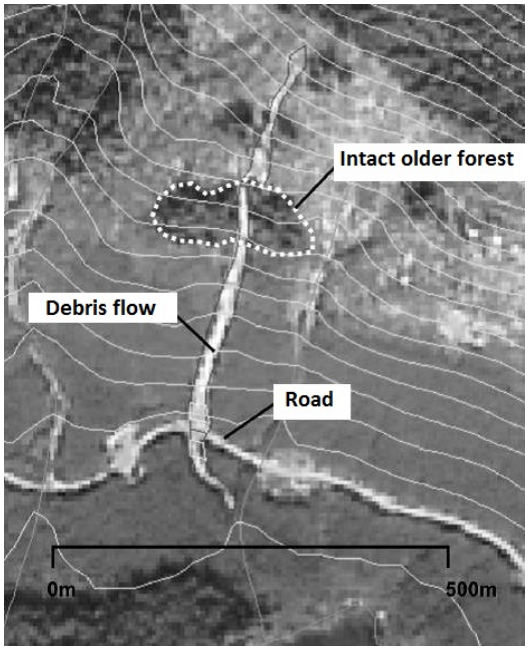


Figure 3~~1~~3. Debris flow path (from bottom to top of the photo) showing width changes from traveling through an older forest stand (Guthrie 2010).

Figure 3~~1~~3 shows the path of an open slope debris flow initiated from a clearcut that traveled through a small stand of older forest to where it narrowed 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.

6.5.6 Deep-Seated Landslide Runout Evaluation

The same tools used to identify deep-seated landslides (Parts 2.3, 5.1.4) can be used by the qualified expert during an evaluation of runout distances. For example, landslide deposits can be mapped with a fair amount of precision using geologic maps, field observations, landslide inventories, and high-resolution topographic data such as LiDAR bare earth 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[95]. For instance, Figure 34 shows the approximate runout distance of neighboring glacial deep-seated landslides in the North Fork Stillaguamish River valley. 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 older deposits may be underestimated by current

[93] Benda et al. 1998.
[94] Eisbacher and Clague 1984.
[95] Schulz 2007.

morphology. This evaluation may be used to supplement other site-specific assessments such as landslide chronology, stratigraphy, mechanics and river channel migration.

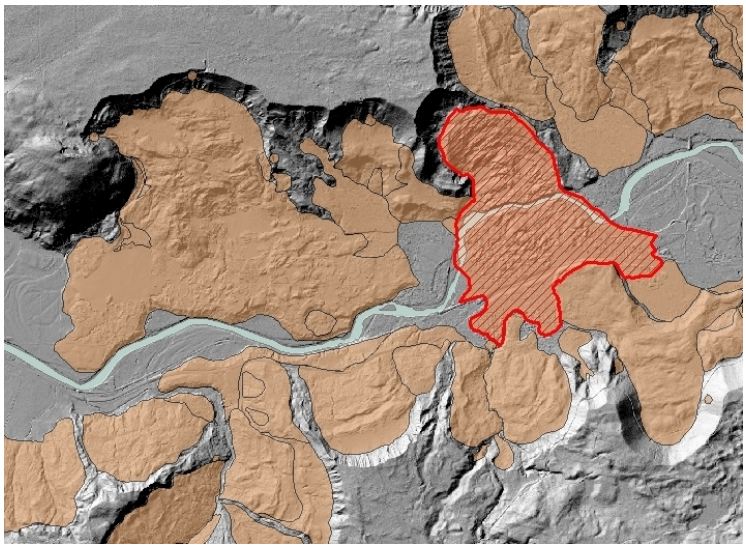


Figure 34. LiDAR derived image revealing past glacial deep-seated landslide deposits in the Stillaguamish River valley. The crosshatch polygon marks the approximate extent of the 2014 SR 530 landslide. (DNR 2016).

PART 7. SYNTHESIS OF RESULTS, EVALUATION, AND GEOTECHNICAL REPORTS

This part is ~~generally reserved~~intended 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?
- 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 for slope stability and sensitivity (see 6.~~5~~4) 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, the analytical methods and processes used by the qualified expert to identify, delineate, and interpret unstable slopes and landforms should 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 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 is 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 http://www.dnr.wa.gov/contact-us.

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~~vicinity map and geographical location 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.[96]

(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.

Relevant field observations, important features, and sampling locations used in project analysis can be displayed on a map in the geotechnical report. Relevant photos and data-sampling observation points should be geo-referenced (i.e., with GPS waypoints) and mapped. GPS track locations of field traverses can 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 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

[96] e.g., Unified Soil Classification System (USCS), American Association of State Highway and Transportation Officials (AASHTO) and Rock Mass Rating (Bieniawski 1989).

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 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.

Complex deep-seated landslide A combination of at least two types of movement (slide, fall, topple, flow or spread) within the same landslide.

Compound deep-seated landslide A large host landslide that encompass smaller secondary slides during a single event or over time.

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 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, 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	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.

REFERENCES

Acme Watershed Analysis: Crown Pacific Limited Partnership and Washington Department of Natural Resources (1999), v.1, (unpaginated).

Adams, W.C., R.W. Prellwitz, and T.E. Koler (2007). Low-Technology Approach to Evaluating Slope Stability in Forested Uplands. IN: First North American Landslide Conference, Vail, CO, 569-577.

American Society for Testing and Materials (ASTM) (2014). Standard test method for Standard Penetration Test (SPT) and split-barrel sampling of soils. IN: Book of Standards, (published by ASTM International, Subcommittee D18.02), 04.08, Active Standard ASTM 1586, 9.

Ardizzone, F., M. Cardinali, M. Galli, F. Guzzetti, and P. Reichenbach (2007). Identification and mapping of recent rainfall-induced landslides using elevation data collected by airborne lidar. Natural Hazards Earth Systems Science, 7, 637-650.

Avery, C.C. and L.J. Fritschen (1971). Hydrologic and energy budgets of stocked and on-stocked Douglas-fir sites as calculated by meteorological methods. Research completion report for U.S. Department of Interior, Office of Water Resources Research, 130.

Badger, T.C. (1993). Structurally-controlled landslides northwestern Olympic Peninsula, USA, Proceedings for Geotechnical Engineering of Hard Soil/Soft Rock, Athens, Greece, 1051-1056.

Barnosky, C. W. (1984). Late Pleistocene and early Holocene environmental history of southwestern Washington State, USA. Canadian Journal of Earth Sciences, 21(6), 619-629.

Bauer, H.H. and A.J. Hansen (2000). Hydrology of the Columbia Plateau regional aquifer system, Washington, Oregon, and Idaho. U.S. Geological Survey, Water Resources Investigations Report 96-4106, 61.

Bauer, H.H., and Mastin, M.C. (1997). Recharge from precipitation in three small glacial-till mantled catchments in the Puget Sound lowland, Washington. U.S. Geological Survey, Water Resources Investigations Report 96-4219, 119.

Bauer, H.H. and J.J. Vaccaro (1987). Documentation of a deep percolation model for estimating ground-water recharge. U.S. Geological Survey, Open File Report 86-536, 180.

Benda, L. and T.W. Cundy (1990). Predicting deposition of debris flows in mountain channels. Canadian Geotechnical Journal. V. 27, 409-417.

Benda, L. E., G. W. Thorsen, and S.C. Bernath (1988). Report of the ID team Investigation of the Hazel landslide on the north fork of the Stillaguamish River (FPA 19-09420): Washington Department of Natural Resources [unpublished report], 13.

Benda, L., C. Veldhuisen, D. Miller, and L.R. Miller (1998). Slope instability and forest land managers: A primer and field guide. Earth Systems Institute, 74.

Benda, L. (1999). Method to Predict Landslide Runout on Non-Convergent Hillslopes, Appendix 3-1. IN: Crown Pacific Limited Partnership (1999), Acme Watershed Analysis (1999). See Washington Department of Natural Resources at https://fortress.wa.gov/dnr/protectionsa/ApprovedWatershedAnalyses, mass_wasting.pdf.

Berti, M., A. Corsini, and A. Daehne (2013). Comparative analysis of surface roughness algorithms for the identification of active landslides. Geomorphology 182, 1-18.

Beverage, J.P. and J.K. Culbertson (1964). Hyperconcentrations of suspended sediment. J. Hydraulics Div. Am. Soc. Civ. Eng., 90(HY-6), 117-128.

Bieniawski, Z.T. (1989). Engineering rock mass classifications: a complete manual for engineers and geologists in mining, civil, and petroleum engineering. Canada: John Wiley and Sons.

Booth, A.M., J.J. Roering, and J.T. Perron (2009). Automated landslide mapping using spectral analysis and high-resolution topographic data: Puget Sound lowlands, Washington, and Portland Hills, Oregon. Geomorphology 109, 132–147.

Booth, D.B., B.S. Golstein, R. Lasmanis, R.B. Cheney, and R.B. Waitt (1994). Patterns and processes of landscape development by the Puget Lobe Ice Sheet. Washington Division of Geology and Earth Resources, Bulletin 80, 207-218.

Booth, D.B., K.G. Troost, J.J. Clague, (2003). The Cordilleran ice sheet. In Gillepsie, A.R., Porter, S.C., and Atwater, B.F. (Eds.), The Quaternary Period in the United States, Developments in Quaternary Science, 1, 17-38

Bosch, J. M. and J.D. Hewlett (1982). A review of catchment experiments to determine the effect of vegetation changes on water yield and evapotranspiration. Journal of hydrology, 55(1), 3-23.

Bovis, M. J. (1985). Earthflows in the interior plateau, southwest British Columbia. Canada Geotechnical Journal, 22, 313-334.

Burns, W. J. and I.P. Madin (2009). Protocol for inventory mapping of landslide deposits from light detection and ranging (LiDAR) imagery, Oregon Dept of Geology Mineral and Industries (DOGAMI), Portland, Special Paper 42.

Burns, W.J., J.A. Coe, B.S. Kaya, and M. Lina (2010). Analysis of elevation changes detected from multi-temporal LiDAR surveys in forested landslide terrain in Western Oregon, Environmental and Engineering Geoscience, 16(4), 315-341.

Campbell, G.S. (1986). An introduction to environmental biophysics. New York: Springer-Verlag.

Carter, W., R. Shrestha, G. Tuell, D. Bloomquist, and M. Sartori (2001). Airborne laser swath mapping shines new light on Earth's topography. EOS, Transactions American Geophysical Union, 82(46), 549-555.

Chatwin, S.C., D.E. Howes, J.W. Schwab, and D.N. Swanston (1994). A guide for management of landslide-prone terrain in the Pacific Northwest, Second Edition. British Columbia Ministry of Forests, Land Management Handbook 18, 220.

Coho, C. S. and S.J. Burges (1994). Dam-break floods in low order mountain channels of the Pacific Northwest: University of Washington Department of Civil Engineering Water Resources Series Technical Report 138; Timber, Fish and Wildlife Program TFW-SH9-93-001, 70.

Corominas, J. (1996). The angle of reach as a mobility index for small and large landslides. Canadian Geotechnical Journal, 33, 260–271.

Corominas, J., C. van Westen, P. Frattini, L. Cascini, J.P. Malet, S. Fotopoulou, … J.T. Smith. (2014). Recommendations for the quantitative analysis of landslide risk. Bulletin of Engineering Geology and the Environment. 73, 209-263.

Corsini, A., L. Borgatti, F. Coren, and M. Vellico (2007). Use of multitemporal airborne lidar surveys to analyze post-failure behavior of earth slides, Canadian Journal of Remote Sensing, 33(2), 116-120.

Crandall, D.R. (1965). The Glacial History of Western Washington and Oregon. Princeton. Princeton Univ. Press.

Cronin, V. S. (1992). Compound landslides: Nature and hazard potential of secondary landslides within host landslides. Geological Society of America Reviews in Engineering Geology, 9, 1-10.

Crozier, M.J., E.E. Vaughan, and J.M. Tippett (1990). Relative instability of colluvium-filled bedrock depressions. Earth Surface Processes and Landforms 15(4), 329-339.

Crown Pacific Limited Partnership (1999), Acme Watershed Analysis (1999). See Washington Department of Natural Resources at https://fortress.wa.gov/dnr/protectionsa/ApprovedWatershedAnalyses, mass_wasting.pdf.

Cruden, D.M. and D. J. Varnes (1996). Landslide types and processes. IN: Turner, A.K., Schuster, R.L. (Eds.), Landslides investigation and mitigation. National Academy Press, National Research Council Transportation Research Board Special Report 247, 36-75.

Daehne, A. and A. Corsini (2013). Kinematics of active earthflows revealed by digital image correlation and DEM subtraction techniques applied to multi-temporal LiDAR data. Earth Surface Processes and Landforms, 38(6), 640-654.

DeLong, S. B., S.C. Prentice, G.E. Hilley, and Y. Ebert (2012). Multitemporal ALSM change detection, sediment delivery, and process mapping at an active earthflow, Earth Surface Processes and Landforms, 37(3), 262-272.

Dietrich, W.E., T. Dunne, N.F. Humphrey, and L.M. Reid (1982). Construction of sediment budgets for drainage basins. ~~Introduction; p. 5- 23,~~ IN: Sediment Budgets and Routing in Forested Drainage Basins, USDA Forest Service, Pacific Northwest Research Station, General Technical Report PNW-141, 5-23.

Dietrich, W. E., J. McKean, D. Bellugi, and T. Perron (2007). The prediction of shallow landslide location and size using a multidimensional landslide analysis in a digital terrain model. IN: C. L. Chen and J. J. Major (editors), Debris-Flow Hazards Mitigation: Mechanics, Prediction, and Assessment: Proceedings 4th International DFHM Conference, Chengdu, China, September 10-13, 2007, Millpress, Amsterdam, The Netherlands (peer reviewed), 12.

Dietrich, W.E., C.J. Wilson, and S.L. Reneau (1986). Hollows, colluvium, and landslides in soil-mantled landscapes. IN: Hillslope Processes, 361-388.

Dingman, S. L. (1994). Physical Hydrology: Englewood Cliffs, N.J.: Prentice Hall, 575.

Dingman, S. L. (2002). Physical Hydrology: Upper Saddle River, N.J.: Prentice Hall, 646.

Edmondo, G.P. (2002). Digital geologic mapping using ArcPad, U.S. Geological Survey Open-File Report 02-370.

Eisbacher, G.H. and J.J. Clague. (1984). Destructive mass movements in high mountains: hazard and management. Geol. Survey. Can., Pap. 84-16. 230.

Fannin, R.J. and M.P.W. Wise (2001). An empirical-statistical model for debris flow travel distance, Canadian Geotechnical Journal, 38(5), 982-994.

Fannin, R. J. and T.P. Rollerson (1993). Debris flows: Some physical characteristics and behavior, Canadian Geotechnical Journal, 30:71-81.

Freeze, R. A. and J. Cherry (1979). Groundwater. Englewood Cliffs, N.J.: Prentice Hall, Inc., 604.

Fritschen, L. J., H.R. Holbo, and M.O. Smith (1975). Evapotranspiration of four forest types measured with the Eddy Correlation Technique. Project Completion Report, OWRR A-061-WASH. University of Washington, Seattle, Washington.

Geertsema, M. and J.J.Pojar (2007). Influences of landslides on biophysical diversity: A perspective from British Columbia. Geomorphology 89, 55-69.

Gerstel, W. J., M.J. Brunengo, W.S. Lingley, Jr., R.L. Logan, H. Shipman, and T.J. Walsh (1997). Puget Sound bluffs: The where, why, and when of landslides following the holiday 1996/97 storms. Washington Geology, 25(1), 17-31.

Gerstel, W.J. and T.C. Bagder (2002). Hydrologic controls and forest land management implications for deep-seated landslides: examples from the Lincoln Creek Formation, Washington, Geological Society of America, Abstracts with Programs, 34(5), 89.

Glenn, N. F., D.R. Streutker, D.J. Chadwick, G.D. Thackray, and S.J. Dorsch (2006). Analysis of LiDAR-derived topographic information for characterizing and differentiating landslide morphology and activity. Geomorphology, 73(1), 131-148.

Guthrie, R.H., A. Hockin, L. Colquhoun, T. Nagy, S.G. Evans, and C. Ayles (2010). An examination of controls of debris flow mobility: evidence from coastal British Columbia. Geomorphology 114, 601–613.

Hall, D.E.; M.T. Long, M.D. Remboldt (Eds.); R.W. Prellwitz, T.E. Koler; J.E Steward (coordinators) (1994). Slope Stability Reference Guide for National Forests in the United States. Publication EM-7170-13. Washington, DC: U.S. Department of Agriculture, U.S. Forest Service, Engineering Staff. 3 volumes, 1091 p.

Handwerger, A.L., J.J. Roering, and D.A. Schmidt (2013). Controls on the seasonal deformation of slow-moving landslides, Earth and Planetary Science Letters.

Hanks, R.J. and G.L. Ashcroft (1980). Applied Soil Physics. Advanced Series in Agricultural Sciences 8, New York: Springer Verlag.

Harbaugh, A.W., E.R. Banta, M.C. Hill, and M.G. McDonald (2000). MODFLOW-2000, the U.S. Geological Survey modular ground-water model – The Ground-Water Flow Process: U.S. Geological Survey.

Harp, E. L., A.F. Chleborad, R.L. Schuster, M.E. Reid, and R.C. Wilson (1997). Landslides and landslide hazards in Washington state due to the February 5-9, 1996 storm; U.S. Geological Survey Administrative Report, 29.

Haugerud, R. A., D.J. Harding, S.Y. Johnson, J.L. Harless, C.S. Weaver, and B.I. Sherrod (2003). High resolution Lidar topography of the Puget Lowland, Washington: A bonanza for earth science. Geological Society Today, 13(6), 4-10.

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.

Heusser, C.J. (1973). Environmental sequence following the Fraser advance of the Juan de Fuca lobe, Washington. Quaternary Research, 3(2), 284-306.

Highland, L.M. and P. Bobrowsky (2008). The landslide handbook; A guide to understanding landslides. Reston, Virginia, U.S. Geological Survey Circular, 1325, 129.

Horel, G. (2007). Overview-level landslide runout study: Western Forest Products Inc., Tree Farm Licence 6. Streamline Watershed Management Bulletin, 10, 15–24.

Hungr, O., G.C. Morgan, and R. Kellerhals (1984). Quantitative analysis of debris torrent hazards for design of remedial measures. Can. Geotech. J. 21, 663-676.

Hungr, O. (1995). A model for the runout analysis of rapid flow slides, debris flows and avalanches. Canadian Geotechnical Journal, 32(4):610-623. http://www.clara-w.com/DAN-W-Manual-Rel-10.pdf

Hungr, O., S. Evans, M.J. Bovis, and J.N. Hutchinson (2001). A review of the classification of landslides of the flow type. Environmental and Engineering Geoscience, 7, 221-238.

Hungr, O., J. Corominas, and E. Eherhardt (2005). Estimating landslide motion mechanism, travel distance and velocity. IN Landslide Risk Management.

Hungr, O., S. Leroueil and L. Picarelli (2014). The Varnes classification of landslide types, an update. Landslides, 11(2),167-194.

Hunter, G. and R. Fell (2003). Travel distance angle for "rapid" landslides in constructed and natural soil slopes. Canadian Geotechnical Journal, 40(6):1123-1141.

Iverson, R. M. and M. E. Reid. (1992). Gravity-driven groundwater flow and slope failure potential 1. Elastic Effective-Stress Model. Water Resources Research, 28(3), 925-938.

Iverson, R.M. and M.E. Reid (1992). Gravity-driven groundwater flow and slope failure potential 2. Effects of slope morphology, material properties, and hydraulic heterogeneity. Water Resources Research, 28(3), 939-950.

Jassal, R. S., T.A. Black, D.L. Spittlehouse, C. Brümmer, and Z. Nesic (2009). Evapotranspiration and water use efficiency in different-aged Pacific Northwest Douglas-fir stands. Agricultural and Forest Meteorology, 149(6), 1168-1178

Johnson, A. C. (1991). Effects of landslide-dam-break floods on channel morphology, Timber Fish Wildlife Report SH17-91-001, 90.

Keaton, J.R. and J.V. DeGraff (1996). Surface observation and geologic mapping. IN: Turner, A.K., Schuster, R.L. (Eds.), Landslides - Investigation and Mitigation. National Academy Press; National Research Council Transportation Research Board Special Report 247, 36-75.

Keaton, J. R., J. Wartman, S. Anderson, J. Benoit, J. DeLaChapelle, R. Gilbert, and D.R. Montgomery (2014). Geotechnical Extreme Events Reconnaissance (GEER) Steering Committee. The 22 March 2014 Oso Landslide, Snohomish County, Washington. Geomorphology, 253, 275-288.

Keefer, D. K. and A.M. Johnson (1983). Earthflows: Morphology, mobilization and movement, U.S. Geologic Survey Professional Paper 1256, United States Government Printing Office, Washington, D.C.

Kelsey, Harvey M. (1988) Formation of inner gorges. Catena, 15(5), 433-458.

Koloski, J.W., S.D. Schwarz, D.W. Tubbs (1989). Geotechnical Properties of Geologic Materials, IN: Engineering Geology in Washington, Washington Division of Geology and Earth Resources, Bulletin 78(1) 19-26.

Krogstad, F. and M. O'Conner (1997). Mass water. IN: Simpson Timber Company; Washington Department of Natural Resources, South Fork Skokomish watershed analysis: Washington Department of Natural Resources, Appendix A (unpaginated).

Lancaster, S.T., S.K. Hayes, and G. Grant (2003). Effects of wood on debris flow runout in a small mountain watershed. Water Resources~~.~~ Research~~,~~, 39(6), 1168.

Leavesley, G.H., R.W. Lichty, B.M. Troutman, and L.G. Saindon (1983). Precipitation-runoff modeling system ~~U~~user's manual. U.S. Geological Survey Water Resources Investigation Report. 83-4238.

Liang, X., D.P. Lettenmaier, E.F. Wood, and S.J. Burges (1994). A simple hydrologically based model of land surface water and energy fluxes for general circulation models. Journal of Geophysical Research, 99(D7), 14~~,~~ 415-14~~,~~ 428.

Link, T. E., M. Unsworth, and D. Marks (2004). The dynamics of rainfall interception by a seasonal temperate rainforest. Agricultural and Forest Meteorology, 124(3), 171-191.

Liu, X. (2008). Airborne LiDAR for DEM generation: Some critical issues. Progress in Physical Geography, 32(1), 31-49.

Mackey, B.H. and J.J. Roering (2011). Sediment yield, spatial characteristics, and the long-term evolution of active earthflows determined from airborne lidar and historical aerial photographs, Eel River, California. Geological Society of America Bulletin, 123, 1560-1576.

Martin, T. A., K.J. Brown, J. Cermak, R. Ceulemans, J. Kucera, F.C. Meinzer, J.S. Rombold, D.G. Sprugel, and T.M. Hinkley (1997). Crown conductance and tree and stand transpiration in a second-growth Abies amabilis forest. Canadian Journal of Forest Research, 27(6), 797-808.

May, C. L. (2002). Debris flows through different forest age classes in the central Oregon Coast Range. Journal of the American Water Resources Association 38:1097–1113.

May, C. L. and R.E. Gresswell (2004). Spatial and temporal patterns of debris flow deposition in the Oregon Coast Range, USA. Geomorphology 57: 135-149.

McGuffey, V. C., V.A. Modeer, A.K. Turner (1996). Subsurface exploration. IN: Turner, A. K. and R.L. Schuster (Eds.), Landslides - Investigation and Mitigation. National Academy Press; National Research Council Transportation Research Board Special Report 247, 231-277.

McGuffey, V.C., V.A. Modeer, Jr., and A. Keith Turner (1996). Surface Exploration. IN: Turner, A. K. and R.L. Schuster (Eds.), Landslides - Investigation and Mitigation. National Academy Press; National Research Council Transportation Research Board Special Report 247, 231.

McKean, J. and J. Roering (2004). Objective landslide detection and surface morphology mapping using high-resolution airborne laser altimetry, Geomorphology, 57(3-4), 331-351.

Melton, M.A. (1965). The geomorphic and paleoclimactic significance of alluvial deposits in southern Arizona. Journal of Geology, 73, 1-38.

Montgomery, D.R., K.M. Schmidt, H.M. Greenberg, and W.E. Dietrich (2000). Forest clearing and regional landsliding. Geology, 28(4) 311-315.

Moore, R. and S.M. Wondzell (2005). Physical hydrology and the effects of forest harvesting in the Pacific Northwest: A Review.

ODF Technical Note 2. Oregon Department of Forestry (2003). High Landslide Hazard Locations, Shallow, Rapidly Moving Landslides and Public Safety: Screening and Practices. Forest Practices Technical Note Number 2, Version 2.0.

ODF Technical Note 6. Oregon Department of Forestry (2003). Determination of Rapidly Moving Landslide Impact Rating. Forest Practices Technical Note No. 6, Version 1.0.

Pierson, T.C. and K.M. Scott (1985). Downstream dilution of a lahar: Transition from debris flow to hyper-concentrated streamflow. Water Resources Research, 21(10), 1511-1524.

Pirulli, M. A., W. Preh, C. Ruth, C. Scavia, and R. Poisel (2003). Rock avalanche run out prediction: Combined application of two numerical methods. In *Proceedings of the International Symposium on Rock Mechanics,* South Africa Institute of Mining and Metallurgy, Johannesburg. pp. 903-908.

Prochaska, A. B., P.M. Santi, J. Higgins, and S.H. Cannon (2008). Debris-flow runout predictions based on the average channel slope (ACS). Engineering Geology 98:29-40.

Prellwitz, R. W., J.E. Steward, D.E. Hall, T.E. Koler, M.D. Remboldt, and M.T. Long (1994). Slope stability reference guide for national forests in the United States. Washington, DC: U.S. Dept. of Agriculture, Forest Service, 3 1091.

Ramirez. J.A. and S.U. Senarath (2000). A Statistical-dynamical parameterization of interception and land surface-atmosphere interactions. Journal of Climate, 13, 4050-4063.

Revellino, P., O. Hungr, F.M. Guadagno, and S.J. Evans (2004). Velocity and run out simulation of destructive debris avalanches in pyroclastic deposits, Campania region, Italy. *Environmental Geology*, 45, 295-311.

Reeves, G.H., L.E. Benda, K.M. Burnett, P.A. Bisson, and R. Sedell (1995). A disturbance based ecosystem approach to maintaining and restoring freshwater habitats of evolutionarily significant units of anadromous salmonids in the Pacific Northwest.
IN: Nielsen, J.L. (Ed.), Evolution and the Aquatic System: Defining Unique Units in Population Conservation, American Fisheries Society Symposium 17, Bethesda, MD, USA, 334-349.

Restrepo, C., L.R. Walker, A.B. Shiels, R. Bussman, L. Claessens, S. Fisch, P. Lozano, G. Negi, L. Paolini, G. Poveda, C. Ramos-Scharro´, M. Richter, and E. Vela´ quez (2009). Landsliding and its multiscale influence on mountainscapes. BioScience, 59, 685-698.

Robison, E.G., K. Mills, J. Paul, L. Dent, and A. Skaugset (1999). Storm impacts and Landslides of 1996: Final Report. Forest Practices Technical Report, Vol. 4, Oregon Department of Forestry, Salem, OR, USA, 145.

Roering, J. J., J.W. Kirchner, and W.E Dietrich (2005). Characterizing structural and lithologic controls on deep-seated landsliding: Implications for topographic relief and landscape evolution in the Oregon Coast Range, USA. Geological Society of America Bulletin, 117(5-6), 654-668.

Roering, J.J., L.L. Stimely, B.H. Mackey, and D.A. Schmidt (2009). Using DInSAR, airborne lidar, and archival air photos to quantify landsliding and sediment transport. Geophysical Research Letters, 36(19), L19402.

Roering, J.J., B.H. Mackey, J.A. Marshall, K.E. Sweeney, N.I. Deligne, A.M. Booth, A.L. Handwerger, and C. Cerovski-Darriau (2013). You are HERE: connecting the dots with airborne lidar for geomorphic fieldwork. Geomorphology 200(1), 172-183.

Scanlon, B.R., R.W. Healy, and P.G. Cook (2002). Choosing appropriate techniques for quantifying groundwater recharge, Hydrogeology Journal, 10, 18-39.

Scheidl, C. and D. Rickenmann (2010). Empirical prediction of debris-flow mobility and deposition on fans. Earth Surface Processes and Landforms, 35, 157-173.

Scheingross, J.S., B. Minchew, B.H. Mackey, M. Simons, M.P. Lamb, and S. Hensley (2013). Fault zone controls on the spatial distribution of slow moving landslides, Geological Society of America Bulletin, 125, 473-489.

Schulz, W. H. (2005). Landslide susceptibility estimated from mapping using light detection and ranging (LiDAR) imagery and historical landslide records, Seattle, Washington, U.S. Geological Survey, Open-File Report 2005-1405.

Schulz, W. H. (2007). Landslide susceptibility revealed by LiDAR imagery and historical records, Seattle, Washington. Engineering Geology, 89(1), 67-87.

Schuster, R. L. and G.F. Wieczorek (2002). Landslide triggers and types. IN: Landslides: proceedings of the first European conference on landslides, Taylor and Francis, Prague. 59-78.

Sharpe, C.F. (1938). Landslides and related phenomena: A study of mass movement of soil and rock. New York: Columbia University Press.

Shu, H. P., D.F. Liu, L.M. Tian, J.Z. Ma, and G. Wang (2014). Study of the Dynamic Characteristics of Landslides Based on the Dan-W Model. Advanced Materials Research, Vols. 1073-1076, 1567-1573.

Sias, J. (2003). Estimation of Multi-season Evapotranspiration in Relation to Vegetation Cover for Regions with Rainy-winter/dry-summer Climate. Washington State Department of Natural Resources.

Sidle, R.C. and H. Ochiai (2006). Landslides: Processes, prediction, and land use. American Geophysical Union and Water Resources Monograph, 18.

Sidle, R.C., A.J. Pearce, and L. O'Loughlin (1985). Hillslope stability and land use. American

Simpson, D. G. (2000). Water use of interior Douglas-fir. Canadian Journal of Forest Research, 30(4), 534-547.

Tabor, R.W. and W.M. Cady (1978). Geologic map of the Olympic Peninsula, Washington, U.S. Geological Survey Miscellaneous Investigation Series MAP I-994.

Tabor, R.W., V.A. Frizzell, J.T. Whetten, R.B. Waitt, D.A. Swanson, G.R. Byerly, D.B. Booth, M.J. Hetherington, and R.E. Zartman (1987). Geologic map of the Chelan 30-minute by 60-minute quadrangle, Washington, U.S. Geological Survey Miscellaneous Series Map I-1661.

Tarolli, P. (2014). High-resolution topography for understanding Earth surface processes: Opportunities and challenges. Geomorphology 216, 295-312.

Tarolli, P., G. Sofia, and G. Dalla Fontana (2012). Geomorphic features extraction from high resolution topography: landslide crowns and bank erosion. Natural Hazards, 61, 65-83.

Terzaghi, K. (1951). Mechanism of landslides. Harvard University, Department of Engineering.

Thorsen, G.W. (1989). Landslide provinces in Washington, IN: Engineering Geology in Washington, Washington Division of Geology and Earth Resources, Bulletin 78, 71-89.

Thorsen, R.M. (1980). Ice sheet glaciation of the Puget Lowland duing the Vashon Stade (late Pleistocene). Quaternary Research 13, 303-321.

Travelletti, J. and J.P. Malet (2012). Characterization of the 3D geometry of flow-like landslides: a methodology based on the integration of heterogeneous multi-source data. Engineering Geology, 128, 30-48.

Tubbs, D.W. (1974). Landslides in Seattle. Information Circular 52, Washington Division of Geology and Earth Resources, Washington Department of Natural Resources, Olympia, Washington.

Turner, A. Keith and Verne C. McGuffy (1996). Organization of Investigation Process. IN: Turner, A. Keith and Robert L. Schuster (Eds.), Landslides--Investigation and mitigation. National Academy Press; National Research Council Transportation Research Board Special Report 247, 121-128.

Turner, A. Keith and Robert L. Schuster (Eds.) (1996). Landslides--Investigation and mitigation. National Academy Press; National Research Council Transportation Research Board Special Report 247.

Turner, T.R., S.D. Duke, B.R. Fransen, M.L. Reiter, A.J. Kroll, J.W. Ward, J.L. Bach, T.E. Justice, and R.E. Bilby, R.E. (2010). Landslide densities associated with rainfall, stand age, and

topography on forested landscapes, southwestern Washington, USA. Forest Ecology and Management 259, 2233-2247.

University of Colorado, Geography Department. A model of hydrologic processes on a hillslope, University of Colorado, Boulder, CO. Web: http://snobear.colorado.edu/IntroHydro/geog_hydro.html.

U.S. Geological Survey (2004). Landslide Types and Processes, Fact Sheet 2004-3072.

U.S. Geological Survey (2007). Digital Mapping Techniques, Open-File Report 2008-1385.

Vaccaro, J.J., A.J. Hansen, Jr., and M.A. Jones (1998), Hydrogeologic framework of the Puget Sound aquifer system, Washington and British Columbia. Regional Aquifer-System Analysis-Puget-Willamette Lowland. U.S. Geological Survey Professional Paper 1424-D, 77.

van Asch, T. W. J. (2005). Modelling the hysteresis in the velocity pattern of slow-moving earth flows: the role of excess pore pressure. Earth Surface Processes and Landforms, 30(4), 403-411.

van Asch, T. W., L.P.H. Van Beek, and T.A. Bogaard (2009). The diversity in hydrological triggering systems of landslides. IN: Proceedings of the First Italian Workshop on Landslides, 8-10.

van Asch, T. W., J.P. Malet, and T.A. Bogaard (2009). The effect of groundwater fluctuations on the velocity pattern of slow-moving landslides. Natural Hazards Earth System Science, 9, 739-749.

Van Den Eeckhaut, M., N. Kerle, J. Poesen, and J. Hervás (2012). Object-oriented identification of forested landslides with derivatives of single pulse lidar data. Geomorphology 173, 30–42.

Van Den Eeckhaut, M., J. Poesen, G. Verstraeten, V. Vanacker, J. Nyssen, J. Moeyersons, L.P.H. Van Beek, and L. Vandekerckhove (2007). Use of LiDAR-derived images for mapping old landslides under forest, Earth Surface Processes and Landforms, 32(5), 754-769.

VanDine, D. F. (1996). Debris flow control structures for forest engineering. B.C. Min. For., Working Paper 22/1996.

Varnes, D. J. (1978). Slope movement types and processes. In Special Report 176: Landslides: Analysis and Control, Schuster and, R.L., Krisek, R.J. (Eds.), TRB, National Research Council, Washington, D. C., 11-33.

Weyerhaeuser Timber Company (1993). Tolt Watershed Analysis, Mass Wasting Prescription Methodology, 98-103 and figures 1-4 unpaginated. See Washington Department of Natural Resources at https://fortress.wa.gov/dnr/protectionsa/ApprovedWatershedAnalyses, prescriptions_causal_mechs.pdf.

Washington State Department of Emergency Management. (2013) Washington State Enhanced State Hazard Mitigation Plan.

Wegmann, K.W. (2003). Digital landslide inventory for the Cowlitz County urban corridor – Kelso to Woodland (Coweeman River to Lewis River), Cowlitz County, Washington, DNR Division of Geology and Earth Resources, Report of Investigations 34, 24.

Whitmeyer, S.J., J. Nicoletti, and J. Madison (2010). The digital revolution in geologic mapping, Geological Society Today, 20(4/5), 4-10.

Wigmosta, M. S., B. Nijssen, P. Storck, and D.P. Lettenmaier (2002). The distributed hydrology soil vegetation model. Mathematical models of small watershed hydrology and applications, 7-42.

Williamson, D. A. (1994). Geotechnical exploration–drive probe method. DE Hall, MT Long, and MD Remboldt, editors. Slope Stability Guide for National Forests in the United States. USDA Forest Service, Washington Office Engineering Staff Publication EM 7170-13, Washington, DC, 317-321.

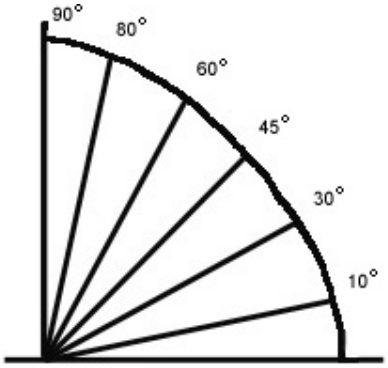
Ziemer, R. R. (1979). Evaporation and transpiration. Reviews of Geophysics and Space Physics, 17 (6), 1175-1186.

APPENDIX A – MEASUREMENTS OF SLOPE GRADIENTS

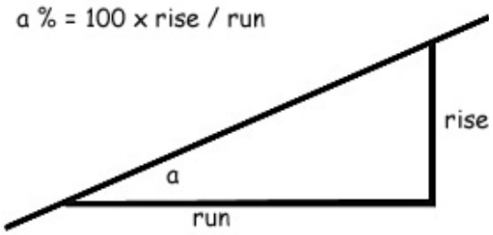
The forest practices rules contain specific slopes gradients (degrees and percent) for potentially unstable slope or landform descriptions. Slope gradients are commonly expressed in two different but related ways, as degrees of arc or percent rise to run. It is important to understand the relationships 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.

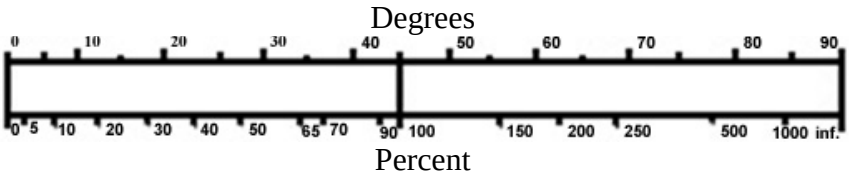
Percent

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.[97] 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.[98] Thick, deeply weathered loess deposits are sources for shallow landslides, debris flows, and avalanches.[99] These deposits are prevalent along the lower Columbia

[97] Tabor and Cady 1978; Badger 1993.
[98] Gerstel and Badger 2002.
[99] 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. Rock falls 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[100], the Columbia River Basalts and other volcanic flow rocks, and Cowlitz Formation and Sandy River Mudstone[101]. 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. Rock falls 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.[102]

[100] Tabor et al. 1987.
[101] Wegmann 2003.
[102] 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 – 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 – 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.[103] 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.[104] 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.[105]

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.[106] 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.[107] 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.[108] 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

[103] Carter et al. 2001.
[104] For a review of filtering techniques, see Liu 2008.
[105] Van Den Eeckhaut et al. 2007.
[106] Corsini et al. 2007; Delong et al. 2012; Daehne and Corsini 2013.
[107] Burns et al. 2010.
[108] Tarolli 2014.

displacement and sediment transport[109]; (2) ortho-rectified historical aerial photographs to map earthflow movement and calculate sediment flux[110]; (3) GIS-based algorithms for LiDAR derivatives (e.g., hillslope gradient, curvature, surface roughness) to delineate and inventory deep-seated landslides and earthflows[111];and (4) subsurface investigations[112].

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.

[109] Roering et al., 2009; Handwerger et al. 2013; Scheingross et al. 2013.
[110] Mackey and Roering 2011.
[111] e.g., Ardizzone et al. 2007; Booth et al. 2009; Burns and Madin 2009; Tarolli et al. 2012; Van Den Eeckhaut et al. 2012.
[112] 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.

WASHINGTON STATE DEPARTMENT OF
Natural Resources

PETER GOLDMARK
Commissioner of Public Lands

MEMORANDUM

April 18, 2016

TO: Forest Practices Board

FROM: Marc Ratcliff
Forest Practices Policy Section Manager

SUBJECT: Rule Making Related to the Board's Practices and Procedures

On May 11, 2016 I will request the Board's approval to file a CR-102 *Proposed Rule Making* with the enclosed draft rule language to amend WAC 222-08-040 to establish a procedure for receipt by the Board of materials and comments for scheduled approval of Sections of the Board Manual. The rule will establish timelines for the public and interested stakeholders to request inclusion of additional technical information in Board Manual sections.

Upon the Board's direction at the February 2016 meeting, staff filed a *CR-101 Preproposal Statement of Inquiry* on March 3 indicating that the Board is considering rule making regarding administrative procedures. Board staff developed language in March and held a meeting for all TFW Policy Committee caucus members on April 1 to discuss proposed language, answer questions and solicit feedback.

Staff recommends a slightly modified procedure from what was discussed at the Board's February meeting. The attached draft rule will apply only to scheduled Board actions on Sections of the Board Manual. DNR will convene stakeholders for the development of Board Manual sections and will post draft revisions on DNR's website as they are being developed in consultation with stakeholders. At Board meetings where a Board Manual section will be considered for approval, the public will be notified and the Board will accept public comments up to six business days prior to the meeting. This rule will allow Board members time to make informed decisions.

A Cost-Benefit Analysis is not required under RCW 34.05.328 because it is only a clarification of the Board's operating procedure. A SEPA analysis is not required because the rule fits the exemption for procedural actions under WAC 197-11-800(19): "…rules…(r)elating solely to governmental procedures and containing no substantive standards respecting use or modification of the environment."

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If you direct staff to file the rule language, it will be published in the Washington State Register in June. Public comments will be received and staff will schedule a public hearing to take place in mid-July, upon which staff will analyze comments, prepare a Concise Explanatory Statement per RCW 34.05.325, and prepare a revised draft rule for the Board to consider adopting in August, 2016.

Please feel free to contact me with any questions at 360.902.1414, or marc.ratcliff@dnr.wa.gov

MR/
Enclosures: Draft Rule Proposal

RULE PROPOSAL
FOR BOARD'S PRACTICES AND PROCEDURES RULE MAKING
May 2016

WAC 222-08-040 Operations and procedures. *[Effective 12/22/08]*

(1) The board holds quarterly scheduled meetings on the second Wednesday of February, May, August, and November, at such times and places as deemed necessary to conduct board business. At regularly scheduled board meetings, agenda time is allotted for public comment on rule proposals and board activities, unless the board has already set public hearings on the rule proposals. Special and emergency meetings may be called anytime by the chair of the board or by a majority of the board members. Notice of special and emergency meetings will be provided in accordance with RCW 42.30.070 and 42.30.080. All meetings are conducted in accordance with chapter 42.30 RCW and RCW 76.09.030(4). A schedule of meetings shall be published in the *Washington State Register* in January of each year. Minutes shall be taken at all meetings.

(2) Each member of the board is allowed one vote on any action before the board; pursuant to RCW 42.30.060(2), secret voting is not allowed. All actions shall be decided by majority vote. A majority of the board shall constitute a quorum for making decisions and promulgating rules necessary for the conduct of its powers and duties. When there is a quorum and a vote is taken, a majority vote is based upon the number of members participating. The chair, designee, or majority of the board may hold hearings and receive public comment on specific issues such as rule making that the board will consider in its actions.

(3) Rules marked with an asterisk (*) pertain to water quality and are adopted or amended with agreement from the department of ecology. See WAC 222-12-010.

(4) The chair or majority of board members shall set the meeting agenda. Public requests for topics to be included in the board's quarterly public meeting agenda must include the name of the requester, and be received at the office at least fourteen days before the scheduled meeting. Topics requested may be added to the meeting agenda at the chair's discretion or by a majority vote of the board members.

(5) Written materials related to board manual action items listed on the board's regular meeting agenda must be provided to board staff at least six business days prior to a regular meeting, unless those materials are less than two pages in length. The Board's administrative record for judicial review shall not include materials violating this rule if the Board acts at the meeting for which over-length materials were submitted and a judicial review appeal is filed challenging the board manual action item.

(6) Written materials for the board which are not provided in advance of the meeting date will not be distributed during the meeting unless fifteen copies are provided to staff.

WASHINGTON STATE DEPARTMENT OF
Natural Resources

PETER GOLDMARK
Washington State Commissioner of Public Lands

MEMORANDUM

April 20, 2016

TO: Forest Practices Board

FROM: Hans Berge, Adaptive Management Program Administrator

SUBJECT: Adaptive Management Program Quarterly Staff Report

This update provides details on progress made for the three areas of the February 2014 Board Motion for Type F. Those pieces include the pilot LiDAR hydrologic model evaluation, best practices of electrofishing in protocol surveys, and off-channel habitat.

Model Evaluation

The Forest Practices Board directed the Adaptive Management Program Administrator (AMPA) "to scope and initiate a pilot project to re-run the existing hydrologic model using LiDAR data, including at least two watersheds; one westside and one eastside" at the 11 February 2014 Board Meeting. Since the November 2015 Forest Practices Board meeting, The University of Washington Precision Forestry Cooperative has been working on the analysis around the model evaluation. The work will be completed in June and will be presented to the Board at your August 2016 meeting.

Type F: Protocol survey electrofishing

Policy's stakeholder electrofishing technical group has been meeting twice per month since October 2015 and will have provided recommendations to Policy at their May 2016 meeting. The recommendations from the group focus on a range of issues addressing site-specific impacts, seasonality, limitations, ways to reduce the use of electrofishing, and ways to better coordinate across agencies to share information. These recommendations will be discussed at Policy over the next several months and I expect that they will be presented to you as part of the Type F strategy in November.

Type F: Off-channel habitat

The off-channel habitat technical group had their first meeting on April 8th, and expect to have a draft report for Policy review by June. The emphasis of this group is to compare the rule language with the Forests and Fish Report to evaluate whether or not the rule addresses off-channel habitats as intended. The technical group will be presenting their findings to Policy at the June meeting and the results of that work will be important for completing the Type F strategy.

WASHINGTON STATE DEPARTMENT OF
Natural Resources

PETER GOLDMARK
Commissioner of Public Lands

MEMORANDUM

March 31, 2016

TO: Forest Practices Board

FROM: Marc Ratcliff
Forest Practices Policy Section Manager

SUBJECT: Board Manual Development Update

Section 16, *Guidelines for Evaluating Potentially Unstable Slopes and Landforms*
I will request the Board's approval of amendments to Board Manual Section 16 at the May Board meeting. This includes the qualified expert group's review and DNR's recommendations to incorporate information on compound deep-seated landslides and deep-seated landslide runout assessments. Added clarifications and minor language improvements are included in the amendments.

Other amendments may occur late 2016, but are dependent on the Board's rule making timeline and completions of TFW Policy Committee's work load.

Please feel free to contact me with any questions at 360.902.1414, or marc.ratcliff@dnr.wa.gov.

MR

MEMORANDUM

TO: Forest Practices Board

FROM: Garren Andrews, Compliance Monitoring Program Manager

SUBJECT: Current status of the Compliance Monitoring Program

2016 Compliance Monitoring field reviews commenced March 2016.

2015-2016 Compliance Monitoring Biennium report work is ongoing. Target completion date is summer 2016.

If you have any questions please contact me at (360) 902-1366 or garren.andrews@dnr.wa.gov

GA

WASHINGTON STATE DEPARTMENT OF
Natural Resources

PETER GOLDMARK
Washington State Commissioner of Public Lands

MEMORANDUM

April 18, 2016

TO: Forest Practices Board

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

SUBJECT: 2016 Rule Making Activity

At your May meeting, staff will request your approval to file a *CR-102 Proposed Rule Making* to amend the Board's rule on Operations and procedures (WAC 222-08-040) to establish a process for the Board to consider comments received on board manual sections. A *CR-101 Preproposal Statement of Inquiry* was filed on March 3rd.

Staff is also working on rule changes to address typographical errors and to make some minor clarifications. Staff is looking to seek your approval for a CR-101 at your August meeting.

I look forward to answering any questions you may have on May 11th.

ME/

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WASHINGTON STATE DEPARTMENT OF
Natural Resources

PETER GOLDMARK
Commissioner of Public Lands

MEMORANDUM

April 11, 2016

TO: Forest Practices Board

FROM: Tami Miketa, Manager, Forest Practices Small Forest Landowner Office

SUBJECT: Small Forest Landowner Office and Advisory Committee

Small Forest Landowner Advisory Committee (SFLAC)
Since my last staff report, the Small Forest Landowner Advisory Committee met on March 9, 2016. This meeting specifically focused on addressing and outlining the short and long term goals for the Small Forest Landowner Advisory Committee.

Forestry Riparian Easement Program (FREP)
For the FY 15-17 biennium, the Forestry Riparian Easement Program received $3.5 million from the State Capital Budget. There are now 139 forestry riparian easement applications on the list waiting for compensation. The oldest application on the list was submitted to the SFLO on 6/28/2008. During this biennium the Program hopes to cruise and value these 139 FREP easement applications that are on the waiting list and to purchase 45 conservation easements encompassing approximately 430 acres.

The SFLO recently hired two project Natural Resource Specialists in the Forestry Riparian Easement Program. These positions are helping the Program by overseeing the cruising contracts to determine the value of all the qualifying timber in the 139 easement applications on the waiting list.

Rivers and Habitat Open Space Program (R&HOSP)
The State Capital budget appropriated the R&HOSP $1 million for the FY15-17 biennium. Generally, when the funding level exceeds $1 million, DNR expects to allocate approximately 70 percent of the funds for critical habitat and 30 percent for channel migration zones (CMZs). If the demand is limited in either funding category, DNR may shift moneys between the funding categories. Applications will be funded in order of ranked priority until all funds are expended. All remaining eligible applications will be offered the opportunity to be considered for future funding.

The R&HOSP application period closed on March 21, 2016. DNR received 25 applications: 5 for CMZ and 20 for critical habitat for state listed threatened or endangered species.

The next step in the process is to prioritize each application for funding based on, but not limited to, the following elements:

- The habitat quality of the property
- Risk of future habitat loss
- Documented occupancy

- Species' landscape continuity
- Species diversity

It is anticipated this prioritization process will be completed by June 2016.

Family Forest Fish Passage Program (FFFPP)
The State Capital budget appropriated $5 million to the Family Forest Fish Passage Program for the FY15-17 biennium. In the 2016 field season, the FFFPP will be correcting 19 fish passage barriers opening up approximately 50 miles of habitat for fish.

The Family Forest Fish Passage Program will be hiring an additional staff person to assist primarily in coordinated outreach for the Program and to assist with fish barrier evaluations. It is anticipated this position will be filled by June 2016.

Long Term Applications (LTA's)
There are now a total of 211 approved long term applications; which is an increase of 6 approved applications since the end of the last reporting period (1/11/2016).

LTA Applications	LTA Phase 1	LTA Phase 2	TOTAL
Under Review	5	2	**7**
Validated	22	0	**22**
Approved	2	211	**213**
TOTAL	**29**	**213**	**242**

Upcoming Landowner Events
The WSU Forestry Extension program, in coordination with DNR, provides education and information about forest management to private forest landowners as well as the general public. They offer classes, workshops, and field days as well as publications, videos, and online resources to help landowners achieve their various land management objectives. Below is a list of upcoming events designed to aid small forest landowners.

Forest Stewardship Coached Planning - WSU's flagship class teaches landowners how to assess their trees, avoid insect and disease problems, attract wildlife, and take practical steps to keep their forest on track to provide enjoyment and even income for years to come. In this class landowners will develop their own Forest Stewardship Plan, which brings state recognition as a Stewardship Forest and eligibility for cost-share assistance, and may also qualify them for significant property tax reductions. The following are scheduled Forest Stewardship Coached Planning classes:

- Deming, September 15 – November 3, 2016
  Class session 6:00 – 9:00 PM Thursday evenings
  Location TBD

- Preston, September 27 – November 15, 2016
  Class session 6:00 – 9:00 PM Tuesday evenings
  Preston Community Center

For more information regarding these classes go to http://forestry.wsu.edu/

2106 Forest Owners Field Days

- Eastern WA: Saturday, June 25 – Colville
- Western WA: Saturday, August 20 – Sequim (tentative)

Over 13,000 landowners have attended these events at over three-dozen venues across the state in the last 20 years.

Forest Stewardship Program Staffing

In eastern Washington there is adequate staffing and a robust landowner cost-share program funded by state and federal forest health-and wildfire hazard reduction funds. In western Washington, with only two Landowner Assistance Foresters available, chronic staffing deficiencies persist due to lack of state funding.

Small Forest Landowner Office New Staffing Opportunity

The Small Forest Landowner Office revised the duties of the current vacant Outreach Specialist/Grant Writer position. The position will now serve as the designated Natural Resource Small Forest Landowner (SFLO) Specialist in western Washington who will provide independent professional on-site technical consultative services to small forest landowners in understanding the Forest Practices Rules, timber harvest systems, small forest landowner alternate plan templates, 20-acre exempt harvest activities, long-term applications, low impact harvest activities, and road construction techniques. This position will also maintain the duties of the Outreach Coordinator by overseeing the development of educational curriculum and outreach activities administered by the Small Forest Landowner Office. The SFLO is currently soliciting applications and is hopeful to fill this important position by June 2016.

Please contact me at (360) 902-1415 or tamara.miketa@dnr.wa.gov if you have questions.

TM/

State of Washington
Department of Fish and Wildlife

Mailing Address: 600 Capitol Way N, Olympia WA 98501-1091, (360) 902-2200, TDD (360) 902-2207
Main Office Location: Natural Resources Building, 1111 Washington Street SE, Olympia WA

April 18, 2016

MEMORANDUM

To: **Forest Practices Board**

From: **Terry Jackson, Forest Habitats Section Manager**

Subject: **Upland Wildlife Update**

The following provides a brief status update for ongoing or pending actions pertaining to priority wildlife species in forested habitats.

Northern Spotted Owl
1988: State listed as endangered
1990: Federally listed as threatened
2012: Designation of revised critical habitat for the USFWS recovery plan

- The results of WDFW's periodic status review for the northern spotted owl was presented to the Board at their February meeting.
- Summary of draft periodic status review: Because of the species' continued population decline, primarily from continued habitat loss due to forest harvest and fire, as well as competitive interactions with Barred Owls, the Washington Fish and Wildlife Commission, at its February meeting, voted to retain the Northern Spotted Owl as endangered in the state of Washington.
- The NSOIT is currently working towards developing a Safe Harbor Agreement for forest landowners to help with federal assurances while protecting existing habitat and recruiting new habitat. The group will also consider other opportunities for landowner incentives.

Western Gray Squirrel
1993: State listed as threatened
1996: Forest Practices Board established voluntary management approach

- The 2015 Annual Report to the Board for the western gray squirrel will be presented at the Board's May 2016 meeting. This report includes an assessment of the past year's activities pertaining to FPAs having a possible nexus to western gray squirrels and associated wildlife management plans. It also includes an update of WDFW's periodic status review, surveys and conservation efforts.
- Summary of WDFW's periodic status review: In January 2016, the Washington Fish and Wildlife Commission took action on the periodic status review for the western gray

squirrel. Because of the species' relatively small total population size, continuing threats, and a lack of information suggesting that any of the three populations have either reached the downlisting goals of the recovery plan or substantially declined since 2005, the Commission voted to retain the species as threatened in the state of Washington. Ongoing surveys will provide information to better clarify current population levels and to assess the status of the species and its habitat for the next scheduled periodic status review.

- WDFW staff continue to:
  - screen FPAs for possible impacts to western gray squirrels;
  - conduct nest surveys as needed, and work with landowners to develop voluntary management plans; and
  - track information on FPAs having potential impacts in order to better assess the effectiveness of the voluntary protection approach.

Fisher

1998: State listed as endangered

2016: Federal listing status: In April 2016, final decision that listing is not warranted.

Current Status:

The fisher, a member of the weasel family, is returning to the state after disappearing from Washington's forestlands during the last century. Since 2008, the Washington Department of Fish and Wildlife (WDFW) and its partners have successfully relocated more than 100 fishers from British Columbia to Olympic National Park and other federal lands within the Cascade Mountain Range.

These recovery efforts were one reason why the U.S. Fish and Wildlife Service (USFWS) determined in April of 2016 that the state's fisher population did not require protection under the federal Endangered Species Act (ESA) as initially proposed.

Another factor in that federal decision was Washington State's leadership in working together with forest industry, landowners and other conservation entities to develop a voluntary program that offers forest landowners an incentive to work as partners in the recovery effort. This voluntary program is called a Candidate Conservation Agreement with Assurances (CCAA). Landowners who choose to enroll in this CCAA receive federal assurances in the event that the fisher ever becomes listed in the future. By signing on to the CCAA, landowners agree to follow certain conservation measures that protect an actively denning female fisher and her young when and if the fisher moves onto the private land. At the time of the listing decision in early April 2016, WDFW had enrolled 25 landowners and 1.4 million acres of forest land in a federal plan called a Candidate Conservation Agreement with Assurances (CCAA). Ongoing landowner enrollment is continuing to occur.

White-Nose Syndrome in Bats

The first confirmed case of white-nose syndrome (WNS) was found in a little brown bat near North Bend in March 2016. This is extremely concerning as it is the first confirmed case in North America west of Nebraska. The disease has been spreading rapidly across the eastern United States and southeastern Canada over the last decade, killing more than an estimated six million bats and leading to dramatic declines in some species.

WNS is a disease caused by the fungus *Pseudogymnoascus destructans*. The fungus grows on noses, wings and ears of bats during hibernation, giving them a white, fuzzy appearance. The

fungus invades deep skin tissues, causing extensive damage to wings, critical physiologic imbalances, and high mortality rates (up to 100%) in bat colonies during hibernation. Affected bats also arouse more often during hibernation, causing them to burn up crucial fat reserves needed for survival. There is currently no indication that humans or other animal species are susceptible to infection with the fungus that causes WNS.

WNS spreads primarily from bat-to-bat contact or infected environment-to-bat contact. People can also carry fungal spores on their clothing, shoes, or recreational equipment. Therefore, WDFW recommends adherence to the national decontamination protocol if people are in close proximity to sites where bats are known to roost (such as buildings, rock crevices, caves, logs, stumps, snags and live trees, etc.).

Bats are an important part of the ecosystem. They consume insects that would otherwise damage valuable crops and forests, or otherwise threaten public health and well-being. Bats are also important for the pollination of plants. It is therefore important that we do what we can to stop the spread of the fungus.

WDFW is developing outreach materials and will be soliciting information about locations of bat aggregations. The public is advised to avoid disturbing bats at their roosts and to report observations of sick, injured or dead bats. More information, including the decontamination protocol, is available at WDFW's website http://wdfw.wa.gov/conservation/health/wns.

Future Updates to the Board

The forest practices rules require that when a species is listed by the Washington Fish and Wildlife Commission and/or the U.S. Secretary of the Interior or Commerce, DNR consults with WDFW and makes a recommendation to the Forest Practices Board as to whether protection is needed under the Critical Habitat (State) rule (WAC 222-16-080). WDFW and DNR continue to coordinate in order to anticipate federal actions and/or state action in response to changes in the status of a species.

cc: Hannah Anderson
Penny Becker
Gary Bell
Marc Engel
Sherri Felix
Joe Shramek
Amy Windrope

WASHINGTON STATE DEPARTMENT OF
Natural Resources

Washington Department of
FISH and WILDLIFE

May 18, 2016

MEMORANDUM

TO: Forest Practices Board

FROM: Sherri Felix, Forest Practices Policy Analyst, Washington State Department of Natural Resources

Gary Bell, Forest Habitats Wildlife Biologist, Washington State Department of Fish and Wildlife

SUBJECT: 2015 Annual Report on the Board's Voluntary Cooperative Protection Approach for Taylor's Checkerspot Butterfly (*Euphydryas editha taylori*)

The eighth annual report on the status of the Forest Practices Board's (Board) voluntary protection approach for the Taylor's checkerspot butterfly is attached. This report covers the 2015 calendar year. Also attached is the current map of buffered habitat areas.

On September 11, 2007, the Board approved a voluntary cooperative protection approach for the state listed Taylor's checkerspot butterfly, as recommended by the Department of Natural Resources (department) and supported by the Department of Fish and Wildlife (WDFW). At that time, the Board also directed staff of the two departments to annually report to the Board on the status of their voluntary protection approach.

On February 11, 2014, the Board accepted the department's recommendation, supported by WDFW, to expand its protection approach to include U.S. Fish and Wildlife Service's newly designated critical habitat for this butterfly under the Endangered Species Act. The Board also accepted the agencies' recommendation to continue annual reporting beyond the initially approved reporting period, given the precarious status of the species. Therefore, this 2015 report is the second annual report on both WDFW identified occupied habitat and federally designated critical habitat for the Taylor's checkerspot.

For your May 2016 meeting, this annual report will not be presented as usual. Rather, time is allotted with "staff reports" should you have questions, comments, or suggestions. In the meantime, please do not hesitate to contact us: sherri.felix@dnr.wa.gov or 360-902-1446; gary.bell@wdfw.wa.gov or 360-902-2412.

Attachment

cc. Joseph Shramek, Marc Engel, Marc Ratcliff
Amy Windrope, Terry Jackson, Ann Potter, Hannah Anderson

2015 Annual Report to the Forest Practices Board

The Status of a Voluntary Cooperative Approach for the Taylor's Checkerspot Butterfly

May 11, 2016

SPECIES BACKGROUND

Once common in the Pacific Northwest, the Taylor's checkerspot butterfly *(Euphydryas editha taylori)* remains on only a handful of sites. The species was listed by the Washington Fish and Wildlife Commission as State Endangered effective March 2, 2006. On November 4, 2013, the U.S. Fish and Wildlife Service also listed the species as endangered and designated critical habitat under the Endangered Species Act (ESA).

In Washington State, the Taylor's checkerspot inhabits highly localized areas. Occupied sites occur within state and private forestland in eastern Clallam and southeast Thurston counties. These sites consist of small grassy "balds", shallow-soiled openings situated within the forest matrix that do not support timber production. Occupied sites also occur on federal land on Joint Base Lewis-McChord in southern Pierce County in native grassland (prairie) settings and on bald habitats within the northeastern Olympic National Forest, and on a non-forested, sandy, coastal private property in Clallam County.

Taylor's checkerspot butterflies complete their entire one-year life cycle in a small area where suitable climate and vegetation occur. Therefore, the species is always present on occupied sites.

The federally designated critical habitat for the species includes unoccupied areas involving non-federal forestland in eastern Clallam, southern Thurston, and northern Island counties. These unoccupied areas meet the habitat needs of the species, and may have historically been occupied sites.

HISTORY

2006 BOARD RESPONSE TO STATE LISTING AS AN ENDANGERED SPECIES

On May 10, 2006, the Forest Practices Board (Board) determined there is sufficient potential risk to the Taylor's checkerspot butterfly from certain forest practices activities to consider rule making and other protection strategies. The Board directed Department of Natural Resources (DNR) staff to notify the public of its intention to consider rule making.

From April 2006 to August 2007, DNR held meetings attended by Washington Department of Fish and Wildlife (WDFW) experts, forest landowners, and other interested stakeholders including the Washington Butterfly Association and The Nature Conservancy. Discussions focused on the butterfly's habitat requirements, potential effects of certain forest practices, and protection strategy options. Additionally, WDFW staff met with individual landowners and land managers to further discuss voluntary protection and management options. During this process, the five large forest landowners who owned or managed occupied butterfly sites committed to develop management plans with WDFW.

On September 11, 2007, the Board approved the voluntary protection approach recommended by DNR and supported by WDFW. This decision recognized the work of DNR and WDFW in conjunction with stakeholders and the commitments from many landowners to develop management plans, as well as DNR's conditioning authority to protect public resources.

In light of the precarious status of the species and the related need for protection and management assistance from forest landowners, the Board directed DNR and WDFW to annually report on 1) any butterfly protection issues associated with individual Forest Practices Applications or Notifications and 2) the status of WDFW-landowner management plans. Additionally, once those landowners who committed to develop management plans with WDFW had successfully done so, annual reports were to shift to every 5 years.

2009 CO-AGENCY TRAINING

In March 2009, DNR and WDFW conducted a formal training for staff from both agencies. This training highlighted the species life cycle and habitat requirements and the sensitivity of the species to possible impacts, and clarified each agency's roles and responsibilities for processing, reviewing, and conditioning Forest Practices Applications and Notifications.

2014 BOARD RESPONSE TO FEDERAL DESIGNATION OF CRITICAL HABITAT

On February 11, 2014, the Board accepted DNR's recommendation supported by WDFW to continue implementation of the voluntary cooperative protection approach for the Taylor's checkerspot and include the federally designated critical habitat in the protection approach. Accordingly, review of Forest Practices Applications and Notifications and outreach to forest landowners was extended to additional nonfederal forestland locations in Clallam and Thurston counties and certain nonfederal forestland in Island and Skagit counties.

The Board also accepted the agencies' recommendation to continue annual reporting to the Board by DNR and WDFW rather than shift reporting to every five years. Hence, annual reports continue on 1) any butterfly protection issues associated with individual Forest Practices Applications or Notifications and 2) the status of WDFW-landowner management plans. Immediate reporting to the Board is to occur if it appears the voluntary approach is not appropriately protecting the Taylor's checkerspot butterfly.

In the spring of 2014, DNR and WDFW incorporated the species' federally designated critical habitat areas into DNR's GIS screening tools. DNR forest practices staff were instructed to implement the DNR-WDFW Forest Practices Application and Notification process for Taylor's checkerspot butterfly in these additional areas.

2015 FOREST PRACTICES APPLICATIONS AND NOTIFICATIONS (FPA/NS)

In the fall of 2006, DNR and WDFW initiated the Board approved interagency screening process for FPA/Ns with the potential to impact the Taylor's checkerspot butterfly on WDFW known occupied sites. In 2014, this screening process was expanded to include both WDFW's GIS locational data for occupied Taylor's checkerspot sites and USFWS GIS data for the newly federally designated Taylor's checkerspot critical habitat.

When an FPA/N is within one mile of, or within, either a WDFW identified occupied site or a federally designated critical habitat area, DNR notifies WDFW. WDFW reviews these FPA/Ns for potential impacts to the butterfly, and if necessary, works with the landowner/land manager to protect the site and species. Short of landowner action, WDFW requests protective FPA/N conditioning by DNR which provides a safety net of protection.

FPA/N SUMMARY FOR 2015

No FPA/Ns were proposed for operations within any WDFW identified occupied habitat or within any federally designated critical habitat for the Taylor's checkerspot butterfly.

A total of nine FPA/Ns were within the one mile screening buffer around WDFW identified sites and federally designated critical habitat:

- Three FPA/Ns related to both a WDFW identified site and federally designated critical habitat.
- One FPA/N related to only WDFW identified occupied habitat.
- Five FPA/Ns related to only federally designated critical habitat.

Within the 0.5 mile portion of the 1.0 mile screening buffers were the following seven FPA/Ns (78%):

- A large landowner had two Class III FPAs to conduct even-aged harvest, uneven-aged harvest, road construction, and rock pit/spoils area work. This landowner has a WDFW approved Taylor's checkerspot protection plan.
- Another large landowner had a CIV-general FPA for a right-of-way harvest. This landowner, Washington State Department of Transportation, does not have a WDFW approved Taylor's checkerspot protection plan.
- Four small forest landowners had two Class III FPAs and two Class II FPNs to conduct even-aged and uneven-aged harvests.

Within the 0.5-1.0 mile portion of the 1.0 mile screening buffers were the following two FPA/Ns (22%):

- A large landowner had a Class III FPA to conduct even-aged harvest and road construction. This landowner has a WDFW approved Taylor's checkerspot protection plan.
- A small forest landowner had a Class III FPA to conduct an uneven-aged harvest.

None of the forest practices activities in these nine total FPA/Ns were determined by WDFW to pose a risk to the species. Therefore, none of these 2015 FPA/Ns were conditioned by DNR with protective measures.

BUTTERFLY SITE MANAGEMENT PLANS AND LANDOWNER STATUS

WDFW, utilizing information developed during the stakeholder process on rules and other protection approaches, developed general guidance on what types of activities should be addressed by management plans in order to protect the habitat of occupied sites. In late 2006, this guidance was distributed to the five large forest landowners who owned or managed sites occupied by the butterfly at the time. WDFW subsequently modified the document based on landowner input. This guidance may be updated in the future to provide clarity or to incorporate knowledge gained relative to protection and management of occupied sites.

Of the original five large forest landowners that owned or managed all or portions of occupied Taylor's checkerspot butterfly sites, three remain: Merrill and Ring Company, Weyerhaeuser Company, and DNR. Each of these landowners has a WDFW approved Taylor's checkerspot butterfly management plan. DNR acquired Green Crow's land and Center for Natural Lands Management (Center) acquired Aloha's parcel (adjacent to the occupied habitat at Dan Kelly Ridge). The Center is a conservation ownership in perpetuity, thus WDFW determined there is no need to develop a management plan for this ownership.

Eight small forest landowners are known to own small portions of sites occupied by the Taylor's checkerspot or own property immediately adjacent to occupied sites. The newly designated federal critical habitat for Taylor's checkerspot butterfly resulted in a multitude of additional landowners in proximity to potentially suitable habitat for the species. WDFW has not pursued contacting these landowners to develop plans to protect and/or restore Taylor's checkerspot habitat. Rather, WDFW continues screening for potential impacts to the species from any FPA/N within one mile of federal critical habitat. This screening is in addition to FPA/Ns within one mile of all nonfederal habitats identified by WDFW. Any potential conflicts for Taylor's checkerspot will continue to be dealt with on a case by case basis. There have been no issues or concerns associated with individual FPA/Ns since the Board approved its voluntary protection approach for the species, leaving WDFW confident the resource risk from forest management remains very low.

PROTECTION BY COUNTIES

WDFW's Priority Habitats and Species (PHS) database with GIS location data for Taylor's checkerspot butterflies is regularly available to, and requested by, counties in order to identify known occupied butterfly sites as they conduct local land use planning. Counties (and the public) have access to this data via PHS on WDFW's website.

Thurston County receives PHS data from WDFW digitally, updated on a regular basis. The county is in the process of developing a Habitat Conservation Plan for prairie and oak woodland species, which will include Taylor's checkerspot butterfly. WDFW is involved in this process. Clallam, Island, and Skagit counties receive this data upon request (e.g., WDFW responds to requests from these counties for PHS data in support of specific plans or projects). This is the same data WDFW biologists use to screen FPA/Ns and proposals going through the State Environmental Policy Act process for potential project impacts to the Taylor's checkerspot butterfly.

2015 SURVEYS AND CONSERVATION ACTIONS

BUTTERFLY SURVEYS

In the spring/summer of 2015, biologists from WDFW, Olympic National Forest, Joint Base Lewis McCord (JBLM), and a private landowner cooperatively conducted surveys to monitor the extant, naturally occurring Taylor's checkerspot populations and the four reintroduction sites in Washington.

South Puget Sound (Thurston and Pierce counties)

Several of the historically occupied sites in the Bald Hill landscape (Thurston County) were surveyed by WDFW for Taylor's checkerspot in 2015 during monitoring efforts for other butterfly species of concern. No Taylor's checkerspots were detected. From 2008-2011, WDFW made intensive survey efforts in this area resulting in no butterfly detections. It is unlikely Taylor's checkerspot persists on any previously occupied sites in the Bald Hill area.

Taylor's checkerspot populations were monitored at one naturally occurring site on JBLM in Pierce County, and on four south Puget Sound prairies where WDFW has reintroduced captive-reared butterflies. Formal sampling data have not yet been analyzed for 2015 however, raw numbers of butterflies counted at the naturally-occurring JBLM site were similar to numbers observed in recent years. Raw counts at the four reintroduction sites showed evidence of natural recruitment at two of the sites (good numbers of butterflies detected following no supplementation with larvae in 2015) and butterfly numbers at the two other reintroduction sites continued to be low.

North Puget Sound (Clallam County)

Taylor's checkerspot was monitored by the Forest Service on four sites, by WDFW on two bald sites located on state and private land, and by WDFW and a private landowner on the sole coastal site. Butterfly survey efforts, which are weather-dependent, benefited from good spring weather in 2015. Butterfly numbers were comparable to previous recent years at four sites and appeared to be higher at the other three, including one site situated on DNR, Center for Land Management, and private timber land.

In total, 12 populations of Taylor's checkerspot are currently known to occur in Washington. The distribution of those populations is:

- Five in South Puget Sound (multiple ownerships; four of which are experimental translocations),
- Four on the Olympic National Forest, and
- Three on state or private land in Clallam County.

CONSERVATION ACTIONS

South Puget Sound (Thurston and Pierce counties)

Significant Taylor's checkerspot conservation actions were achieved by WDFW, DNR's Natural Areas Program, and Center for Natural Lands Management in partnership with the U.S. Fish and Wildlife Service (USFWS), JBLM, and Washington State Recreation and Conservation Office (RCO). U.S. Department of Defense's Army Compatible Use Buffer Program funds Taylor's checkerspot conservation actions outside JBLM. USFWS Recovery Funds supported WDFW's efforts to re-establish Taylor's checkerspot populations in south Puget Sound. DNR and WDFW also received grant monies for south Puget Sound prairie

restoration from the RCO's Washington Wildlife and Recreation Program. Using these funding sources:

1) WDFW restored and enhanced habitat for Taylor's checkerspot on three sites in Thurston County,
2) WDFW oversaw a large-scale captive-rearing and reintroduction effort on two Thurston County and two Pierce County butterfly translocation sites,
3) DNR restored and enhanced habitat in their Bald Hill Natural Area Preserve, and
4) Center for Natural Lands Management restored and enhanced habitat on several Thurston County sites in preparation for ongoing and future reintroductions of the butterfly.

North Puget Sound (Clallam County)

In partnership with the Forest Service, WDFW and Forest Service biologists conducted habitat management and restoration at three occupied sites in the Dungeness River Watershed. Working together, DNR and WDFW continued habitat management and restoration at two Taylor's checkerspot sites located on DNR managed lands. The Center for Natural Land Management conducted habitat management and restoration at their newly acquired property (and occupied site) on Dan Kelly Ridge.

Additional Conservation Actions

Additionally, Taylor's checkerspot is one of 21 Oregon and Washington rare and/or declining prairie and oak woodland species that received support from a 2012 and a 2014 USFWS State Wildlife Grant (SWG). The SWG Prairie-Oak project has conducted conservation work for Taylor's checkerspot on south and north Puget Sound sites. Many partners cooperated to develop this project and have received funding, including WDFW, DNR, Oregon Department of Natural Resources, Center for Natural Lands Management, The American Bird Conservancy, local land banks, public land managers, and private landowners from both states. Weyerhaeuser is a participant and the project will enhance and restore Taylor's checkerspot habitat on their lands in the Bald Hill area. WDFW is the project lead for Washington.

2015 SUMMARY

On November 4, 2013, the U.S. Fish and Wildlife Service listed the Taylor's checkerspot butterfly in Washington as endangered and designated critical habitat under the Endangered Species Act. On February 20, 2014, the Forest Practice Board accepted DNR's recommendation supported by WDFW to include the newly designated federal critical habitat in the Board's voluntary cooperative protection approach for the species. So, this 2015 report is the second annual report to include the federal critical habitat areas, which are located in Thurston, Clallam, Island, and Skagit counties.

Currently, there are 12 known Taylor's checkerspot butterfly populations in Washington State, four of which are experimental reintroductions in the south Puget Sound area. No new Taylor's checkerspot populations have been located in Washington since 2009, when survey efforts discovered a site within the Olympic National Forest.

All known occupied sites were monitored in 2015 by WDFW and partners. Butterfly survey efforts, which are weather-dependent, benefited from good spring weather in 2015. In Clallam County (north Puget Sound area), butterfly numbers were comparable to previous recent years at four sites and appeared to be higher at the other three. In the south Puget Sound area (Thurston and Pierce counties), butterfly numbers at the sole naturally-occurring population were comparable to recent years, and two of the four reintroduction sites showed evidence of recruitment. No Taylor's checkerspots were observed on Thurston County sites except where WDFW has translocated butterflies in an attempt to re-establish populations.

The year 2015 marks the eighth year since the Forest Practices Board approved their voluntary, cooperative protection approach for the Taylor's checkerspot butterfly. In 2015, there were nine FPA/Ns within the one mile screening buffer of a WDFW identified occupied butterfly site and/or federally designated critical habitat for the species. No FPA/Ns were within a WDFW site or within federal critical habitat.

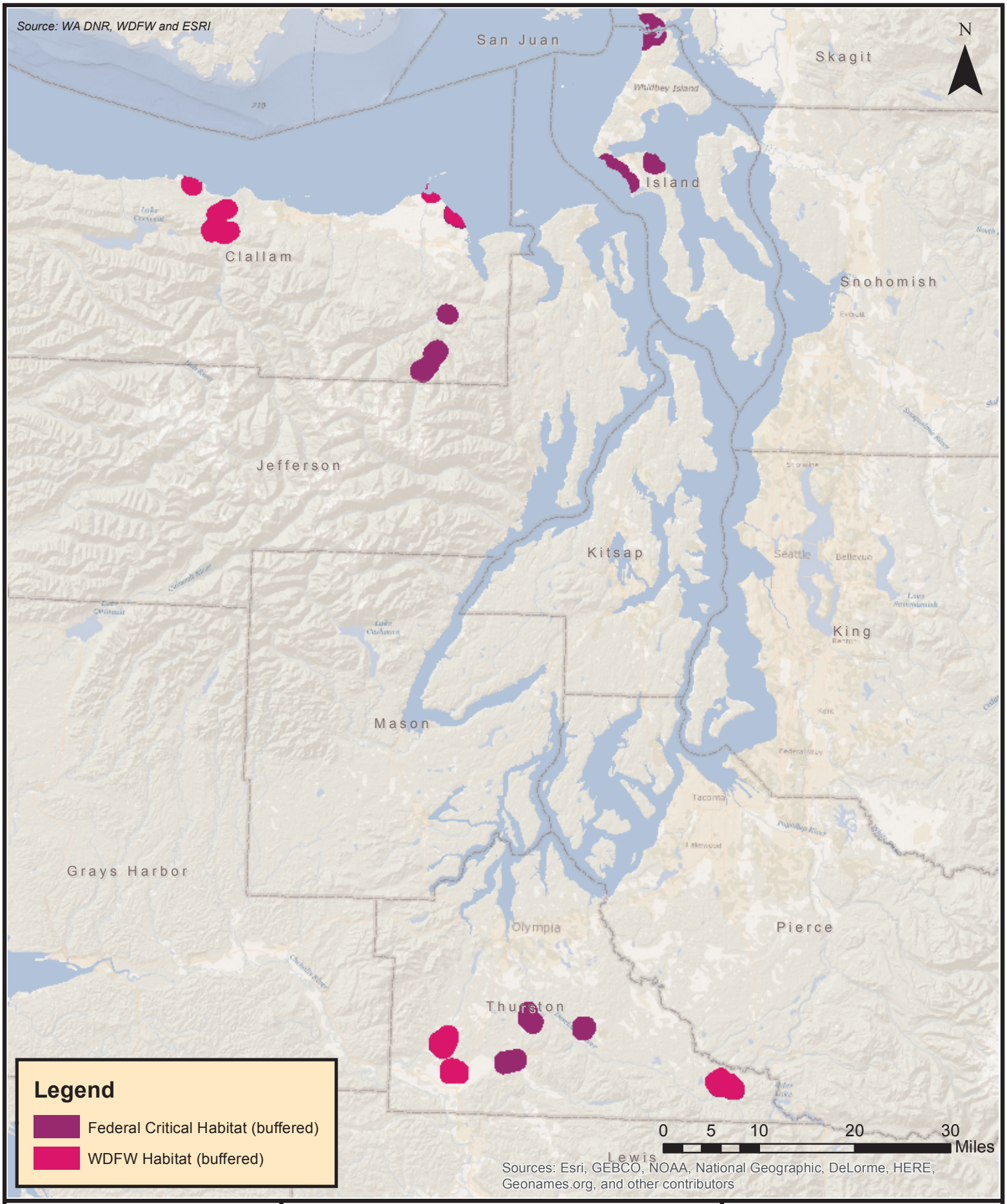
In the eight years of implementing the Board's voluntary protection approach for the Taylor's checkerspot butterfly, a total of 95 FPA/Ns have been within the 1.0 mile FPA/N screening buffer:

- 39 FPA/Ns within the 0.5 mile portion of the buffers.
- 56 FPA/Ns within the 0.5-1.0 mile portion of the buffers.

There has not been any Taylor's checkerspot protection issues associated with these individual forest practices activities. Therefore, WDFW has not requested and DNR has not applied any conditions to these FPA/Ns for Taylor's checkerspot butterfly protection. There was one issue associated with an FPA just prior to the 2007 Board action implementing their protection approach for the species.

Regarding butterfly management plans, three of the original five large forest landowners still own or manage occupied butterfly habitat. Merrill & Ring, Weyerhaeuser Company, and DNR continue to protect and manage for Taylor's checkerspot according to their WDFW approved management plans. Green Crow exchanged their parcel with DNR. Aloha sold their parcel adjacent to DNR's occupied habitat at Dan Kelly Ridge to the Center for Natural Lands Management. Taylor's checkerspot habitat restorations activities are underway by the Center for Lands Management, thus WDFW has determined no management plan is needed for this landowner.

County governments of Thurston, Clallam, Island, and Skagit continue to utilize WDFW's GIS locational data as they conduct their local land use planning. Thurston County is developing a Prairie Habitat Conservation Plan for prairie and oak woodland species, including the Taylor's checkerspot butterfly. WDFW is involved in this process.



Forest Practices Division

File: TCB_Screening_Areas_2015

WASHINGTON STATE DEPARTMENT OF **Natural Resources**

Peter Goldmark - Commissioner of Public Lands

Figure 1:

Taylor Checkerspot Butterfly Screening Areas

NAD_1983_HARN_StatePlane_Washington_South_FIPS_4602_Feet

Drawn by: JT Couillard | Date: 4/7/2015

Timber, Fish, & Wildlife Policy Committee
Policy Co-Chair:
Adrian Miller, Olympic Resource Management

April 20, 2016

TO: Forest Practices Board

FROM: Adrian Miller, Co-Chair

SUBJECT: TFW Policy Committee Quarterly Update since January 20, 2016

The Timber, Fish, & Wildlife Policy Committee (Policy) continues to manage a workload in excess of capacity driven by internal process deadlines and priorities directed by the Forest Practices Board. The major topics are summarized below.

Existing Priorities

Identification of a Co-Chair

After much outreach, no potential Co-Chair for Policy has been identified. Policy will be discussing at their May meeting some potential short and long term options including; identifying existing Policy members to act as Co-Chair on specific issues, a full interim Co-Chair, and asking for a facilitator to fill that role. The need to fill this vacancy is critical to managing the workload of the group in addition to providing transparency and balance in the leadership of the group.

Adaptive Management Program Budget

In 2014, Policy adopted a biennial budget process that was fully implemented beginning in 2015. While Policy and the Board made recommendations and approved the biennial budget, respectively, Policy did not review the CMER work plan, nor was that work plan updated. CMER is in the process of updating the work plan and it will be used in its draft state as a reference document for Policy's Recommendations.

Policy has approved minor adjustments to the FY 2016 budget. Policy has scheduled a special additional meeting in April to complete adjustments to the FY 2017 based on projected fund balances and projected spending levels. At this meeting, Policy will also recommend a budget for the next biennium so that the Board has a basis for a recommended legislative request. Policy will also make any adjustments to the long term Master Project Schedule if necessary.

After the funding levels are established for the next biennium by the legislature, Policy will prepare a specific biennial spending plan for the Board's consideration at their May 2017 meeting.

Water Typing

Type F

- Off Chanel Habitat – Workgroup to implement the technical elements of the Proposal Initiation has been convened. Upon completion of that work, we will integrate the other Policy Element of the Proposal initiation. On track for July 2016.
- Electrofishing – Workgroup to address technical questions from Policy has been convened. Two phases of work, first addressing elements of Board motion and second focusing on spatial/temporal variability issues in the use of this tool. Expecting a report out to Policy at May 2016 meeting.
- Physicals – Policy has discussed different approaches to evaluate the use of the physical defaults without agreement. Large landowners are shopping a Proposal Initiation with Policy for feedback. Large Landowners will likely submit the Proposal Initiation in April, potentially with some additional caucuses. Expect to discuss the Adaptive Management Administrator's Recommendations at the June 2016 Policy meeting.
- Integration of restorability and habitat – After some exploration by Policy subgroups, these specific topic areas have not had direct discussion, but are likely to be integrated into the Policy responses primarily through the Policy discussions on Electrofishing and Physicals, and to a lesser extent, Off Chanel Habitat.
- Policy has convened a subgroup to begin to think about how to integrate all of these elements into a coherent set of recommendations. This group has met once, but cannot move too far ahead of the specific Policy discussions on the issues identified above.

Type N

Policy has been inactive on Type N due to the Board's direction to focus on Type F. The remaining issue surrounds the development of "wet season defaults" for identifying the Upper-Most Point of Perennial Flow (UMPPF).

Small Forest Landowners' Alternate Template

TFW Policy Stakeholders have been meeting on evaluating the Small Forest Landowners' Alternate Template. This work has taken place outside of formal Policy meetings, but Policy has been briefed on the progress. The group has been working to develop a pathway to evaluate the prescription options presented by the Small Forest Landowners. No recommendations to Policy have been made and we currently do not have a firm timeline for when we can expect any.

CMER Work

TFW Policy has responded to CMER projects at various stages of the process. With CMER input, we have developed a more formal presentation structure and written documentation to help all parties in the Adaptive Management Program understand their respective roles at different stages in the process.

The following studies may be before Policy to provide recommendations to the Forest Practice Board in 2016: Buffer Shade Integrity, Glacial Deep Seated Literature Review, Wetland Mapping Project, and Eastside Type F Modeling Evaluation Project.

New Work

Unstable Slopes Proposal Initiation

Policy received and began discussion on the Adaptive Management Administrator's recommendations in response to the Board's Unstable Slopes Proposal Initiation. Given the breadth of the recommendations, Policy initially focused on elements of the recommendations that had a science path. Policy agreed to have a subgroup develop a more structured set of questions related to the recommendations in order to get some initial feedback from CMER, particularly in terms of capacity and timing before Policy takes any formal action. Policy still needs to discuss the other elements of the recommendations at their May meeting.

cc: Forest Practices Board Liaisons
TFW Policy

FOREST PRACTICES BOARD
2016 WORK PLAN

TASK	COMPLETION DATE/STATUS
Adaptive Management Program	
• CMER Master Project Schedule Progress*	May
• ~~*Forest Hydrology Study*~~	*No Board Action Req'd*
• Buffer/Shade Effectiveness Study (amphibian response)	*November*
• Hardwood Conversion Report	*2017*
• LiDAR Pilot Report	August
• Proposal initiation to review unstable slopes rules and guidance	February
• Type F* *Recommendations*	November
• Type N* *Recommendations*	*2017*
• Alternate Plan Template Timeline*****	November
• *Policy Recommendations & Timelines on PI for Unstable Slopes**	*August*
Annual Reports	
• Clean Water Act Assurances	August
• Compliance Monitoring Annual Report	August
• Northern Spotted Owl Conservation Advisory Group	*August*
• Taylor's Checkerspot Butterfly Report	May
• TFW Cultural Resources Roundtable including WAC 222-20-120	August
• TFW Policy Committee Priorities*	August
• Western Gray Squirrel	May
Board Manual Development	
• Section 7, Guidelines for Riparian Management Zones	*2017*
• Section 16, Guidelines for Unstable Slopes	May
• Section 21, Alternate Plan	*August*
CMER Membership	As needed
Field Tour	October
Rule Making	
• *Board's Practices and Procedures (WAC 222-08-040)*	*August*
• NSO Clarification (and other clarifications)	February 2017
• Road Notice Clarification	*2017*
• RMZ Clarification	*2017*
TFW Cultural Resources Roundtable Recommendations on Cultural Resources Protection	November
Upland Wildlife - Northern Spotted Owl	On-going
Quarterly Reports	
• Adaptive Management Program & Strategic Plan Implementation*	Each regular meeting
• Board Manual Development	Each regular meeting
• Compliance Monitoring	Each regular meeting
• Clean Water Act Assurances	February
• Legislative Update	February & May
• NSO Implementation Team	Each regular meeting
• Rule Making Activities	Each regular meeting
• Small Forest Landowner Advisory Committee & Office	Each regular meeting

Italics = proposed changes *May 2016*
**= TFW Policy Committee*

FOREST PRACTICES BOARD
2016 WORK PLAN

TASK	COMPLETION DATE/STATUS
• TFW Cultural Resources Roundtable	Each regular meeting
• TFW Policy Committee Work Plan Accomplishments & Priorities*	Each regular meeting
• Upland Wildlife Working Group	Each regular meeting
Work Planning for 2017	November

Italics = proposed changes *May 2016*
**= TFW Policy Committee*