FOREST PRACTICES BOARD

Regular Board Meeting

May 12, 2015

Natural Resources Building, Room 172

Olympia, Washington

Members Present

Aaron Everett, Chair, Department of Natural Resources
Bill Little, Timber Products Union Representative
Bob Guenther, General Public Member/Small Forest Landowner (participated 9-11:40 a.m.)
Brent Davies, General Public Member
Carmen Smith, General Public Member/Independent Logging Contractor
Court Stanley, General Public Member
Dave Somers, Snohomish County Commissioner
David Herrera, General Public Member (participated by telephone)
Joe Stohr, Designee for Director, Department of Fish and Wildlife (participated 9-3:10 p.m.)
Heather Ballash, Designee for Director, Department of Commerce
Patrick Capper, Designee for Director, Department of Agriculture
Tom Laurie, Designee for Director, Department of Ecology

Members Absent

Paula Swedeen, General Public Member

Staff

Chris Hanlon-Meyer, Forest Practices Division Manager
Marc Engel, Forest Practices Assistant Division Manager
Patricia Anderson, Rules Coordinator
Phil Ferester, Senior Counsel

WELCOME AND CALL TO ORDER

Aaron Everett called the Forest Practices Board (FPB or Board) meeting to order at 9 a.m.

APPROVAL OF MINUTES

MOTION: Bob Guenther moved the Forest Practices Board approve the February 10-12, 2015 meeting minutes.

SECONDED: Court Stanley

Brent Davis suggested that the word “policy” be added before “recommendation to page 6, line 28.”

ACTION: Motion passed unanimously.

REPORT FROM CHAIR

Everett acknowledged Kirk Cook, Department of Agriculture, for his service on the Board and welcomed his replacement, Patrick Capper.

Everett also acknowledged Stephen Bernath's work as TFW Policy Committee co-chair for the past six years. He will be stepping down after the May or June TFW Policy Committee meeting.

GENERAL PUBLIC COMMENT

Mary Scurlock, conservation caucus, said that no work has been done on the Type N board manual for over a year, and that discussions were at an impasse. She suggested the Board direct DNR to initiate a Board Manual process because TFW Policy consensus is not required and stakeholder input would still occur. The Conservation Caucus recommends this course rather than following dispute resolution at Policy because adequate data is available for DNR to act. She said dispute resolution would be resource intensive and unlikely to produce consensus.

Chris Mendoza, conservation caucus, said that the identification of the uppermost point of perennial flow has been an issue for a long time. He said it is not an issue with the data rather its Policy members not able to agree on how to use the data to develop the wet season method. He indicated much frustration within the technical committees in putting in all the work and then stopping at TFW Policy with no good reason and not moving it forward to the Board.

Karen Terwilleger, Washington Forest Protection Association (WFPA), stated that a technical/science group dedicated to the Type F issue is needed in order to do the policy work that needs to be done. She said science is extremely critical in this process especially determining a solution for the large water type issues. She also mentioned that the key study Chris Mendoza referred to for Type N focused on an issue relating to finding the upper most point of perennial flow but looked at only one methodology. She said the dispute has to do with the methodology to identify a default method to locate the upper most point of perennial flow during the wet season not that TFW Policy cannot decide on what to do with the data.

Peter Goldman, WFLC, expressed concern with the lack of progress on a permanent water typing rule. He said TFW Policy has been grappling with this for almost 2½ years. He said most caucuses agree on the parameters of what a rule should look like and asked the Board to direct TFW Policy to bring a majority and minority report to the Board in November. He indicated that they would soon release a White Paper to TFW Policy and the Board explaining why the existing interim water typing rule is not biologically adequate to the extent it permits take and excludes potential fish habitat.

STAFF REPORTS

Joe Stohr expressed his frustrations with the adaptive management program where decisions take 10-20 years to make and questioned if there is something else the Board could do to expedite the process or if there was some other process to put in place.

<u>Adaptive Management</u>

Hans Berge, DNR, updated the Board on the water typing model evaluation using LiDAR. He also provided an update on CMER's work on the Hard Rock Study.

<u>Small Forest Landowner Advisory Committee and Small Forest Landowner Office</u>

Tami Miketa, DNR, reported on the small forest landowner communities RMAP progress and how they are in meeting the requirements of RMAPs. She indicated in preparation for a small forest landowner's roads report it appears that good management practices are being taken on small landowner roads, the report providing an overview on the status of small forest landowner's RMAP obligations will be available later this year.

She said the biggest challenge faced in performing the roads surveys was landowners not wanting "government employees" on their property.

Tom Laurie asked what the percentage of roads owned by small versus large forest landowners is and Miketa said it is unknown. She added the answer to this is a challenge.

Court Stanley asked if Washington Farm Forestry Association (WFFA) could help. Miketa responded WFFA is helping do outreach with the one dedicated DNR staff person working on this which has been helpful.

<u>Northern Spotted Owl Conservation Advisory Group</u>
The Board considered whether this group should continue and they agreed it should.

Joe Stohr stated that Washington Dept. of Fish and Wildlife (WDFW) has had the northern spotted owl (NSO) on its review list for state listing and the review is expected to be completed by the end of 2015. He suggested a presentation to the Board on the review at the February 2016 meeting. He also said that the US Fish and Wildlife Service (USFWS) are also looking at the listing status and looking at a barred owl pilot project that may help the NSO.

Stohr agreed with Everett to have a "process check-in" at the August meeting in order to keep this topic front and center. Everett also suggested having USFWS provide an update on their process of the species status review and the barred owl experiments.

No further discussion on the following staff reports:

- Board Manual Development
- Compliance Monitoring
- Rule Making Activity & 2014 Work Plan
- Upland Wildlife Working Group

LEGISLATIVE UPDATE
Chris Hanlon-Meyer, DNR, reported the only bill to pass that affects the Forest Practices program is Senate Bill 5088 requiring expansion of LiDAR mapping of geologic hazards. He also reviewed the status of DNR's requested budget enhancements. He also recognized all the work done by DNR and the Timber, Fish and Wildlife collaborators to get the Adaptive Management Program fully funded in the Governor's, House and Senate proposed budgets.

BOARD MANUAL SECTION 16 PROGRESS
Marc Ratcliff, DNR, said the stakeholder group is working to incorporate guidance for identifying methods for assessing run-out potential for unstable slopes and are well into drafting guidance for estimating run-out distances.

He said since the landslide risk can involve initial screening and possibly an in-depth analysis, it is important to provide guidance for both the general practitioner and the qualified expert. As a result, the group decided to provide an initial framework for the general practitioner to use for determining possible run-out distances for particular landslides. He also said that brief descriptions of specific methodologies will be included which will provide the qualified experts with options for determining the appropriate method depending on geographical location and landslide risk.

He said the methods for calculating distances for run-out will be for shallow rapid landslides only. These are by far the most frequent landslide types observed on the landscape, they cause the most damage, and the parameters for initiation can be calculated somewhat readily.

He concluded that given the expectation of this group and the fact that they have day jobs apart from this work group, the commitment is impressive.

Marc Engel responded there is no data available to Everett's questions regarding methods to calculate runout for deep-seated landslides. .

Engel said DNR would like to field test the manual before Board approval but would not have time before the August Board meeting and requested the Board delay their review and approval for their November meeting.

Everett noted the concern of timeline but was not willing to change the due date. He said at the August meeting the Board can reevaluate the situation.

TFW POLICY COMMITTEE'S WORK PRIORITIES

Stephen Bernath, co-chair reported that in addition to the Type N and F priorities, Policy has worked on the following:

- Bull trout overlay
- Small forest landowner template proposal
- Schedule Nancy Sturhan to conduct Adaptive Management training for TFW Policy members.

He said that nothing has occurred since 2013 due to other priorities and lack of consensus on a pathway forward.

Adrian Miller, co-chair, reported on progress made with Type F which included field trips, identified concerns with the rules, initiated a literature review on the use of electro-fishing and mentioned that DNR will submit a proposal initiation for a concept for off-channel habitat.

Hans Berge, DNR described what electrofishing is and provided an overview on the literature review that he developed.

Bernath and Miller agreed that TFW Policy needs to keep moving forward and not dawdle on this topic. Somers expressed the same concern and said that he appreciates the option to bring the majority/minority opinions to the Board for a decision to get to a resolution sooner rather than later.

Court Stanley cautioned Somers in that approach as he wants to ensure the adaptive management process is adhered to.

Joe Stohr said he is encouraged of progress, however not encouraged with the length of time for a recommendation.

TFW Policy co-chairs will present at the August meeting a schedule to reach a recommendation plan for the off-channel habitat and a progress report for electrofishing.

CLEAN WATER ACT ASSURANCES

Mark Hicks, Department of Ecology, reported that during this period, the following four milestones were completed:

- Developing guidance strengthening the process for issuing Alternate Plans
- Bull Trout Overlay Temperature Effectiveness Monitoring Study
- Forested Wetlands Literature Synthesis
- Revised Wetland Program Research Strategy

He also reported that work was initiated on several additional milestones and that the Type N strategy was changed from "Completed" to "Off Track" to reflect the substantial delay in implementing a key milestone component.

TAYLOR'S CHECKERSPOT BUTTERFLY ANNUAL REPORT

Sherri Felix, DNR, said that this was the seventh annual report that implements the Board's protection strategy for the Taylor's checkerspot butterfly (TCB). She said the approach relies on the following process.

- Tracking FPAs proposed within one mile of WDFW identified butterfly habitat (new, renewed, or amended FPAs);
- Conditioning FPAs if/when WDFW determines the FPA poses a potential risk to the butterfly;
- Voluntary landowner planning with WDFW to develop TCB management plans;
- Annual reports to the Board by DNR and WDFW on program issues associated with individual FPAs and the status of landowner-WDFW management plans.

She said the Board's unanimous approval in 2014 to expand its protection approach to include the newly designated Federal critical habitat sites that have private or state managed forest land within one mile added about half dozen habitat areas, and added Skagit and Island counties to the screening process.

She said 17 permits were within one mile of either WDFW identified TCB habitat or Federal habitat and were determined by WDFW to pose a potential risk to the butterfly. However no FPAs needed to be conditioned and no protection issues have arisen during those activities.

Gary Bell, WDFW, said that there are currently three large landowners with TCB plans in place and all are going well.

He said conservation activity continues in North and South Puget Sound areas and counties continue to utilize WDFW's data for planning.

Bob Guenther asked what is involved in the restoration efforts. Bell responded that most restoration efforts to date have included targeted brush and limited conifer removal to maintain nectar plants that support the butterfly.

WESTERN GRAY SQUIRREL REPORT

Donelle Mahan, DNR, provided highlights of the report that implements the Board's protection strategy for Western Gray Squirrel (WGS). She said the voluntary protection approach involves the following process:

- Tracking and screening FPA's proposed within 0.25 miles of WDFW identified occurrences/habitat;

- WDFW determines WGS presence/absence via nest surveys; if present, develop voluntary management plan with landowners
- WGS plan completed/implemented.

Gary Bell, WDFW, said for the period of January 1 through December 31, 2014, there were 109 FPA/Ns identified as potentially being associated with WGS with the majority in Klickitat County. He said 42 were associated with large landowners and 67 were associated with small forest landowners.

He said 100 of the 109 FPA/Ns needed further review, including confirming presence or absence, conducting a nest survey, or confirming appropriate protection measures implemented. Thirty-one of those 100 required development or implementation of a management plan.

He said overall, all known WGS related FPAs were identified and plans continue achieving conservation.

Tom Laurie said he is pleased with the report and that it seems like an effective in tracking. He noted that all FPA have been reviewed and thought it was great. He asked when the formal status review will begin and how long it will take. Bell stated starting in May/June and go for 2-3 years. This will be the best way to determine the broader population and distribution.

Joe Stohr asked Bell to confirm the status listing until the 3-year information gathering was done to take action. Bell agreed not until info is gathered can any action be taken/decision.

Brent Davis asked what the process for the FPAs that were identified with less than ideal conditions. Bell responded that there is no regulatory process as it is a voluntary approach; however they are required by law to maintain the required nest trees.

UPDATE ON DEPARTMENT OF ECOLOGY'S NONPOINT PLAN
Melissa Gildersleeve, Department of Ecology, provided an update on what the plan looks like and how the work by the Board fits into the plan. She said the updates will include short and long-term goals, objectives and strategies; have an implementation focus; strengthening partnerships and management measures. She said that the Board's rules addressing forestry nonpoint pollution will be a critical piece of the plan as well as the regulatory framework on forest practices for implementing the plan as well as the adaptive management process and effectiveness monitoring.

PUBLIC COMMENT
Karen Terwilleger, WFPA, said they support the CMER budget and additional staff position within Adaptive Management Program.

Marc Gauthier, Upper Columbia United Tribes, recommended that the Type F literature review consider seasonal variability, winter fish habitat or limitations of electrofishing technology itself to determine if the appropriate call on viable fish habitat and potential fish habitat is made.

PUBLIC COMMENT OF SMALL FOREST LANDOWNER ALTERNATE PLAN TEMPLATE PROPOSAL INITIATION
Ken Miller, WFFA, thanked the Board for moving the template into the adaptive management process. He said that small landowners believe this will help them resolve what they believe was the

intent with the Regulatory Fairness Act and the Small Business Economic Impact Statement 15 years ago. He also invited the Board to a mini field day at his family tree farm on June 6, 2015.

Doug Hooks, WFPA, said he supports the Adaptive Management Program Administrator's recommendation for a science and policy track for the proposal.

SMALL FOREST LANDOWNER ALTERNATE PLAN TEMPLATE PROPOSAL INITIATION

Hans Berge, DNR, recommended a three step strategy which would include a "policy track" and a "science track" to move this proposal through the adaptive management process. The 3 steps include:

- TFW Policy Committee to determine whether the alternate plan template proposal meets the criteria outlined in WAC 222-12-0403 for alternate plans by October 2015.
- Conduct a literature synthesis to evaluate the forest practices functions of the riparian zone by March 2016.
- Provide recommendation to the Board at the May 2016 meeting.

MOTION: Tom Laurie moved the Forest Practices Board direct TFW Policy to implement the strategy as recommended. The steps forward include

- Beginning no later than October 2015, determine whether the alternate plan template proposal meets the criteria outlined in WAC 222-12-0403 and consider different strategies for moving forward;
- Beginning October 2015 initiate a literature synthesis to evaluate forest practices functions of the riparian zone; and
- Providing a recommendation of next steps to complete the evaluation of the proposal at the May 2016 Board meeting.

SECONDED: Heather Ballash

ACTION: Motion passed unanimously.

PUBLIC COMMENT ON THE ADAPTIVE MANAGEMENT PROGRAM 2016-2017 BUDGET

None.

ADAPTIVE MANAGEMENT PROGRAM 2016-2017 BUDGET AND CMER MASTER PROJECT SCHEDULE PROGRESS

Hans Berge, DNR, reviewed the budget with the Board and highlighted the following:

- Continuing Lean improvements/staffing Environmental Planner 3
- LiDAR model
- Riparian Function Literature Synthesis
- TFW Policy Committee facilitation
- CMER Conference
- Report to Legislature

Berge requested the Board's approval of the 2016-2017 budget as proposed with the expectation that the budget may need to be revised at the August 2015.

Tom Laurie asked what the contingency fund is used for. Berge responded that it is used for unplanned projects that may come up.

MOTION: Dave Somers moved the Forest Practices Board approve the 2016-2017 budget dated 5/12/15.

SECONDED: Tom Laurie

AMENDMENT TO MOTION: Court Stanley moved to amend the motion to include an additional $140,000 per fiscal year for CMER Science Staff (line 7).

SECONDED: Carmen Smith

ACTION ON AMENDMENT: Motion passed unanimously.

ACTION: Motion passed unanimously.

PUBLIC COMMENT ON CULTURAL RESOURCE PROTECTION CONCERNS AND TFW CULTURAL RESOURCES ROUNDTABLE PROPOSED ACTION ITEMS

John Sirois, Upper Columbia United Tribes, said he was concerned about the recent inconsistencies that have taken place in terms of change or interpretation of the authorities DNR has for protecting cultural resources. He added that as we move forward we need to look at commitment to uphold the original HCP that provided a basis of establishing a process for protecting cultural resources. He encouraged the Board to engage in the discussions and process.

Marc Gauthier, Upper Columbia United Tribes (UCUT), stated that there are some shortcomings in the current process that have hindered his Tribes ability to appropriately protect cultural resources. He is hopeful that a resolution will come to pass and applications will be conditioned again to protect cultural resources. He also referenced the UCUT's resolution that identified six suggestions that they would like to see occur.

David Powell, Yakama Nation, spoke on behalf of Councilwoman Ruth Jim. Jim submitted a comment that referenced a letter sent to the Board in March 2015 that included a solution for implementing the cultural goals of the 1987 TFW Agreement. Powell shared his disappointment with the Forest Practices Division in not consistently complying with WAC 222-20-120. He indicated that if the Forest Practices Division continues to approve FPAs without the required tribal-landowner meeting, they will be forced to appeal one of those FPAs. He encourage the Board to advise the division to comply with all provisions of WAC 222-20-120 to avoid costly appeals.

Jim Peters, Squaxin Island Tribe, said he disappointed that DNR has back stepped from where they were when he was at DNR as the tribal liaison. He said at that time the Forest Practices Division worked on ways to implement protection measures and provide training for FP foresters and others. He said the Division then encouraged tribes and landowners to develop plans to work on prior to the application submittal.

TFW CULTURAL RESOURCES ROUNDTABLE REPORT AND PROPOSED ACTION ITEMS

Karen Terwilleger, co-chair, provided an overview on the “draft discussion strategy” document which outlines the issue and next steps as well as identifies additional information needed for discussion to move the issue forward. She said understanding DNR conditioning authority under 222-20-120(4) is key in order for the group to move forward with a solution.

She also asked the Board for funding for a facilitator to assist the Roundtable in developing solutions and place the Cultural Resources Roundtable quarterly report as a standing agenda topic rather than a staff report.

Jeffrey Thomas, co-chair, stated that this is a Board issue and that the Roundtable is doing work on the Board’s request. He stated that this has been a long standing issue and that the Board should have acted on it last year. He presented and referenced several documents that referenced the issues and commitments made by stakeholders to protect cultural resources.

Everett said that he supports the request for funding for a facilitator and that the Roundtable should continue with the task of sorting out the conditioning authority issue. He also thought the Roundtable should expand the scope of the annual survey.

Terwilleger and Dave Herrera both acknowledged the frustration by the Tribes with the process and how long of an issue this has been.

Dave Somers acknowledge the long standing issue and the commitment from day one as Thomas presented. He noted some progress, however is unclear if the current issue is a legal or policy issue. He said he is also confused that a process was in place that was working and now it’s not. He also supports funding for a facilitator.

Herrera stated Commissioner Goldmark has spoken in support of resolving the issue and made a commitment for his staff to work with the Tribes for a resolution. He said that all parties need to be involved for the solution and supports funding for facilitation and note taking.

Court Stanley suggested the Tribal, industry and agency leaders get together to reenergize the commitment made long ago.

Brent Davies acknowledged the Tribal members who attended the meeting today from Spokane, Yakima and Colville. She also stated that she is looking forward to hearing more about the issue and getting to a solution together.

Joe Stohr noted the importance of protecting these cultural resources and making a commitment in some way is necessary.

MOTION: Aaron Everett moved the Forest Practices Board recommend and request DNR to allocate funding from the Forests and Fish Support Account to retain professional facilitation and note taking services at TFW Cultural Resources Roundtable meetings.

He further moved the Forest Practice Board direct the TFW Cultural Resources Roundtable to:

- Continue work to resolve the Forest Practices Application conditioning issues identified in the "draft discussion strategy" dated April 21, 2015; by
    - Understanding the extent of DNR's conditioning authority, and the role of the Department of Archaeology and Historic Preservation in the Forest Practices Application approval process;
    - Expanding the scope of the annual survey to collect more complete information on how the current system of cultural resource protection is working;
    - Reporting to the Board on its progress in a standing agenda item at each quarterly meeting; and
- At the August 2015 meeting, the report will include a strategy and a timeline for reaching resolution.

He further moved the Board request a short public memo from the Board's counsel on the extent and nature of DNR's conditioning authority for cultural resource protection.

SECONDED: Bill Little

Board Discussion:
Dave Somers asked if the public memo would be available by the August Board meeting and Everett responded yes.

Tom Laurie asked if there would be a duration or the facilitation services. Everett suggested to start with a year.

ACTION: Motion passed unanimously.

PUBLIC COMMENT ON RIPARIAN MANAGEMENT ZONE CLARIFICATION RULE MAKING

Kevin Godbout, Weyerhaeuser, said he believes that this rule making is more than just a clarification of the current rule. He said the ability to move outer zone trees around within one riparian management zone segment is a practical way in which they manage their riparian management zones.

Doug Hooks, Washington Forest Protection Association, said he agrees with Kevin Godbout and questioned the priority of this rule making at this time. He asked the Board to consider the current workload of all stakeholders and if this can be put off for a while.

RULE MAKING ON RIPARIAN MANAGEMENT ZONE CLARIFICATION

Sherri Felix, DNR, asked the Board to consider rule making to clarify the riparian management zone (RMZ) rules for outer zone leave trees by approving the filing of a CR-101 Preproposal Notice of Inquiry with the Code Reviser's Office to notify the public of the Board's consideration.

She said that current RMZ rules set up three different zones starting from the water; the core, inner and the outer. The outer zone is furthest from the water. The rules require trees to be left in the outer zone of the RMZ according to certain harvest options.

Staff is recommending the Board considering clarifying when more than one harvest option is chosen along a stream that outer zone leave trees are to be left in the same RMZ segment as the chosen harvest option.

Several board members questioned the priority of this rule making and asked for additional information to warrant the need for rule making. The Board rescheduled this discussion for a future meeting.

ADAPTIVE MANAGEMENT PROGRAM WETLAND RESEARCH AND MONITORING STRATEGY: FOREST PRACTICES AND WETLANDS REPORT AND EFFECTS OF FORESTED ROADS AND TREE REMOVAL IN OR NEAR WETLANDS OF THE PACIFIC NORTHWEST LITERATURE SYNTHESIS

Due to time constraints, topic moved to the August meeting.

PUBLIC COMMENT ON BOARD'S 2015 WORK PLAN

None.

2015 WORK PLANNING

Marc Engel, DNR, recapped some of the changes made today. The Board adjusted their work plan to reflect the following:

- Adjust time line from November to August for Type F;
- Adjust time line from November to 2016 work plan for RMZ rule clarification and Board Manual Section 7; and
- Add Cultural Resources Roundtable Recommendations task for August

EXECUTIVE SESSION

None.

Meeting adjourned at 4:15 p.m.

WASHINGTON STATE DEPARTMENT OF
Natural Resources

PETER GOLDMARK
Commissioner of Public Lands

MEMORANDUM

July 24, 2015

TO: Forest Practices Board

FROM: Marc Ratcliff
Forest Practices Policy and Services Section

SUBJECT: Board Manual Section 16, *Guidelines for Evaluating Potentially Unstable Slopes and Landforms* – Approval of Step 1, Phase 2

On August 11, 2015, I will request the Board's approval of DNR's recommended revisions to Board Manual Section 16. These revisions involve adding clarity to the guidance, making the process for evaluation easier to follow for field practitioners and Qualified Experts and completing the steps to fulfill the Board's direction in 2014. This memorandum includes a brief background of the Board's direction, a summary of the Phase 2 stakeholder process, an overview of the current recommended revisions and staff's recommendations for completing the Board's direction.

Background

- On May 13, 2014, the Board directed staff to convene qualified experts to amend guidance on identifying and delineating groundwater recharge areas (GWRAs) associated with glacial deep-seated landslides (DSLs), and in a second phase, amend guidance specific to assessing delivery potential.
- On November 12, 2014, the Board approved amendments pertaining to delineating GWRAs (which we call Phase 1), and directed staff to convene a stakeholder process to review for clarity the newly approved amendments to Section 16 and complete guidance specific to delivery potential (Phase 2). The Board gave staff a deadline of August 11, 2015 to complete the guidance.

Phase 2 Stakeholder Process

Pursuant to the Board's direction, DNR convened a stakeholder group by soliciting participation via TFW Policy Committee representatives. To date, the stakeholder group met from January 21 to July 8, in 14 all-day meetings. This was a cooperative effort as outlined in WAC 222-12-090, which directs DNR to prepare, in cooperation with interested parties, advisory guidance to supplement the rules. The revisions in the enclosed draft are the result of changes group members suggested to make the document more user-friendly. All suggested changes were discussed during the group meetings, and in most cases group members agreed on the changes. Where agreement was not reached, DNR made the final decision based on Board Manual purpose: to create guidance, not rules.

Although the process to review the November 2014 amendments to Section 16 is complete, we were unable to finalize changes to the delivery assessment portion of the document. The group has made good progress, including new sections regarding factors influencing debris flow runout and methods for delivery assessments. Unfortunately, this work is not yet ready for recommending to the Board at this time.

Recommended revisions
The amendments in Section 16 range from simple sentence structure to re-organization of certain portions. In summary:

- *Part 1, Introduction* – Streamlining the objectives, refining the targeted audiences and moving the purpose of the rules into the introduction.

- Part 2, *Landslides Types in Washington* – Changes to ensure that descriptions of landslide types coincide with the terminology used in Washington State and DNR literature, and eliminate the inference that all DSLs are rule-identified landforms.

- Part 4.5, *Areas Containing Features Indicating the Presence of Potential Slope Instability* – Improving the classifications of, and providing examples for 'category E' landforms.

- Part 5, *Identifying Potentially Unstable Slopes and Landforms* – Amending the introduction to improve the goal of the part, and better defining the field practitioner's and qualified expert's review processes and outcomes.

- Part 6, *Additional Analysis for Unstable Landforms* – Combining the discussion on subsurface investigations and other additional assessments into one part. Removing the decision pathway flow chart and amending the steps to coincide with guidance for the landslide activity assessment listed earlier in the section.

  During the group's discussion on landslide assessments, the use of a risk matrix was proposed that would lead the user to a prescribed outcome based on screening tools, investigative methods and landslide assessment. DNR decided not to incorporate the risk matrix because the guidance must not result in a predetermined mitigation or avoidance outcome based on a method used (or not used). Mitigation must be based on the qualified expert's assessment.

- Part 7.5, *Synthesis* and Part 8, *Geotechnical Reports* – Combining these parts to eliminate redundancy and streamline the synthesis needed for preparing geotechnical reports.

Staff Recommendations for Completing Revisions to Section 16
DNR is requesting the Board direct staff to continue the stakeholder process with an anticipated approval date for delivery assessment guidance in November 2015. We are planning stakeholder meetings to resume early in August and continue into September. This will provide time to finalize draft language the group has already produced and field test some of the methods the group is considering. DNR and the group participants are confident the new section can be completed in time for your November meeting.

Lastly, we want to thank those who worked with DNR during the stakeholder meetings and review. Stakeholder participants from DNR, Tribes, Department of Ecology, counties, Conservation Caucus and the Large Landowner Caucus assisted with revisions for improving Section 16 organization and guidance. We asked a lot from this group and received a lot in return.

Marc Engel and I will be available to provide further explanations to amendments, clarify the next steps for finalizing delivery guidance and answer any questions. Please feel free to contact me at 360.902.1414 or marc.ratcliff@dnr.wa.gov.

MR
Attachment (2)

Section 16
Guidelines for Evaluating
Potentially Unstable Slopes and Landforms

PART 1. INTRODUCTION

Board Manual Section 16 contains guidelines to evaluate potentially unstable slopes and landforms on forest lands. Like all Board Manual sections, it does not contain rules or impose requirements. Instead, it is an advisory technical supplement to the forest practices rules~~, offering approaches for landowners and other forest professionals to achieve complete assessments that will lead to complete Forest Practices Applications (FPAs) and successful proposals~~. The ~~objectives of S~~section ~~16 are: 1) to provide~~

- Provides general practitioners with tools to better understand ~~the geology and hydrology~~potential landslide hazards and risks in the areas of ~~a~~ proposed forest practices ~~activity~~activities;
- ~~, and to determine~~Identifies when a qualified expert is needed ~~to conduct further geotechnical analysis; and 2) to assist~~
- Assists qualified experts with tools and methods to conduct geotechnical investigations; and
- Provides guidance to ~~and~~ prepare ~~complete~~ 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; ~~this group is referred to as "general practitioners" in this Board Manual section;~~ and
- Qualified experts, as that term is defined in WAC 222-10-030(5).

~~The objectives of Section 16 are: 1) to provide general practitioners with tools to better understand the geology and hydrology in the area of a proposed forest practices activity, and to determine when a qualified expert is needed to conduct further geotechnical analysis; and 2) to assist qualified experts with methods to conduct geotechnical investigations and prepare complete geotechnical reports.~~

The current rules related to potentially unstable slopes and landforms were developed to ~~protect public resources and prevent threats to public safety~~avoid an increase over natural background rates from forest practices on high-risk sites at a landscape scale. ~~They~~The rules apply when it is determined that proposed forest practices activities may contribute to the *potential* for sediment and debris ~~to be delivered to a~~ delivery to a public resource ~~stream, lake, marine water, or other fish and wildlife habitat, domestic water supplies, public capital improvements,~~ or ~~to~~ cause a threat to public safety. When the potential for slope instability is recognized, the likelihood of damage ~~that sediment and debris would~~ ~~travel far enough to threaten a public resource or public safety~~ must be considered. Other factors in determining this likelihood could include initial failure landslide volume, the nature of the landslide, potential landslide runout distance, and ~~the~~ slope or channel conditions ~~to determine the potential to deliver to a public resource or threaten public safety~~.

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 as a "Class IV-special" FPA 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.

The sectionBoard Manual Section 16 is composed of eight seven parts; a glossary, references, and appendices:

- The first five partsParts 2, 3, and 4 contain general background information for all readers on how to recognize the various landslide types and provinces in Washington State (Part 2), how to measure slope angles (Part 3), how to recognize slope form (Part 43), and how to recognize potentially unstable slopes and landforms for purposes of identifying them in the area of a proposed forest practices activity (Part 54).
- The final three partsParts 5, 6, 7 contain recommended procedures and resources, as applicable, for conducting reviews and assessments of potentially unstable areas in relation to proposed forest practices. **General practitioners** will find Parts 65.1.1 and 65.2.1 most useful for their office reviews and field assessments. The remainder of Part 6 5 and all of Parts 7 6 and 8 7 are geared towardgive guidance to the work of **qualified experts** to conduct expert-level office reviews and field assessments, and to prepare geotechnical reports.
- The sectionIt ends with a glossary of terms that may not be familiar to many readers; a list of the references cited throughout the document; and several appendices containing lists of resources that any reader may find informative or useful.

PART 2. OVERVIEW OF LANDSLIDE TYPES AND PROVINCESIN 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]

Under past forest practices rules, forest practices-caused landslides contributed to the acceleration of naturally occurring landslide processes[2] and may have contributed to the threatened and endangered status of certain species[3] as well as endangered human life in some instances[4]. The current rules were developed to protect public resources and prevent threats to public safety. They apply when it is determined that proposed forest practices activities may contribute to the *potential* for sediment and debris to be delivered to a stream, lake, marine water, or other fish and wildlife habitat, domestic water supplies, public capital improvements, or to cause a threat to public safety. When the potential for instability is recognized, the likelihood that sediment and debris would travel far enough to threaten a public resource or public safety must be considered. Other factors include initial failure volume, the nature of the landslide, landslide runout distance, and the slope or channel conditions to determine the potential to deliver to a public resource or threaten public safety.

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 as a "Class IV-special" FPA and receive additional environmental review under the State

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

2 e.g., Swanson et al., 1977; Robinson et al., 1999; Montgomery et al., 2000; Turner et al., 2010.

3 e.g., Sidle et al., 1985; Beechie et al., 2001.

4 e.g., Oregon Landslides and Public Safety Project Team, 2001.

~~Environmental Policy Act (SEPA). These landforms, commonly referred to as "rule identified landforms", are listed in WAC 222-16-050(1). They are:~~
- ~~Inner gorges, convergent headwalls, and bedrock hollows with slopes >70% (35 degrees);~~
- ~~Toes of deep-seated landslides with slopes >65% (33 degrees);~~
- ~~Groundwater recharge areas for glacial deep-seated landslides;~~
- ~~Outer edges of meander bends along valley walls or high terraces of an unconfined meandering stream; and~~
- ~~Any areas containing features indicating the presence of potential slope instability which cumulatively indicate the presence of unstable slopes.~~

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

Landslides can be classified in several ways. The ~~method~~ classification shown in Part 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 ~~failure surface geometries~~translational and rotational geometries (Figure 1). Translational failures can also occur on non-planar surfaces (i.e., concave or convex) in shallow soils overlying bedrock on steep slopes[5] 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 ~~considered~~ a "relict" landslide.

~~Ground failures~~Slope instability resulting in landslides occurs when gravitational forces~~, in combination with soil and other factors,~~ overcome the strength of the soil and rock on a slope. Contributing factors may include:
- The presence of an impermeable stratigraphic layer ~~beneath~~ underlying a permeable stratigraphic layer.
- Saturation by snowmelt, ~~rain~~ rain-~~on~~ on-snow events or heavy and/or prolonged rains that can saturate soils and create instability in soil and weakened bedrock.
- Erosion by rivers, glaciers, or ~~ocean waves~~ wave action that causes the over-steepening of slopes ~~resulting in~~and ~~removing~~ 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.~~Volcanic eruptions that produce lahars and instability on the lateral flanks of the volcano.~~
- Excess weight from ~~accumulation of rain or snow,~~activities such as stockpiling of rock or earth, ~~from waste piles, or manmade structures that exert excessive stress on slopes~~and road sidecast and landing construction.

[5] Robinson et al., 1999; Turner et al., 2010.

- ~~Human activities~~ Activities such as timber harvest and construction ~~activities~~ that disturb soils, weaken or remove the support for slopes, or increase runoff and groundwater recharge over a seasonal timescale or during prolonged heavy precipitation events.
- Activities such as stream pirating or concentrating water in unstable locations during road construction.

2.1 Landslide Types and Effects

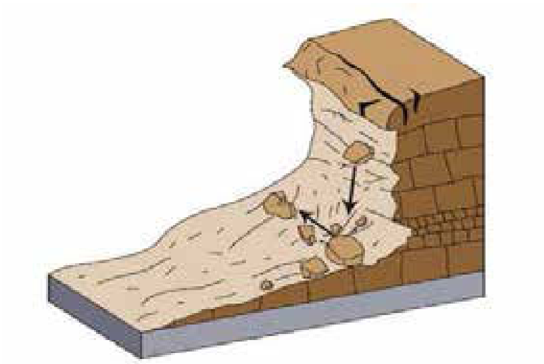
Several classification schemes are used by geologists, engineers, and other professionals to identify and describe landslides. The classification scheme of Varnes (1978), as modified by the U.S. Geological Survey (~~U.S. Geological Survey,~~ 2004)~~,~~ and Hungr et al. (2001) is used for the purposes 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. 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. In the forested environment where coarse materials including wood are common, the terms under "Predominately Fine" are seldom used.

Table 1. Landslide Classification

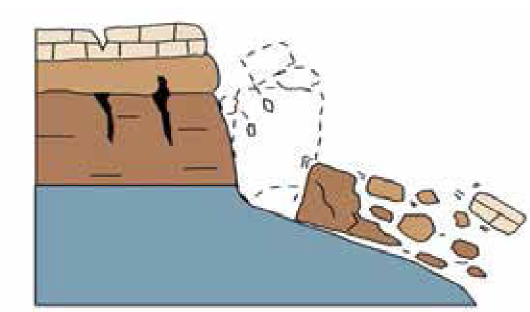
~~Modified from~~Based on Varnes (1978) as modified by U.S. Geological Survey (2004) and ~~Varnes (1978)~~Hungr (2001).

Type of Movement		Type of Material		
		Bedrock	Soils	
			Predominately Coarse	Predominately Fine
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		

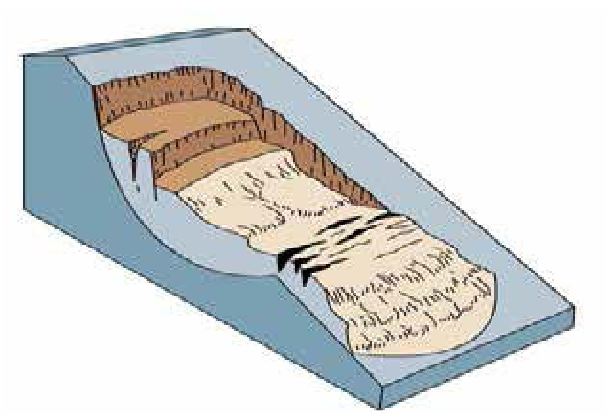
~~In this scheme, landslides are classified by types of materials and movement.~~ Materials in a landslide mass are either rock or soil (or both) and may ~~also~~ include organic debris. In this context, soil is composed of sand-sized or finer particles and debris is composed of coarser fragments. The types of landslides commonly found in forested areas in Washington ~~include~~ are slides, flows, and complex landslides. The types of movement describe the actual internal mechanics of how the landslide mass is displaced: fall, topple, slide, spread, or flow. Thus, landslides are described ~~using~~ with two terms that refer ~~respectively~~ to the type of material and method of movement (rockfall, debris flow, and so forth). Landslides may also occur as a complex failure encompassing more than one type of movement ~~(e.g., debris slide - debris flow)~~. 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.



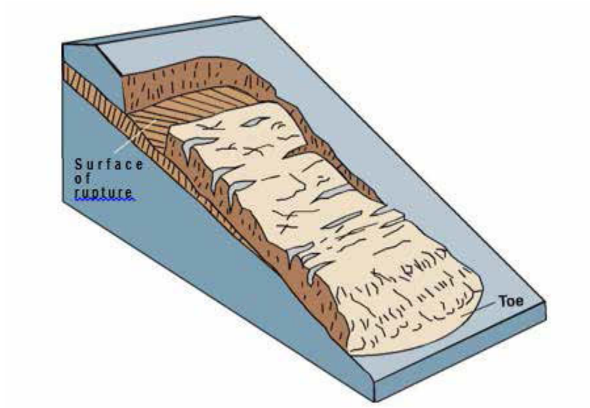
Falls: Falls occur when a mass of rock or soil detaches from a steep slope or cliff, and ~~is~~ are often caused by the undercutting of the slope. The failure is typically rapid to very rapid. The fallen mass may continue down the slope until the terrain flattens.



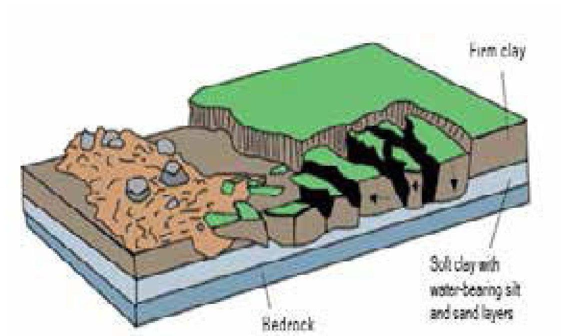
Topples: Landslides where the forward rotation of a mass of rock or soil breaks away or 'topples' from the slope. Their failure rates range from extremely slow to extremely fast.



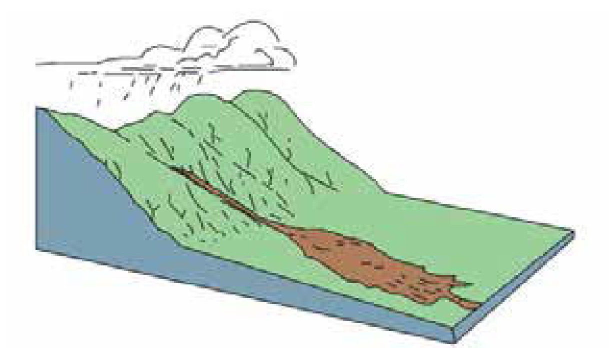
Rotational slides: ~~These are l~~Landslides where the surface of rupture is concave-up and the slide movement is rotational about an axis that is parallel to the contour of the slope. Glacial deep-seated landslides can be rotational slides developed in glacial sediments common in the Puget Sound area,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



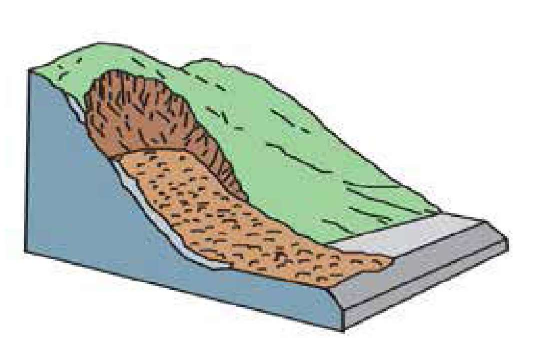
Translational slides: Landslides where the surface of the rupture is roughly planar with a surface roughly parallel to the ground surface. These are called rock slides, block glides, slab slides, or debris slides.



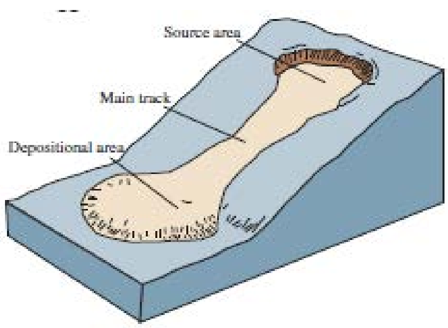
Lateral spreads: Landslides that generally occur on very gentle or level slopes and are caused by subsidence of a fractured mass of cohesive material into softer, often liquefied underlying material.



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



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



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

Figure 1. Illustrations of the major types of landslide movement (all from Highland and Bobrowsky, 2008, except "earth flows" is from U.S. Geological Survey, 2004).

2.2 Shallow Landslide Types

Shallow landslides are unstable features ~~which~~ that typically fail within the vegetation rooting zone and may respond to rainfall events over periods of days to weeks. They occur on a variety of landforms including bedrock hollows, convergent headwalls, inner gorges, toes of deep-seated landslides, the outer edges of meander bends, and in other areas with steep slopes. The amount of water and the materials contained within shallow landslides affect the manner and ~~the~~ 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 down slope by sliding or rolling forward. The results are irregular hummocky deposits that are typically poorly sorted and non-stratified. Debris slides include those types of landslides also known as shallow rapid, soil slips, and debris avalanches. If debris slides entrain enough water they can become debris flows.

Debris flows are channelized slurries composed of sediment, water, vegetation, and other debris. Solids typically constitute >60% of the volume.[6] Debris flows usually occur in steep channels as debris becomes charged with water (from soil water or upon entering a stream channel) and liquefies as it breaks up. Channelized debris flows often entrain material and can significantly bulk up in volume during transport. These landslides can travel thousands of feet or miles from the point of initiation, scouring the channel to bedrock in steeper channels. Debris flows commonly slow where the channel makes a sharp bend and stop where the channel slope gradient becomes gentler than about 3 degrees (5%), or the valley bottom becomes wider and allows the flow to spread out. Hyper-concentrated floods may travel greater distances and on shallower slopes than debris flows based on their water content.[7]

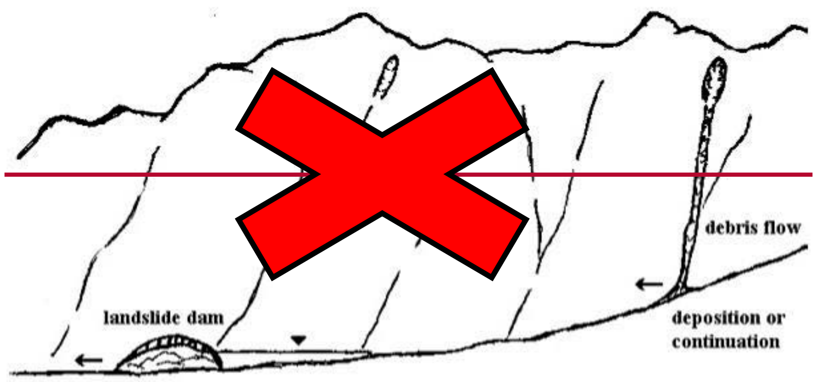
[6] Pierson and Scott, 1985.
[7] Iverson and Reid, 1992.

Figure 2. Debris flow (DNR, 2000).

Debris avalanches. Hungr et al., 2001 defined debris avalanches as follows: "Debris avalanche is a very rapid to extremely rapid shallow flows of partially or fully saturated debris on steep slopes, without confinement in an established channel." Sharpe (1938) defined debris avalanche as a shallow landslide that is morphologically similar to a snow avalanche. Debris avalanches may enter steep drainage channels or gullies and become debris flows. Therefore, the term debris avalanche should be reserved for events that remain poorly channeled over most of their length, without a defined recurrent path and a laterally bounded deposition landform.

Hyper-concentratedDam break floods are a subset of debris flows-type landslides defined as very rapid surging flows of water, heavily charged with debris, in a steep channel.[8] They containing a mixture of water and sediment (dominantly sand-sized), and organic debris with solids that range between 20% and 60% by volume.[9] In forested mountains, they are commonly caused by the collapse of dams, such as those formed by landslide dams (Figure 23) 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.[10] Such hyper-concentrated floods can rise higher than normal rainfall- or snowmelt-induced flows along relatively confined valley bottoms, driving flood waters, sediment, and wood loads to elevations high above the active channel, and the active floodplain, if present.

[8] Hungr et al., 2001.
[9] Pierson and Scott, 1985.
[10] Johnson, 1991.



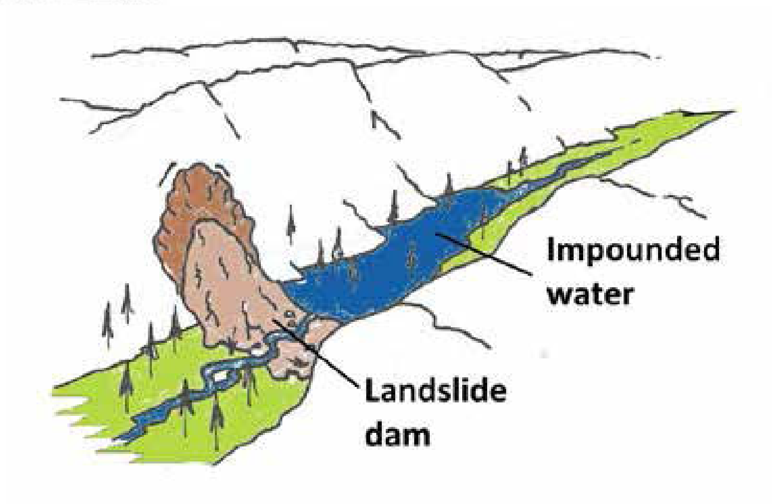


Figure ~~2~~3. ~~Debris flows, and hyper-concentrated floods~~Impounded water caused by landslide dam.

Debris flows and ~~hyper-concentrated~~dam break floods can occur in any unstable or potentially unstable terrain with susceptible valley geometry. In natural systems, debris flows and ~~hyper-concentrated~~dam break floods ~~caused by dam breaks~~ are responsible for moving sediment and woody debris from hillslopes and small channels down into larger streams. ~~But debris flows~~They can also ~~cause damage to streams by~~ scour~~ing~~ channel reaches, disturb~~ing~~ riparian zones, ~~impacting habitat, and~~ dump~~ing~~ debris onto salmonid spawning areas~~. ~~, ~~Debris flows can cause~~ elevate~~d~~ turbidity, and adversely affect water quality downstream~~, pose threats to public safety, and damage roads and structures in their paths~~ and threaten public safety (Figure 3).

Figure ~~3~~4. Left: Road-initiated debris flows in ~~inner gorges~~unstable landforms, Sygitowicz Creek, Whatcom County (Photo: DNR, 1983). Right: Same hillslope 28 years later (2011 aerial photo).

The ~~debris flows shown~~photo on the left in Figure ~~3~~ 4 shows debris flows that coalesced and, after exiting the confined channel at the base of the mountain, formed a new debris flow spreading across a 1,000-foot wide swath for a distance of 2,000 feet before entering the South Fork Nooksack River. Between the base of the mountain and the river, the debris flow affected (if not severely damaged) a county road, farmyard, house sites, and more than 60 acres of cultivated farm fields. The photo on the right shows the same hillslope after harvest with leave tree areas in the slide-prone inner gorges.

2.3 Deep-Seated Landslides

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

Deep-seated landslides can occur almost anywhere on a hillslope~~ and are usually associated with hydrologic responses in permeable materials overlying less permeable materials~~. Many ~~deep-seated landslides~~ occur in the lower portions of hillslopes and extend directly into stream channels, whereas those confined to upper slopes may not have the ability to deposit material directly into channels. ~~Deep-seated landslides~~They ~~characteristically~~ 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 to weather patterns over months to years or even decades.[11] The larger deep-seated landslides can usually be identified from LiDAR (Light Detection and Ranging) imagery, topographic maps, and aerial photos, whereas the identification of smaller landslides are more difficult to identify and often requires a field inspection and comprehensive inventory maps.

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). These can be seen in Figures 18 and 23. The downslope edge of the toe can become over steepened from stream erosion or from the rotation of the slide mass. 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. These three main parts are shown in Figure 23. 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 odd ways due to differential movement of discrete landslide blocks. The parts of deep-seated landslides that are most susceptible to shallow landslides and potential sediment delivery are steep scarps (including marginal stream side slopes) and toe edges.

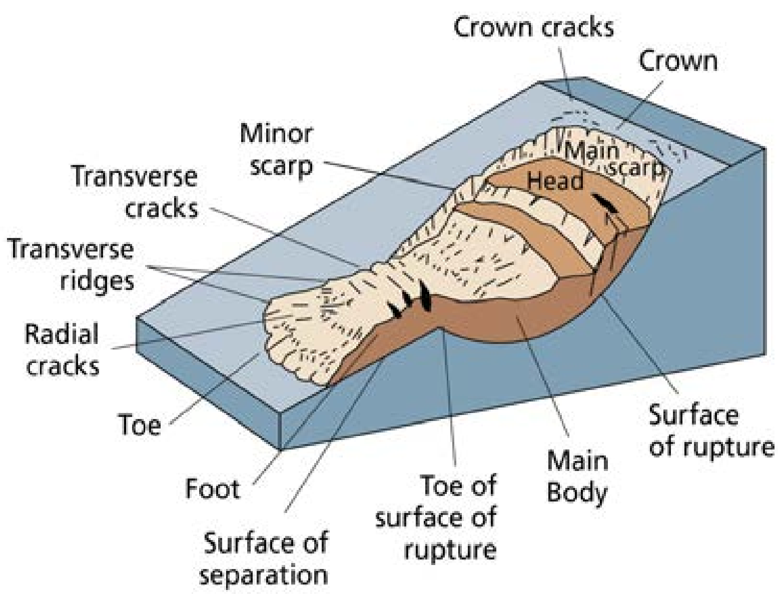


Figure 235. Rotational deep-seated landslide. Rotational displacement of blocks of soil commonly occur at the head of the landslide (adapted from USGS, 2004).

Movement of deep-seated landslides can be complex, ranging from slow to rapid, and may include numerous small to large horizontal and vertical displacements variously triggered by one or more failure mechanisms.[12] Deep-seated landslides often are part of large landslide complexes that may be intermittently active for hundreds of years or more.[13] The bodies and toes of deep-seated landslides and earth flows are made up of incoherent collapsed materials that were weakened from previous movement of the materials, and therefore may be subject to debris flow initiation. As a

[11] Washington State Department of Emergency Management, 2013.
[12] Roering et al., 2005.
[13] Bovis, 1985; Keefer and Johnson, 1983.

result, ~~Sediment~~ sediment delivery ~~is common~~can occur from shallow ~~landslides~~ landsliding on steep stream-adjacent toes of deep-seated landslides and from steep side slopes ~~of~~ along marginal stream~~s flowing on~~ channels within the bodies of deep-seated landslides. ~~More detailed descriptions of deep-seated landslides are provided in Part 5 (5.2 and 5.5.1).~~

~~One common t~~Triggering mechanisms of deep-seated landslides can result~~s~~ from ~~the~~ over-steepening of the toe by natural means such as glacial erosion or fluvial undercutting, ~~fault uplift~~earthquakes, or ~~by~~ anthropogenic activities such as excavating for land development.[14] Movement in landslides is usually triggered by accumulations of water at the slide zone, ~~so~~therefore land use changes that alter the amount or timing of water delivered to a landslide can start or accelerate movement.[15] Initiation or reinitiation of such landslides has also been associated with ~~changes in land use[16],~~ increases in groundwater levels[17] due to individual storms or in response to seasonal accumulation from rainfall or snow melt, depending on soil and bedrock properties, and the degradation of material strength through natural processes. ~~The technical~~When subsurface water is assumed to influence the movement of a deep-seated landslide, the methods used to identify groundwater recharge areas ~~in~~associated with glacial deep-seated landslides ~~are no different than those for~~may apply to other (e.g., non-glacial) deep-seated landslides.

The loss of tree canopy interception of moisture and the reduction in evapotranspiration through timber removal on areas up-gradient of the slide may also initiate movement of the slide. However, many deep-seated landslides are not hydrogeologically connected to groundwater sources up-gradient.[18] Generally, avoiding the following practices will ~~prevent most problems~~ avoid reinitiating or accelerating deep-seated landslide movement: removing material during road construction or quarrying ~~which could destabilize~~at the toe; ~~dumping~~overloading slopes by placing spoils on the upper or mid-scarp areas~~, which could overload the slopes, or compacting the soil in these places which could change~~changing subsurface hydrology by excessive soil compaction; and directing additional water into the slide from road drainage or ~~drainage capture~~captured streams.

~~**2.4 Geographic Distribution of Landslides in Washington**~~

~~Landsliding is a widespread geomorphic process which actively modifies the varied topography and diverse underlying geologic materials present throughout the 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.~~

~~The Puget Lowlands-North Cascade Foothills is a region that 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~~

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14 Schuster and Wieczoreck, 2002.
15 Cronin, 1992.
~~16 Van Beek and van Asch, 2004.~~
17 van Asch et al., 2005.
18 van Asch, et al., 2009.

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.

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.[19] Debris flows and avalanches are often generated in steeper drainages and slopes.

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.[20] Thick, deeply weathered loess deposits are sources for shallow landslides, debris flows, and avalanches.[21] These deposits are prevalent along the lower Columbia River valley, as well as other areas where colluvial deposits have accumulated on slopes and in drainages underlain by strong and relatively unweathered rock.

The Cascade Range is generally divided on the basis of rock types into northern and southern provinces occurring geographically in the vicinity of Snoqualmie Pass. Strong crystalline rocks intensely scoured by alpine glaciations occur to the north. Weaker volcanic flows, typically pyroclastic and volcaniclastic rocks occur to the south, much of which was beyond the reach of the last continental glaciation. Rockfalls and complex rock slides are dominant in the steep bedrock slopes in the North Cascades. In the South Cascades and Columbia Gorge, weak interbeds control large translational failures in the Chumstick and Roslyn Formations[22], the Columbia River Basalts and other volcanic flow rocks, and Cowlitz Formation and Sandy River Mudstone[23]. Shallow landslides generating debris avalanches and flows are common on steep slopes and drainages. Pleistocene glacial sediments that mantle the mostly crystalline core of the Okanogan Highlands are prone to both shallow and deep-seated landslides. Rockfalls and rock slides are common from the many steep bedrock exposures in the region. The Blue Mountains in southeastern Washington also

[19] Tabor and Cady, 1978; Badger, 1993.
[20] Gerstel and Badger, 2002.
[21] Thorsen, 1989.
[22] Tabor et al., 1987.
[23] Wegmann, 2003.

have experienced recurring and widespread shallow landsliding and debris flows related to storm events.[24]

PART 3. MEASUREMENT OF SLOPE ANGLES

The forest practices rules contain specific slopes gradients (degrees and percent) for potentially unstable slope or landform descriptions. Part 3 provides guidance in determining slope gradients when evaluating the feature on site. 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.

3.1 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 (Figure 4a).

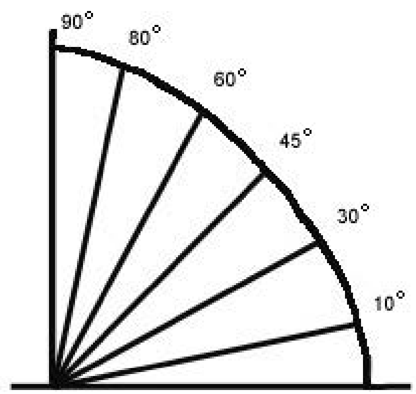


Figure 4a. Angles in degrees.

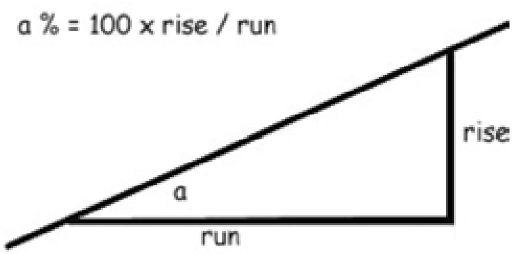


Figure 4b. Angles in percent.

3.2 Percent

In Figure 4b, 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.

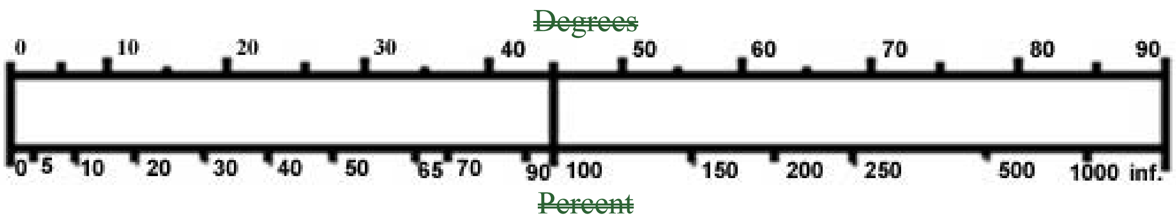
3.3 Relationship of Degrees to Percent

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

[24] Harp et al., 1997.

~~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.~~

~~Figure 5 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.~~



~~*Figure 5. Slope gradients in degrees and percent.*~~

PART ~~4~~3. SLOPE FORM

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

~~Additionally, s~~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.

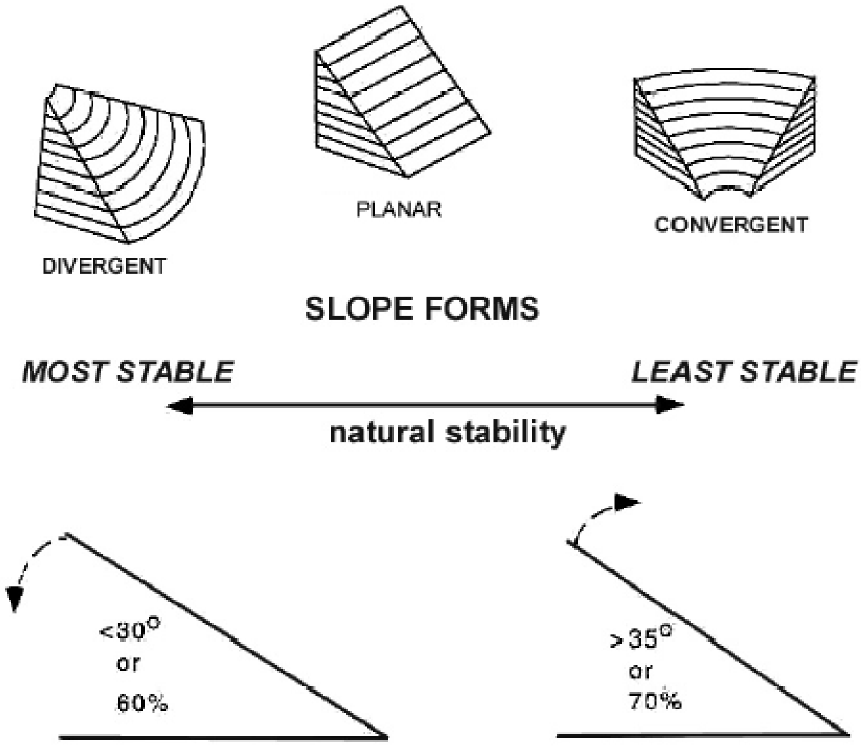


Figure 6a. Slope configurations as observed in map view.

Figure 6a shows three major slope forms (divergent, planar, and convergent) and their relative stability. These slope form terms are used in reference to contour (across) directions on a slope. Typically, convergent areas with slope gradients equal to or greater than 35 degrees (70%) are at a higher risk of sliding.[25]

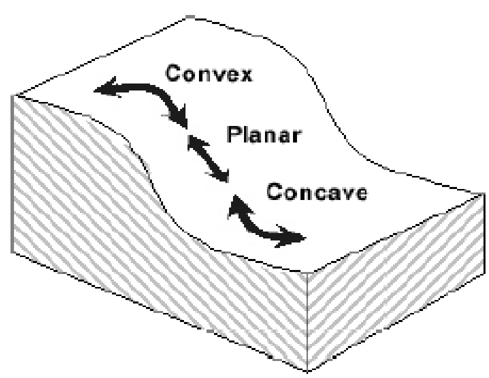


Figure 6b. Slope configurations as observed in profile: convex, planar, and concave. These terms are used in reference to up and down directions on a slope (Drawing: Jack Powell, DNR, 2004).

[25] Benda et al., 1997.

PART 54. 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 54.1);[26]
B. Toes of deep-seated landslides with slopes steeper than 33 degrees (>65 %) (see 54.2);
C. Groundwater recharge areas for glacial deep-seated landslides (see 54.3);
D. Outer edges of meander bends along valley walls or high terraces of an unconfined meandering stream (see 54.4); or
E. Any areas containing features indicating the presence of potential slope instability which cumulatively indicate the presence of unstable slopes (see 54.5).

The rule-identified landforms represent the most common landforms with the potential to fail in response to natural and management factors. Unstable landformsThey can initially 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 then needed to verify their presence and precisely delineate landform boundaries, measure gradients, and note other characteristics. In addition to the information provided in this partPart 4, more informationguidance for identifying potentially unstable landforms is offered in Part 65, and tools and resources are listed in appendices A through G.

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

54.1 Bedrock Hollows, Convergent Headwalls, Inner Gorges

These three landforms are commonly associated with each otherfound together as shown in Figures 7 and 8.

[26] See Appendix A for guidance on determining slope gradients.

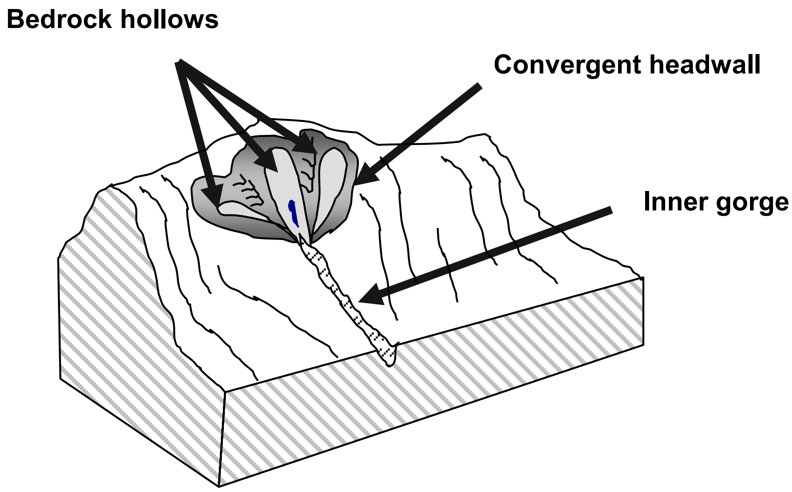


Figure 7. Typical hillslope relationships between bedrock hollows, convergent headwalls, and inner gorges (Drawing: Jack Powell, DNR, 2003).

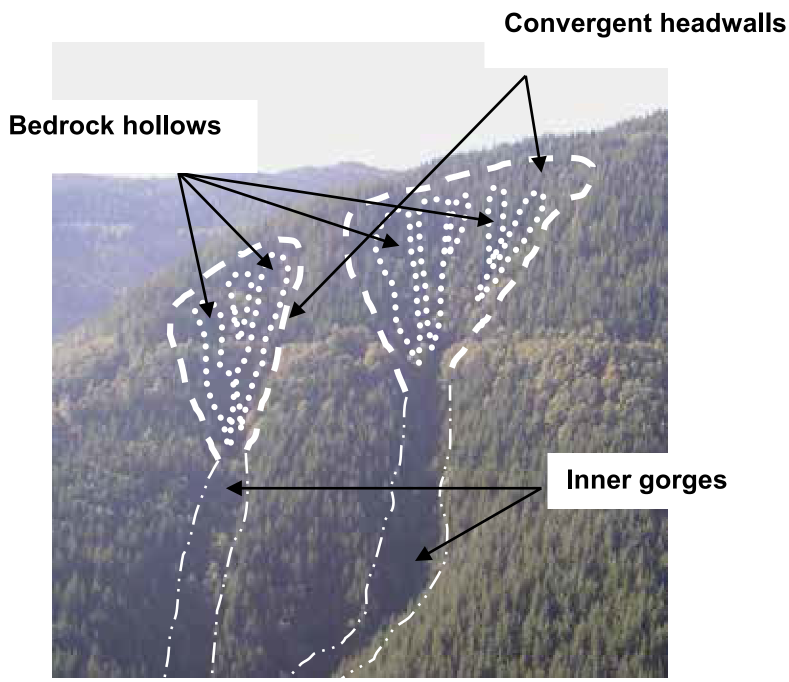


Figure 8. Common hillslope relationship: bedrock hollows in convergent headwalls draining to inner gorges (Photo and drawing: Jack Powell, DNR, 2003).

Bedrock hollows are also called colluvium-filled bedrock hollows, zero-order basins, swales, bedrock depressions, or simply hollows.[27] Not all hollows contain bedrock so the term "bedrock" hollow can be a misnomer. ~~However,~~In the forest practices rule~~s cite these features as~~context, the "bedrock~~"~~ hollows~~ so this" is the term used in this document~~listed in category A are hollows formed in bedrock. However, hollows formed in other materials such as glacial outwash without a bedrock

[27] Crozier et al., 1990; Dietrich et al., 1986.

substrate may also show signs of instability and would need evaluation similar to hollows containing bedrock. Such hollows that show signs of instability would fit into category E of the rule.

Bedrock Hollows hollows are commonly spoon-shaped areas of convergent topography with concave profiles on hillslopes. They tend to be oriented linearly up- and down-slope. Their upper ends can extend to the ridge or begin as much as several hundred feet below the ridge line. Most bedrock hollows are approximately 75 to 200 feet wide at their apex (but they can also be as narrow as several feet across at the top), and narrow to 30 to 60 feet downhill. Bedrock Hollows 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 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).

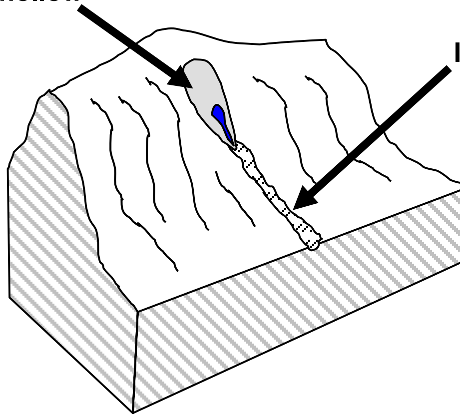


Figure 9. Bedrock hollow and relationship to inner gorges (Drawing: Jack Powell, DNR, 2003).

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

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

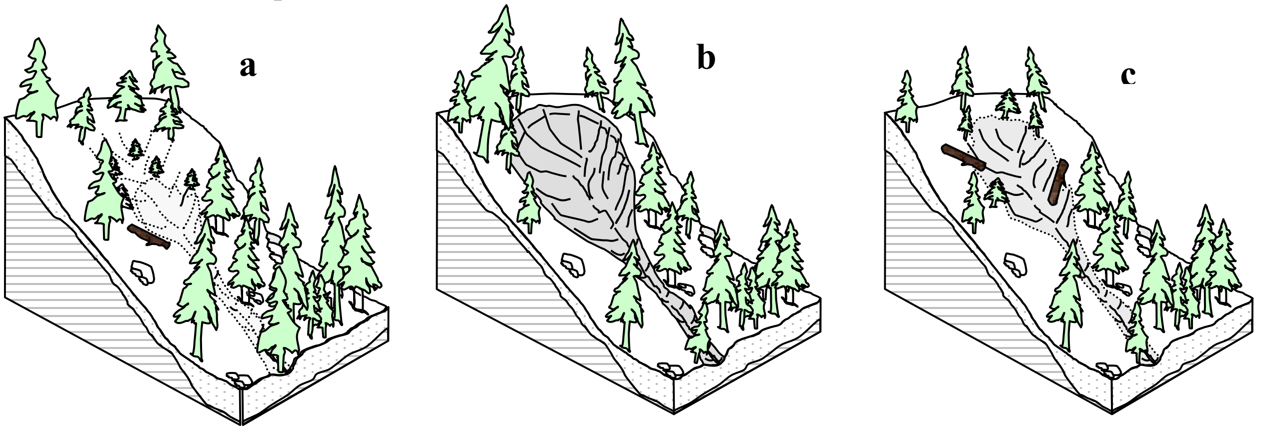


Figure 10. Evolution of a bedrock hollow following a landslide (adapted from Dietrich et al., 1988; drawing by Jack Powell, DNR, 2004).

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

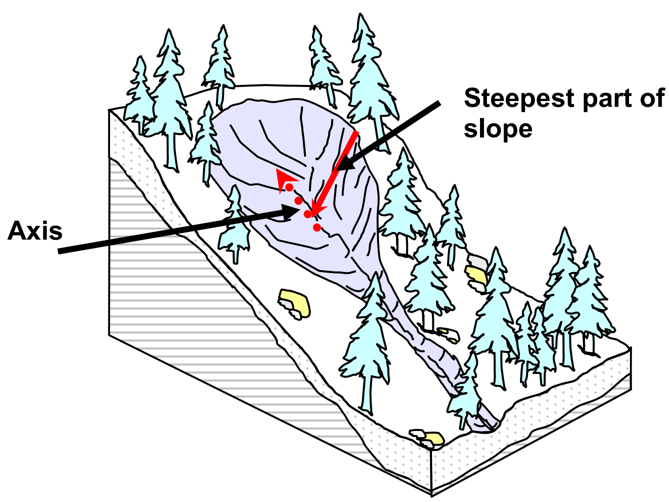


Figure 11. Bedrock hollow slopes are measured ~~on~~ at the steepest part of the slope, ~~generally not~~rather than along the axis (Drawing: Jack Powell, DNR, 2004).

Vegetation can provide the critical cohesion on marginally stable slopes and removes water from the soil through evapotranspiration. Leaving trees in steep, landslide-prone bedrock hollows helps maintain rooting strength and should reduce the likelihood of landsliding (Figure 12).[28] However, windthrow of the residual trees following harvest can be associated with debris slide or debris flow events. In high wind environments, ~~it is essential to~~ harvest ~~in a manner~~practices that will limit the susceptibility of the residual trees to windthrow as well as to reduce the potential for landslides, ~~(for example~~include leaving wider strips, pruning or topping trees in the strips, or feathering the edges of reserve strips~~)~~.

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

Convergent headwalls are funnel-shaped landforms, broad at the ridgetop and terminating where headwaters converge into a single channel. A series of converging bedrock hollows may form the upper part of a convergent headwall ~~(Figure 13)~~. Convergent headwalls are broadly concave both longitudinally and across the slope, but may contain sharp ridges that separate the bedrock hollows or headwater channels (Figure ~~14~~ 13 and Figure ~~15~~14).

~~*Figure 13. Convergent headwall example (Photo: Venice Goetz, DNR, 1995).*~~

[28] Montgomery et al., 2000.

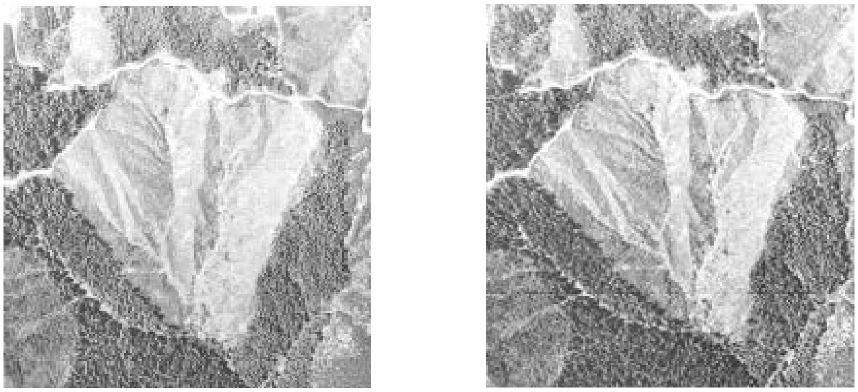
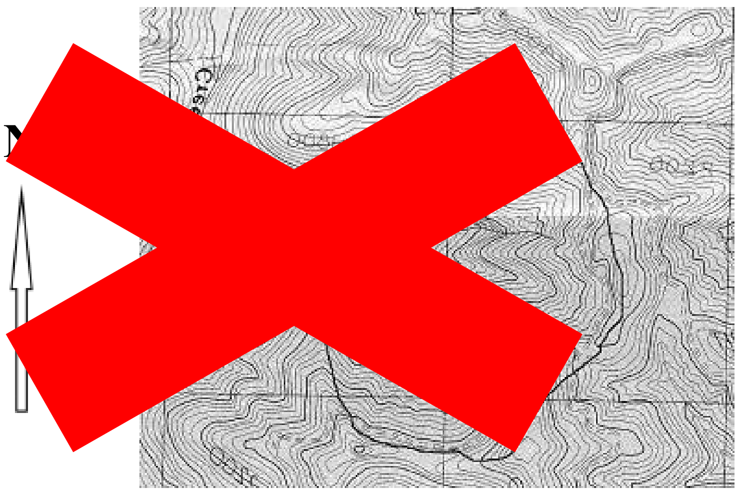


Figure 1413. Stereo- pair of a clearcut convergent headwall in Pistol Creek basin, North Fork Calawah River, Washington.



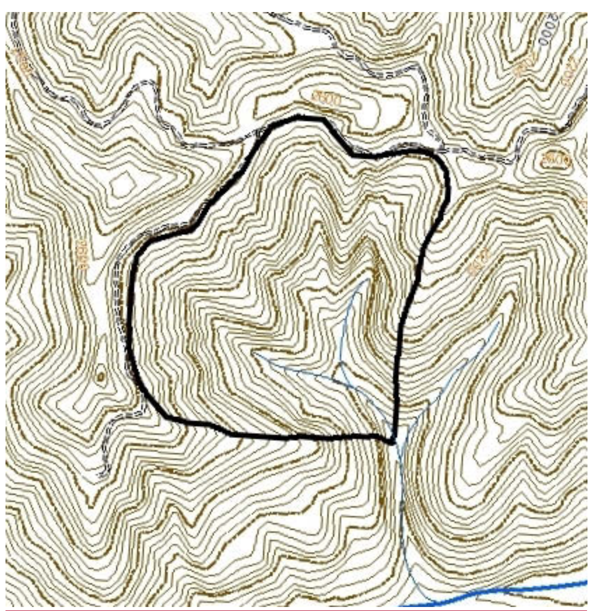


Figure 1514. Rotated Topographic topographic map and outline of convergent headwall displayed in the stereo- pair of Figure 1412. Scanned from portions of Hunger Mountain and Snider Peak USGS 7.5' quadrangles.

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%). ~~Unlike bedrock hollows, which exhibit a wide range of gradients, only very steep convergent landforms with an obvious history of landslides are called convergent headwalls.~~ Soils are thin because landslides are frequent in these landforms. History of ~~evacuation~~ 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 ~~(due to frequent landslides)~~, may allow~~s~~ for a more rapid onset of ~~subsurface storm water flow~~soil saturation. The mass wasting response of these landforms due to storms, disturbances such as fire, and forest practices activities is much greater than is observed on other steep hillslopes in the same geologic settings. In Figure 15, the convergent headwall has approximately 25 bedrock hollows today (not visible through the canopy) and eons of high erosion have caused the entire ridgeline to set back several hundred feet from that of the extended hillslope. Landslide scars from ~~Convergent~~ convergent headwalls may be ~~also~~ prone to surface erosion ~~from the scars of frequent landslides~~.

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

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

Inner gorges are canyons created by a combination of stream down-cutting and mass movement on slope walls.[29] Inner gorges are characterized by steep, straight or concave side~~-~~slope walls that commonly have a distinctive break in slope (Figure 16). Debris flows, in part, shape inner gorges by scouring the stream, undercutting side slopes, and/or depositing material within or adjacent to the channel (Figure 17). Inner gorge side slopes may show evidence of recent landslides, such as

[29] Kelsey, 1988.

obvious landslides, 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 exist of sufficient size to stop moving material exist along the gorge walls, but these are uncommon.

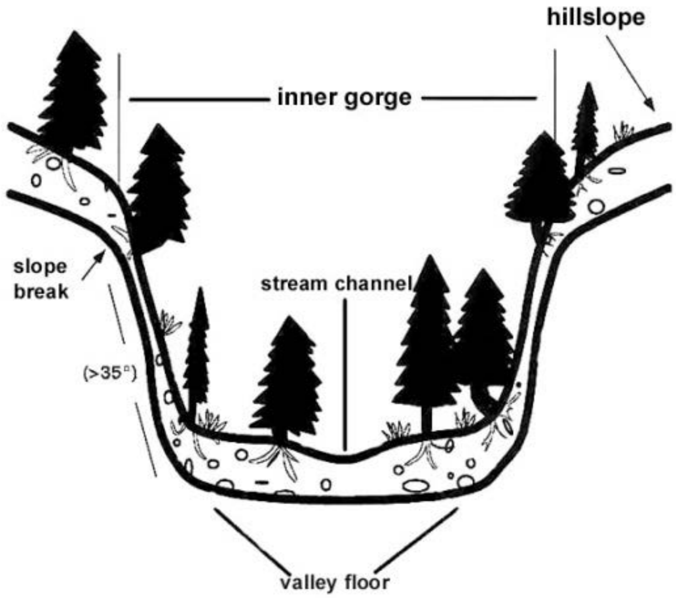


Figure 16. Cross-section of an inner gorge. This view emphasizes the abrupt steepening below the break-in-slope (Drawing: Benda et al., 1998).

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

The geometry of inner gorges varies from simple to complex. Steep inner gorge walls can be continuous for great lengths, as along a highly confined stream that is actively down cutting~~,~~; but there may also be gentler slopes between steeper ones along valley walls. Inner gorges can be asymmetrical with one side being steeper than the other. Stream-eroded valley sides along main stem rivers, ~~which~~ can be V-shaped with distinct slope breaks at the top~~,~~. These commonly ~~do not~~ show evidence of ~~recent~~ small-scale landsliding ~~as do~~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 (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, ~~(18%)~~ 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. ~~which~~ This can ~~destabilize the soil mass and initiate~~increase the likelihood of ~~movement~~landsliding. ~~Just as for~~As with all other landforms, inner gorge slopes should be measured along the steepest portion of the slope (see Figure 11).

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

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

54.2 Toes of Deep-Seated Landslides

Toes of deep-seated landslides with slopes greater than 33 degrees (65%) are a rule-identified forest practices regulatory landform. In this context, "toes of deep-seated landslides" means the down slope toe edges, not the entire toe area of displacement material. (Figures 23 5 and 19 shows the toe in relation to other landslide features).

Landslides that havewith 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 18 20 may have removed a portion of the toe, causing re-activation of the landslide. Resulting instability can take the form of shallow landslides, small-scale slumping, or reactivation of parts or the whole of a deep-seated landslide. Because deep-seated landslides are usually in weak materials (further weakened by previous movement), an angle of 33 degrees (65%) is the regulatory threshold value used on the potentially unstable toe edges. Regardless of the surface expression of the toe, it is best to avoid disrupting the balance of the landslide mass by cutting into or removing material from the toe area.

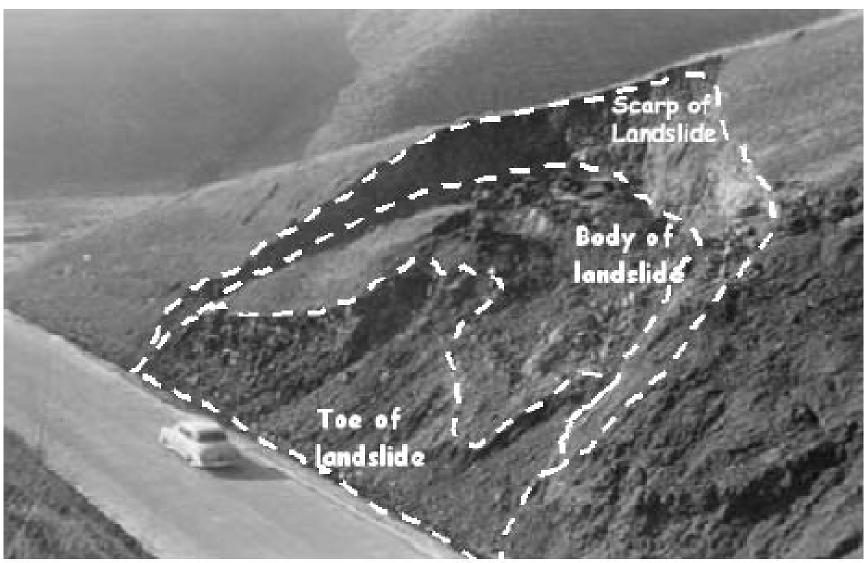


Figure 1819. Deep-seated landslide showing the head scarp, side-scarps, body, and toe. Some of the toe has been removed in building and maintaining the highway (adapted from USGS photo).

4.3 Groundwater Recharge Areas, and the Effects of Groundwater on Landslide Stability of (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~~s~~ in glacial terrain, it is necessary to first identify ~~and delineate glacial deep-seated~~the associated landslide~~s~~. ~~Glacial deep-seated landslides are distinguished from other forms of deep-seated landslides by the materials in which they occur; however, their failure mechanics are similar to deep-seated landslides developed in other materials.~~[30] ~~Deep-seated landslides developed in other materials are also susceptible to forest practices activities in the groundwater recharge area. Consequently, scientific knowledge regarding the dynamics of deep-seated failures can be applied to better understand and manage glacial deep-seated landslides.~~

Glacial deep-seated landslides occur in glacial terrain and are defined as a landslide feature 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 ~~are~~can be similar to deep-seated landslides developed in other materials.[31]

Glacial deep-seated landslide deposits occur in continental or alpine glacial deposits, or a combination of both. The continental glacial deposits in Washington are located in the northern areas of the state (Figure ~~19~~20a), ~~whereas~~ and the alpine glacial deposits (Figure ~~19~~20b) ~~can be~~are found in mid-to-high elevation mountain ranges.[32]

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

~~30 Terzhagi, 1951.~~
31 Terzhagi, 1951.
32 Booth et al., 2003; Booth et al., 1994; Thorsen, R.M., 1980; Barnosky, 1984; Heusser, 1973; Crandall, 1965.t

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

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

Glacial and interglacial deposits ~~and other earthen materials~~ display a wide range of hydrogeologic characteristics, including permeability (the rate water moves through a geologic material) and storage capacity (the amount of water released or taken into storage per unit area of geologic material for a given change in hydraulic head). Glacial till is comprised of unsorted and non-stratified glacial materials (ranging in size from clay to boulders) that was generally overrun by glacial ice during periods when the ice was advancing. ~~Glacial t~~Till ~~generally~~ 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 ~~either~~ the advance or the retreat of the glacier, and have higher permeability and ~~higher~~ 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 ~~tile~~till. See Appendix ~~F~~ H for ~~hydraulic~~ the hydrologic properties of various soils.

Glacial ~~Deep~~deep-seated landslides can be affected by the hydrologic budget of an area (Figure 20). 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~~, or vadose zone,~~ and ~~the~~ saturated zones.

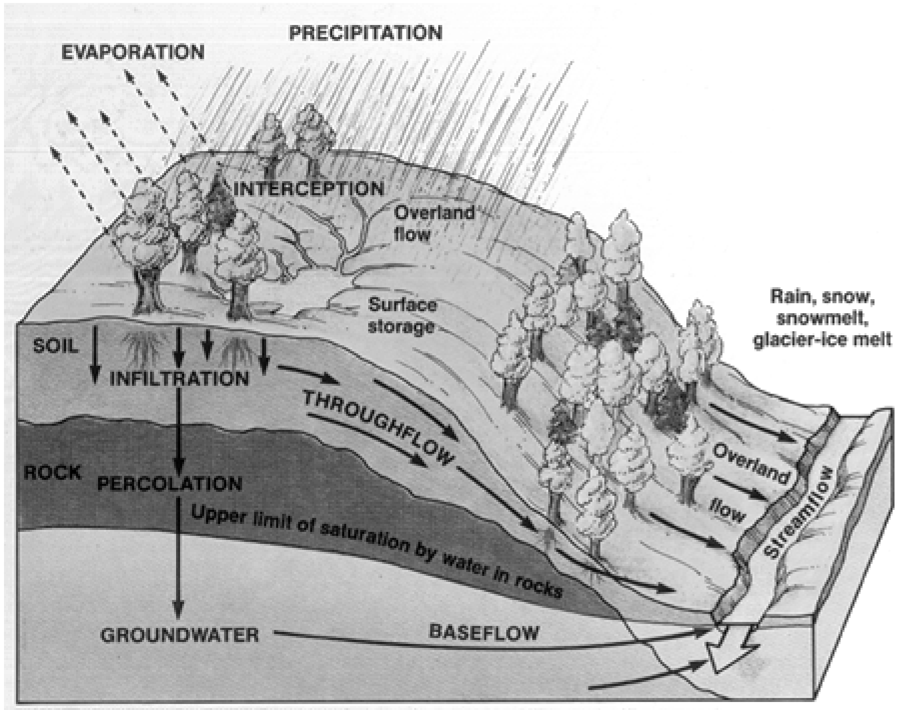


Figure ~~20~~21. Hydrologic budget of a hillslope (University of Colorado).

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

~~5.3.1 Groundwater Flow~~

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

Differences in permeability within glacial sediments control the infiltration and movement of groundwater within the recharge area.[33] 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 ~~clay~~ deposits, ~~or~~ till, or bedrock (Figure ~~21~~22). This is a common configuration of the glacial deposits in much of the ~~northern half of western Washington, for example~~Puget Lowlands (e.g. landslides in Seattle)[34] and ~~landslides in~~in the North

[33] Bauer and Mastin, 1997; Vaccaro et al., 1998.
[34] Gerstel et al., 1997.

Cascades foothill river valleys (e.g. the Stillaguamish River valley)[35]~~, but~~. However, this type of landslide also occurs in alpine glacial deposits elsewhere in ~~southwest~~ Washington, ~~far~~ apart from the maximum extent of continental glaciation.

A common example of failure is where ~~Groundwater~~ groundwater is flowing through permeable sand layers ~~is~~ perched above the less permeable clay or till layers. ~~During and following~~ Glacial deep-seated landslides can respond to precipitation events, where the permeable layer (e.g., sand ~~above the clay~~ and gravel from recessional outwashes) becomes saturated ~~creating a buoyant effect and lowering cohesion in the sand, both of which~~ above a less permeable layer (e.g., glaciolacustrine clay) forming a perched groundwater table that weakens the contact between the clay and sand. ~~This in turn may cause the overlying mass to slide~~The saturated conditions can increase soil pore water pressures and reduce the soil strength. Glacial deep-seated landslide failure planes can occur along these sand/clay contacts. A common predictor of perched groundwater is the presence of ~~a horizontal line of~~ springs (groundwater discharge) or ~~a line of~~hydrophytic (moisture loving) vegetation ~~at the contact point between the permeable and less permeable layers~~. Groundwater discharging as springs along the sand-clay contact can aid draining of the aquifer.

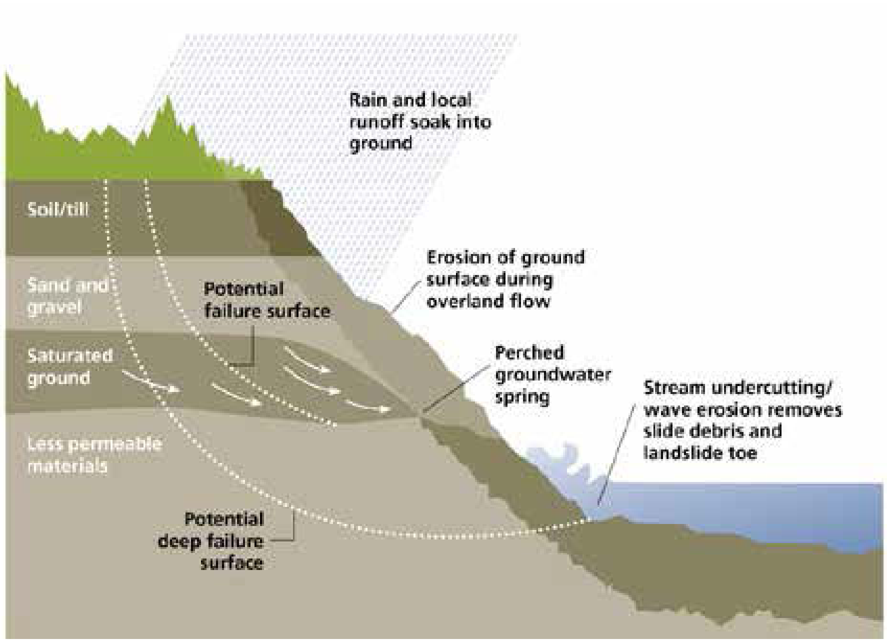


Figure ~~21~~22. Diagram illustrating failure surface resulting from groundwater recharge to a glacial deep-seated landslide (DNR, 2014).

A classic example of a geologic setting where glacial deep-seated landslides are common is in the Puget Sound lowlands where the Esperance Sand or Vashon advance outwash overlies the Lawton Clay. In this setting, groundwater recharge from precipitation infiltrates downward within the hillslope until it encounters the relatively impermeable Lawton Clay. Because the water cannot infiltrate into the Lawton Clay at the same rate ~~at which~~ 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 ~~which~~ that causes water to flow horizontally along the sand-clay contact, resulting in springs where this contact is exposed at the surface.[36]

[35] Benda et al., 1988.
[36] Tubbs, 1974.

~~5.3.2 Effects of Groundwater on Slope Stability~~
Saturation of the pore spaces within sediments reduces ~~grain-~~grain-~~to-~~to-grain contact which reduces the effective strength of materials. ~~This phenomenon of~~ Because soil saturation reduces the effective strength of the soil, which in turn reduces the stability of a slope ~~comprised of saturated sediments. Because of the likelihood of subsurface water flow along and within perching layers in glacial strata~~, certain forest practices activities proposed within recharge areas for glacial deep-seated landslides may be classified “Class IV-special” per WAC 222-16-050(1)(d)(i)(C). Such Class IV-special proposals ~~and~~ 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 ~~can be effectively~~is delivered to a glacial deep-seated landslide.

The first order approximation of the recharge area is the surface basin (topographically defined) directly above and including the landslide. The spatial extent of a groundwater recharge area can ~~also~~ be interpreted from field observation of soil profiles, geologic structure, stratigraphy, well logs or boreholes, and geologic maps, to the extent these resources are applicable. ~~Additional information regarding delineating and assessing the groundwater recharge areas is included in Part 6.3 and Part 7.2.~~

~~5~~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 (see Figure ~~22~~23).[37] The outer edges of meander bends are susceptible to deep-seated and shallow landsliding, including debris avalanching and small-scale slumping. ~~The outer edges of meander bends may be protected by the riparian management zone (RMZ) or channel migration zone (CMZ) rules if the~~They are less susceptible where mature trees exist on lower terraced slopes ~~are not particularly high and are contained within the riparian leave areas or within the CMZ (see Board Manual Section 2)~~in riparian or channel migration zones. The roots and woody structure of riparian trees act to deflect erosive flows and lessen undercutting along the meander bend walls. ~~As with other situations of overlapping forest practices rules, the harvest unit layout should reflect the extent of the greater of the protections.~~

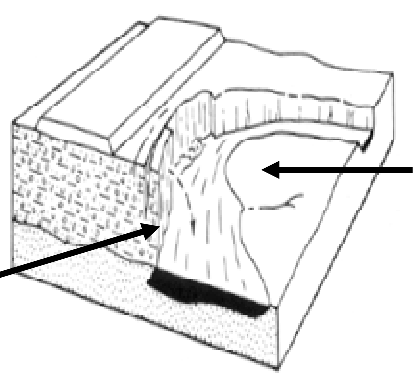


Figure ~~22~~23. Outer edge of a meander bend showing mass wasting on the outside of the bend and deposition on the inside of the bend (adapted from Varnes, 1978).

[37] Schuster and Wieczorek, 2002.

~~5~~4.5 Areas Containing Features Indicating the Presence of Potential Slope Instability

Apart from the rule-identified landforms described above, there are other slope indicators that can point to instability. When the feature or landform indicates the presence of slope instability which cumulatively indicates the presence of unstable slopes, the area can be considered a rule-identified landform. ~~A proposed~~ Proposed forest practices ~~activity~~ 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 ~~damage~~ deliver sediment and debris to a public resource or threaten public safety. General practitioners and qualified experts commonly refer to these features as "category E" landforms.

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

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

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

Topographic indicators

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

Hydrologic indicators

- Ponding of water in irregular depressions in undrained swampy or poorly drained areas on the hillslope above the valley floor. These conditions are often associated with hummocky topography which can be a signature of landslide activity.
- Seepage lines or spring and groundwater piping. These conditions often mark the contact between high permeability and low permeability soils.
- Sag ponds (ponded water in a tension crack or low depressions on a landslide body).
- Deflected or displaced streams (streams that have moved laterally to accommodate landslide deposits).
- Chaotic drainage patterns ~~as a result of~~ resulting from landslide activity.

~~Vegetational~~ Vegetative indicators

- Jack-strawed, back-rotated, or leaning trees and stumps. These are typically indicative of active or recently active landslides.
- Trees with ~~curved~~ curved-based lower stems and vertical upper boles may indicate slope movement stabilizing over time.
- Bowed, kinked, or pistol-butted trees. These are typically indicative of soil creep, but may indicate incipient land sliding, particularly if other indicators are present.
- Split trees and split old growth stumps. These may be associated with tension cracks.
- Hydrophytic ~~Water~~(water-loving) vegetation (~~horsetail,~~ skunk cabbage, devil's club, salmon berry, etc.) on slopes. These conditions may indicate the presence of groundwater seeps and associated hydrogeologic conditions.
- Other patterns of disturbed vegetation. Changes in stand composition (early seral stage or lack of mature trees within a hillslope) or small grouping 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 indicators 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 (Chatwin et al., 1994); Hillslope Stability and Land Use (Sidle et al., 1985); ~~and~~ Landslides, Processes, Prediction and Land Use (Sidle and Ochiai, 2006); and Slope Stability Reference Guide for National Forests in the United States (USFS 1994).

~~5.5.1 Deep-Seated Landslides~~

~~Deep-seated landslides are those in which the slide plane or zone of movement is below the maximum rooting depth of forest trees (generally greater than 10 feet or 3 meters). Deep-seated landslides may extend to hundreds of feet in depth and may involve underlying bedrock. Deep-seated landslides can occur almost anywhere on a hillslope where geologic and hydrologic conditions are conducive to failure. They can be as large as several miles across or as small as a fraction of an acre.~~

~~Deep-seated landslides can be identified from topographic maps, aerial photographs, LiDAR images, and field observations. Many deep-seated landslides occur in the lower portions of hillslopes and extend directly into stream channels whereas those confined to upper slopes may not~~

have the ability to deposit material directly into channels. Deep-seated landslides often are part of large landslide complexes that may be intermittently active for hundreds of years or more.[38]

One common triggering mechanism of deep-seated landslides results from the over-steepening of the toe by natural means such as glacial erosion or fluvial undercutting, fault uplift, or by activities such as excavating for land development.[39] Initiation of such landslides has also been associated with changes in land use[40], increases in groundwater levels[41], and the degradation of material strength through natural processes. Movement can be complex, ranging from slow to rapid, and may include numerous small to large horizontal and vertical displacements variously triggered by one or more failure mechanisms.[42]

Deep-seated landslides characteristically occur in weak materials such as thinly layered rocks, unconsolidated sediments, deeply weathered bedrock, or rocks with closely spaced fractures. Examples include: clay-rich rocks, such as the Lincoln Creek Formation of west-central Washington[43]; thinly layered rocks, such as phyllite in northwest Washington[44]; and deeply weathered volcanic rocks present in the Willapa Hills of southwest Washington[45]. Deep-seated landslides can also occur where a weak layer or prominent discontinuity is present in otherwise strong rocks, such as sedimentary interbeds within basalts or a fault plane or intersecting joint set.[46] In northwest Washington and on the Olympic Peninsula, deep-seated landslides commonly occur along silt or clay beds that are overlain by sandy units such as glacial deposits.[47]

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. These can be seen in Figures 18 and 23. The downslope edge of the toe can become over steepened from stream erosion or from the rotation of the slide mass. 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. These three main parts are shown in Figure 23. 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 odd ways due to differential movement of discrete landslide blocks. The parts of deep-seated landslides that are most susceptible to shallow landslides and potential sediment delivery are steep scarps (including marginal stream side slopes) and toe edges.

[38] Bovis, 1985; Keefer and Johnson, 1983.
[39] Schuster and Wieczoreck, 2002.
[40] Van Beek and van Asch, 2004.
[41] van Asch et al., 2005.
[42] Roering et al., 2005.
[43] Gerstel and Badger, 2002.
[44] Kovanen and Slaymaker, 2008.
[45] Turner et al., 2010.
[46] Sidle, 1985.
[47] Gerstel et al., 1997.

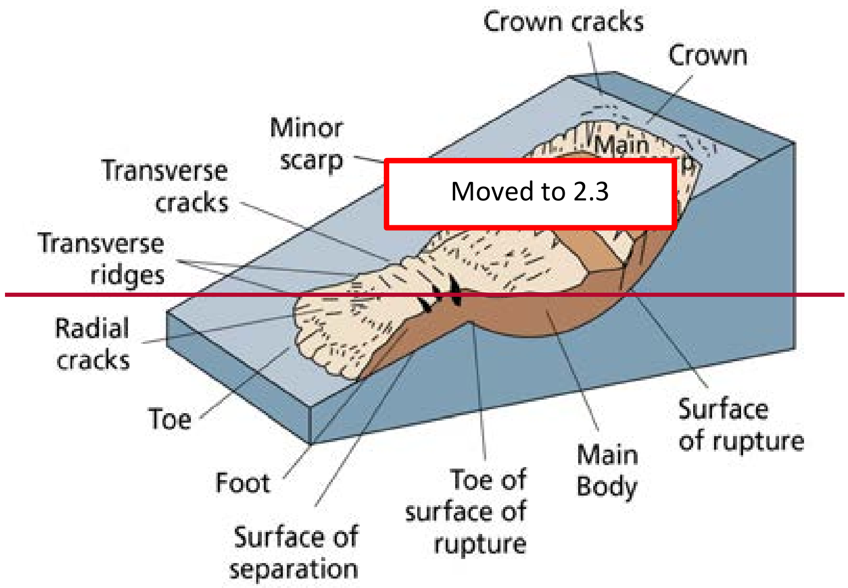


Figure 23. Rotational deep-seated landslide. Rotational displacement of blocks of soil commonly occur at the head of the landslide (adapted from USGS, 2004).

The sensitivity of any particular landslide to forest practices is highly variable. Deep-seated scarps and toes may be over-steepened, and streams draining the displaced material may be subject to debris slide and debris flow initiation in response to harvest or road building. Movement in landslides is usually triggered by accumulations of water at the slide zone, so land use changes that alter the amount or timing of water delivered to a landslide can start or accelerate movement.[48] Generally, avoiding the following practices will prevent most problems: removing material during road construction or quarrying which could destabilize the toe; dumping spoils on the upper or mid-scarp areas which could overload the slopes, or compacting the soil in these places which could change subsurface hydrology; and directing additional water into the slide from road drainage or drainage capture.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.[49]

Part 6.3 provides methods for describing and delineating groundwater recharge areas for deep-seated landslides in glacial sediments.

PART 65. HOW TO IDENTIFYING POTENTIALLY UNSTABLE SLOPES AND LANDFORMS

When planning timber harvest and construction activities, general practitioners (landowners, foresters, engineers, and other field staff) need to determine whether potentially unstable slopes and landforms exist on or around the site of their proposed activities.[50] If so, a qualified expert may be needed to perform additional analysis. The identification, delineation, and characterization of unstable and potentially unstable landforms should be completed to address the relevant questions

[48] Cronin, 1992.
[49] van Asch, et al., 2009.
[50] In this context, potentially unstable slopes and landforms that exist "around" a proposed timber harvest or construction activity are those that could possibly be influenced by, or be caused to move due to, the harvest or construction activity.

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 for potentially unstable slopes and landforms. 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 assessment steps in the review process typically includes the following components:

1. The general practitioner assesses the project sites for potentially unstable slopes and landforms through:
   - initial office screening (Part 6.1.15.1); and
   - field assessment and review (Part 6.2.15.2 and 5.3).

If desired by the landowner or required by rule, a qualified expert conducts afurther geotechnical assessment throughmay include:

- office review (Part 6.1.2);
- field review (Part 6.2.2);
- landslide/landform activity assessment (Part 76.1);
- glacial deep-seated landslide assessment (Part 6.2);
- quantitative field assessment methods for the qualified expert's subsurface investigations (Part 6.3);
- water budget and slope stability modeling assessments for glacial deep seated landslides (Part 7.26.4);
- slope stability sensitivity assessment (Part 7.36.5);
- deliverability delivery assessment (Part 7.46.6);
- summary of findings, results, and conclusionssynthesis and evaluation (Part 7.51); and
- geotechnical reports (Part 87.2).

The elements and recommended sequence of the assessment are generally as follows (modified from Turner and Schuster, 1996)While an appropriate investigation process cannot be defined by the rigid application of a set of procedural rules[51], Turner and Schuster (1996) suggest the following elements and sequence of the assessment:

1. Preliminary fact-finding to answer: What actions does do the proposed forest practices activities include (e.g., partial cut, clear cut, road building, stream crossing)? In which landslide province (Part 2.4Appendix B) are the proposed forest practices activities located and what are the hydrogeologic 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 (Light Detection and Ranging) data, and other information identified during the preliminary fact-finding phase.
3. Field review to observe the site, confirm office review findings, and identify unstable and potentially unstable landforms that were 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.

[51] Turner and Schuster, 1996.

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.

65.1 Office Review Process for the General Practitioner and the Qualified Expert

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

A typical office review utilizes all accessible pertinent site-specific and regional remote sensing data to help identify, delineate, and interpret potentially unstable slopes and landforms (e.g., aerial imagery, LiDAR, GIS-based model predictions of earth surface attributes derived from digital, high-resolution topographic data). In addition, it is helpful to utilizeIt 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 natural public resource and public safety considerations, and make a determination regarding next steps in the site assessment. Please see appendices A C through F E for data sources, and 65.1.3 and 65.1.4 for information regarding remote sensing tools and topographic data.

65.1.1 General Practitioner's Office Review

It is recommended that the initialThe goals of the general practitioner's office review and screening conducted by general practitioners achieveare to: identification ofidentify and locate potential and existing areas of slope instability within or around proposed forest practices activities; delineation of unstable landforms using descriptions provided in Part 54; location of locate areas of public resource sensitivity or public safety exposures in the vicinity area of the planned operations that could be adversely affected by mass wasting processes; and development of develop a plan strategy for assessing the landforms in the field.[52]

The information resulting from the general practitioner's office review will be useful for completing the FPA and providing information on the supplemental slope stability form if it is required.

Summary of Procedures. The office review process generally includes compiling and evaluating availablefollowing are typical resources for a general practitioner's office review:

- maps 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 BD. This initial screening is supplemented with general practitioner's knowledge about site-specific conditions, and with
- publicly 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

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

landforms and processes (e.g., watershed analyses conducted under chapter 222-22 WAC; see Appendix ~~D~~F).

- ~~Information sources~~ Sources ~~are~~ that may be available to the user online via the Forest Practices Application Review System (FPARS) and Washington State Geologic Information Portal. ~~Additional sources of imagery, data, maps, reports, and other documents are listed in appendices A through F. 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 B.~~ 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~~However, if these tools are not available, an initial screening can be performed manually ~~without such tools if they are unavailable to the general practitioner (i.e.,~~ by inspecting each map or image separately~~)~~. Various county websites also offer online interactive GIS information for maps and imagery products ~~(see Appendix A)~~. ~~Additional s~~Sources of imagery, data, maps, reports, and other documents are listed in appendices ~~A~~C through ~~F~~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 ~~screening~~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, the general practitioner ~~might~~may not be able to identify the full extent of a groundwater recharge area from topographic maps, or ~~to~~ detect landslides under a mature forest canopy if using aerial photography exclusively. ~~Follow-up~~Therefore, one or more follow-up field assessments are needed to verify results of the initial screening ~~because not all features can be identified during the office review~~. ~~It is helpful~~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 screening process aids the general practitioner in targeting portions of the proposed harvest and construction area that may need further assessment in the field. ~~The office screening 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, the general practitioner might not be able to identify the full extent of a groundwater recharge area from topographic maps, or to detect landslides under a mature forest canopy if using aerial photography exclusively.~~ A field assessment is typically conducted while performing reconnaissance and marking (flagging) the boundaries of the proposed harvest and construction area; see Part ~~6~~5.2 for guidance on conducting field reviews. The general practitioner might also elect to have a more thorough office review conducted by a qualified expert.

~~6~~5.1.2 Qualified Expert's Office Review

~~An assessment by a~~A qualified expert is needed when an ~~assessment~~ 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 ~~geotechnical~~ geologic assessment of landform characteristics and landslide potential prior to initiating field work~~,~~; ~~in order to~~field work can then refute or verify initial interpretations~~ in subsequent field investigations~~. The qualified expert's ~~geotechnical~~ 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~~ Screens the site with ~~available~~ pertinent data in order to identify physical indicators of past, existing, and potential landslide ~~activities~~instability, noting their spatial and temporal distributions;
2. ~~delineates~~ Delineates on preliminary maps the identified features and associated potentially unstable landforms;
3. ~~formulates~~ Formulates initial hypotheses regarding landslide and landform behavior and failure mechanisms, to be evaluated further in the field; and
4. ~~determines~~ Determines the type and level of field investigation needed to ~~verify preliminary landslide interpretations, develop cause-effect relationships, and~~ assess any potential for ~~material~~ delivery ~~and potential adverse impacts to natural~~ of sediment or debris to a public resource~~s~~ ~~and~~ or ~~threats to~~in a manner that threatens public safety.

Summary of Procedures. The ~~geotechnical~~ office review ~~is performed as the initial office screening for compiling and evaluating available~~involves compiling and evaluating pertinent information. Most qualified experts have GIS capabilities, are experienced in using ~~remote sensing~~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 usually 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 site characteristics or physical features based on these data sources. The qualified expert determines the appropriate combination of assembled information based on the project objectives, requirements, and desired level of confidence in assessment products.

Outcome. The office review typically leads to a field review of the findings by either a general practitioner or the qualified expert, especially where potentially unstable ~~areas~~ slopes and landforms are suspected or known and verification is required. ~~Office review findings are included in the report written by the qualified expert.~~ Interpretations based solely on remote sensing data should not be used as substitutes for site-specific field assessments. ~~From~~ If the expert determines from the office review~~, the expert might determine~~ that ~~no~~ potentially unstable slopes or landforms are likely present, ~~or such features are present and~~ the landowner ~~agrees to~~may exclude these areas from the proposed forest operations. Any reports or information provided to DNR should include relevant results of the qualified expert's office review findings.

5~~6~~.1.3 Remote Sensing Tools Available for Office Reviews

Common sources of remotely sensed information used in identifying, delineating, and interpreting landforms can be grouped broadly in ~~the following~~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, technical reports, and other published/unpublished literature, and physical databases. ~~Appendices A through E list the most common data sources in each category.~~ Among the available remote sensing technologies, LiDAR has proven to be a valuable source of topographic data with distinct advantages over traditional analytical methods (e.g., aerial photo interpretation) for mapping landslides and interpreting landform characteristics (see Figure 24).[53] ~~Consequently, LiDAR capabilities and applications are discussed in more detail below.~~ However, LiDAR is not a panacea; rather it complements traditional aerial photo interpretation and the analysis of both information sources are useful. For more information about LiDAR processing, applications, and data sources, see Appendix E.

~~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.[54] Examples include using LiDAR-derived Digital Elevation Models (DEM) and Digital Terrain Models (DTM) with: (1) radar data and historical aerial photographs to quantify deep-seated landslide displacement and sediment transport[55]; (2) ortho-rectified historical aerial photographs to map earthflow movement and calculate sediment flux[56]; (3) GIS-based algorithms for LiDAR derivatives (e.g., hillslope gradient, curvature, surface roughness) to delineate and inventory deep-seated landslides and earthflows[57]; and (4) subsurface investigations[58]. Such innovative approaches likely will continue to emerge as more sophisticated high-resolution surface and subsurface technologies are developed. It is the task of qualified experts to seek out, evaluate, and apply new remote sensing methods as they become available.~~

~~6~~5.1.4 LiDAR ~~and High-Resolution Topographic Data~~Use in Identifying Potentially Unstable Landforms

It is beneficial for general practitioners and qualified experts to obtain ~~high-resolution~~the best available topographic maps derived from hillshade and slope maps when unstable areas exist around the proposal.

~~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.[59] 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~~

[53] e.g., Haugerud et al., 2003; Burns and Madin, 2009; Roering et al., 2013; Tarolli, 2014.
~~[54] Tarolli, 2014.~~
~~[55] Roering et al., 2009; Handwerger et al., 2013; Scheingross et al., 2013.~~
~~[56] Mackey and Roering, 2011.~~
~~[57] e.g., Ardizzone et al., 2007; Booth et al., 2009; Burns and Madin, 2009; Tarolli et al., 2012; Van Den Eeckhaut et al., 2012.~~
~~[58] Travelletti and Malet, 2012.~~
~~[59] Carter et al., 2001.~~

~~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.[60] 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.[61]~~

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

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

LiDAR hillshades can be used to delineate and interpret deep-seated~~,~~ and, with less~~er~~ 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.[62] Recent regional examples of deep-seated landslide mapping that used LiDAR-based protocols include Burns and Madin (2009), Schulz (2005, 2007), and Haugerud (2014).

~~[60] For a review of filtering techniques, see Liu, 2008.~~
~~[61] Van Den Eeckhaut et al., 2007.~~
[62] McKean and Roering, 2004; Glenn et al., 2006; Booth et al., 2009; Berti et al., 2013.

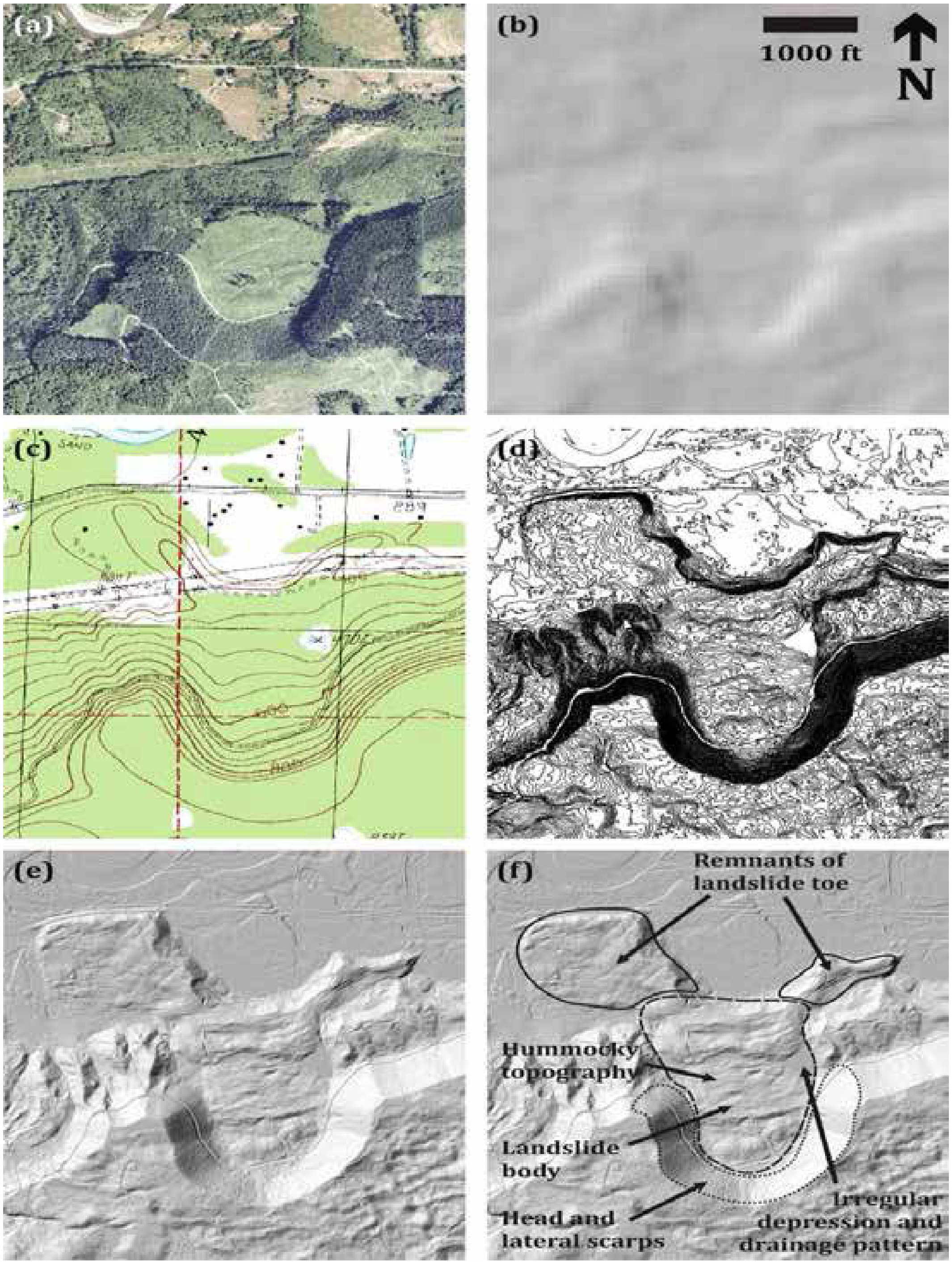


Figure 24. Example of a dormant glacial deep-seated landslide as seen in different types of remotely sensed data and in varying resolution quality:
(a) Digital Orthophoto Quadrangle, (b) hillshade map derived from 30-meter resolution ASTER Global Digital Elevation Model, (c) topographic map, (d) 6-foot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

~~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.[63] 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.[64] Care should be taken to precisely align the repeat LiDAR DEMs.~~

~~6~~5.2 Field Assessment ~~Process for the General Practitioner and the Qualified Expert~~

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

~~The field assessment performed by the general practitioner determines the presence or absence of potentially unstable slopes and landforms. If such features are identified and forest practices are proposed on these features, the landowner may retain a qualified expert to perform additional geotechnical reviews.~~

~~6~~5.2.1 General Practitioner's Field Assessment

The objective of the general practitioner's field assessment ~~conducted by a general practitioner~~ is to determine the presence or absence of ~~unstable slopes and~~rule-identified landforms~~, using definitions of the landform types and guidance provided~~ described in ~~this Board Manual section~~Part 4. ~~In addition to assessing the potentially unstable areas identified in the initial office screening, the~~The general practitioner surveys the operations area for any landforms missed in the office review. This assessment is typically accomplished while laying out the proposed forest practices activities (e.g., marking unit boundaries, establishing riparian management zones, laying out road systems). ~~See Qualified Expert's Field Assessment for Groundwater Recharge Areas (Part 6.3.2) for information on conducting field reviews on groundwater recharge systems, and Additional Features and Landforms Indicating Potential Slope Instability (Part 5.5) for discussions on landform features that may indicate slope instability.~~ When the field assessment indicates complex geological features are present or the scenario is beyond the general practitioner's expertise, the landowner may wish to have a qualified expert complete a further assessment. The practitioner should refer to Part 4.5 for indicators of slope instability and Part 5.3.2 for field review on groundwater recharge systems.

Outcomes. Common results of the general ~~practitioner-conducted~~practitioner's field assessment ~~generally include~~are one of the following:

- The ~~finding, documented in the slope stability sections of the FPA, that the assessment did~~ general practitioner does not identify any potentially unstable slopes or landforms within or around the planned area for the forest practices activities~~,~~. ~~and the office/field review process is assumed complete; or~~
    - The landowner documents the finding in the slope stability sections of the FPA.

~~[63] Corsini et al., 2007; Delong et al., 2012; Daehne and Corsini, 2013.~~
~~[64] Burns et al., 2010.~~

- The ~~finding that~~general practitioner identifies potentially unstable slopes ~~and~~ or landforms ~~exist within~~in or around the planned operations area, and the landowner ~~completes and attaches the appropriate~~avoids timber harvest or construction on them.
    - The landowner documents the finding in the slope stability sections ~~to~~ of the FPA, along with any additional required information DNR may have requested~~; or~~, and submits the FPA.
- The general practitioner identifies potentially unstable ~~areas within~~slopes or landforms in or around the planned operations area, and the landowner proposes ~~to conduct~~ timber harvest or construction activities on them.
    - The landowner ~~may~~ retains a qualified expert to conduct ~~geotechnical~~ geologic office and field reviews, and prepare a geotechnical reports (see Part 7.2) ~~as required by WAC 222-10-030 or other format, depending on DNR's particular request for information~~for information required in a geotechnical report.[65] ~~The landowner submits the FPA and includes the geotechnical information. (See Washington State Department of Department of Natural Resources website for a list of qualified experts.)~~
    - The landowner documents the finding in the slope stability sections of the FPA, along with the geotechnical report prepared by the qualified expert.

5~~6~~.2.2 Qualified Expert's ~~Office and~~ Field Assessments

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

1. ~~refine~~ Refine any preliminary maps constructed during office reviews. This may include features not detected in the office review;
2. ~~confirm or refute initial hypotheses regarding landslide behavior, failure mechanisms, and level of activity~~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. ~~solidify understanding of~~ Analyze cause-effect relationships relative to the proposed activity;
4. ~~assess~~ Assess ~~relative potentials for material delivery associated with the proposed forest practices to areas of resource sensitivity and~~ 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;
~~5.~~6. ~~evaluate~~ Evaluate levels of confidence in office and field findings; and
~~6.~~7. Produce geologic information when requested, or write a geotechnical report when required, summarizing review findings, conclusions, and recommendations (see Part ~~8~~ 7.2 for information required in a geotechnical report).

Summary of Procedures. The qualified expert determines the nature of the field review required to meet the objectives stated above. ~~Field~~The field work ~~needed to complete the review~~ can take one

[65] 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.

or more days, and the landowner may ask the qualified expert ~~might be asked~~ to return to the field for an interdisciplinary team meeting~~s~~ if required by DNR. Depending on the analyst's level of confidence in potentially unstable landform identifications, delineations, and interpretations for any given site, the field assessment might range from qualitative to more quantitative in nature.

An example of a qualitative assessment would be one in which visual observations and photos of geological features and other site indicators at identified locations (e.g., GPS waypoints) are summarized in a geotechnical report to substantiate landform and process interpretations. A more quantitative investigation might include such data collection techniques as topographic surveying for measuring landslide surfaces (i.e., that needed for slope stability modeling), soil sampling to test material properties, and subsurface sampling that ~~is especially~~could be important in analyzing the depths, materials, and hydrology of deep-seated landslides. ~~Field work needed to complete the review can take one or more days, and the qualified expert might be asked to return to the field for an interdisciplinary team meetings if required by DNR.~~

~~It is recommended that the field assessment performed by a qualified expert include the preparation~~Preparation of a site-specific ~~geologic~~ geomorphic map~~,~~ is helpful because ~~the scope of work associated with~~ most published geologic maps, ~~is~~ although useful for understanding and locating bedrock and Quaternary sediment deposits, are insufficient to identify small-scale unstable landforms that could have a significant effect on the proposed ~~forest~~ activity. In addition, some geologic information may not have been field verified or developed with high-resolution LiDAR. The purpose of ~~geologic~~ mapping is to ~~document~~ capture surface conditions, ~~and~~ provide a basis for the interpretation of subsurface conditions, and prepare more site-specific descriptions of relevant features. ~~Ideally the geologic map should be prepared on a scale of 1:10,000 or less using high-resolution LiDAR-generated topography. 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.~~

A ~~geologic~~ geomorphic map ~~should~~ ideally includes the location, elevation, and ~~altitude~~ attitude of ~~all~~ known geologic contacts ~~between permeable and non-permeable soils~~and relevant landforms, although such data collection is not feasible or necessary in all situations. ~~Particular~~ 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. ~~If an unstable or potentially unstable landform is present, the~~The location of pertinent geologic components and ~~effects of the landform~~ potentially unstable indicators should be identified on the map or in the geotechnical report. Ideally, ~~the geologic map~~mapped products should be prepared on a scale of 1:1~~0~~2,000 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~~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.[66] To ~~be fully effective~~facilitate the review, geologic reports prepared for FPAs ~~should~~ can include GPS locations of landforms and other relevant features ~~within~~ with sufficient accuracy ~~sufficient~~ for others to identify the landforms in the field. It is also effective to include photographs of significant

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

landforms, or their components should also be photographed if they can be fully capturedthe 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 vegetation vegetative indicators as described in Part 54.5.

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. Common results of a qualified expert's geotechnical field assessment may include determinations thatone of the following:

- The potentially unstable landformsfinding that areas of concern identified in the preliminary office review and field assessment do not meet the definitions of the rule-identified landforms (Part 54).
  - The qualified expert reports these findings to the landowner that no potentially unstable landforms are present and the slope stability assessment is assumed complete; or the landowner documents the findings in the slope stability sections of the FPA.
- Potentially The finding that potentially unstable slopes or landforms within in or around the operations area have minimal potential for material deliveryto deliver sediment or debris to areas ofa public resource sensitivity and/or threats tothreatens public safety.
  - The qualified expert reports these findings to the landowner; the landowner documents the findings in the slope stability sections of an FPA.

  The qualified expert completes a geotechnical report for the landowner summarizing these findings, as outlined in WAC 222-10-030(1), and slope stability assessment is complete; or Unstable
- The finding that potentially unstable slopes or landforms within or, when appropriate, around the operations area have the potential for materialto deliverysediment or debris to areas of naturala public resource sensitivity or threats to threatens public safety.
  - The qualified expert completes a geotechnical report forprepares information listed in WAC 222-10-030(1) in a geotechnical report, and provides the report to the landowner summarizing these findings to be included with the FPA. 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 an FPA and attaches the report to the FPA.

65.3 Qualified Expert's Office Review and Field Assessment forDelineating Groundwater Recharge Areas for Glacial Deep-Seated Landslides

TheAs explained in Part 4, the groundwater recharge area for a glacial deep-seated landslides is a rule-identified landform. A groundwater recharge area of a deep-seated landslide It is the area up-gradient of a landslide that can contribute water to the landslide. In simple terms, the groundwater recharge area is the topographic or hillslope area that is at a higher elevation and capable of delivering water into the landslide. When a timber harvest or construction activity isactivities 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 Part 6.1), the area adjacent to the landslide needs to be assessed by a qualified expert to determine if including determining if a groundwater recharge area exists and, if so, determining its spatial extent. DNR requires that a qualified expert make the final determinations about the existence and boundaries of a groundwater recharge area for a glacial deep-seated landslide. However, a general practitioner may have a role in office reviews and field work under the direction of the qualified expert.

Typically, once a landslide has been mapped, an initial designation of the topographic groundwater recharge area is a straightforward task that can be performed on a detailed topographic map of the area. Topography developed fromThe most accurate tool available for mapping surface topography is high resolution DEM generated from LiDAR is preferred as the most accurate tool available for mapping surface topography. Figure 25(a) shows the approximate groundwater recharge area for a landslide based on upslope topographical delineation. The cross section shown in Figure 25(b) 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. 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[67] and the Columbia Plateau[68]. However, it is also important to understand groundwater movement at smaller local scales.

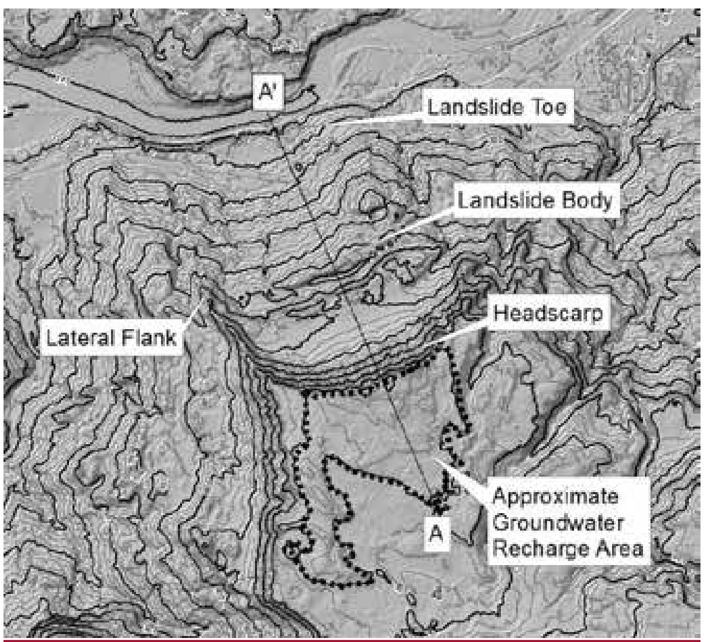


Figure 25a. Glacial deep-seated landslide. The blackdash-lined polygon is an approximate upslope contributingdelineation of a groundwater recharge area baesd on LiDAR data (DNR, 2014).

[67] Vacarro et al., 1998.
[68] Bauer and Hansen, 2000.

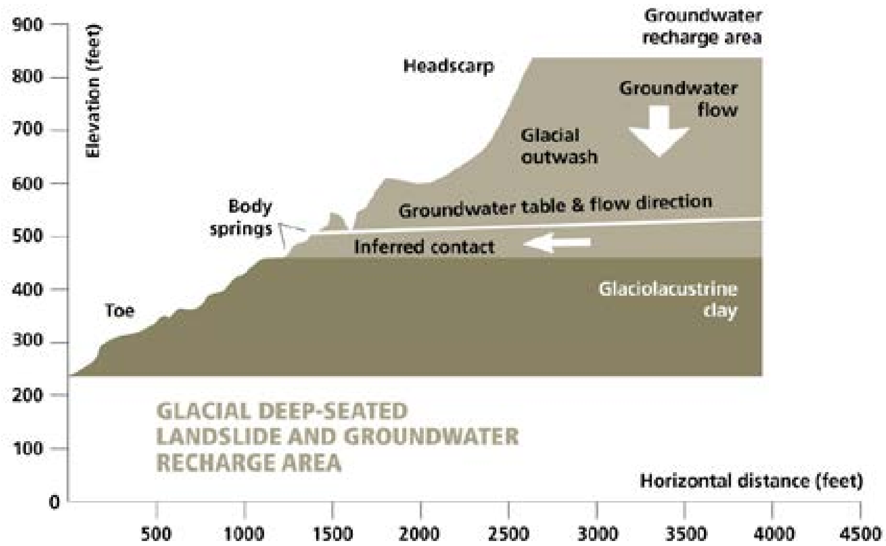


Figure 25b. Hillslope cross-section (A-A' in figure 25a) derived from 2-meter DEM of a glacial deep-seated landslide showing groundwater recharge area, geologic units, and generalized groundwater flow paths (DNR, 2014).

~~The groundwater recharge area for glacial deep-seated landslides is a rule-identified landform. The technical methods used to identify groundwater recharge areas in glacial deep-seated landslides are no different than those for other (e.g., non-glacial) deep-seated landslides.~~

The recommended first step in delineating the groundwater recharge area is to evaluate its stratigraphic and/or topographic relationship to the landslide. When uncertainties remain as to the accuracy of the area boundary, further investigations and analysis ~~should be performed~~are necessary. ~~This further analysis will provide necessary information DNR uses to review the proposed activity. If an in-depth investigation is performed, the information~~The results of these analyses provided by the qualified expert in a geotechnical report ~~is~~ are used by DNR to determine the FPA classification and other decisions based on the applicant's proposed activity. ~~The following discussions and Part 7 will help the qualified expert determine next steps if further investigation is needed.~~

~~6~~5.3.1 ~~Qualified Expert's~~ Office Review for Groundwater Recharge Areas

~~When a qualified expert performs an office review for evaluating the area contributing groundwater recharge to a landslide, it is recommended that~~ The office review should include an assessment of the surrounding topography, land cover and vegetation, soils, and the distribution of hydrogeologic units ~~are reviewed~~. ~~Time scales of g~~Groundwater movement from areas of recharge to discharge may vary over several orders of magnitude, depending on the hydraulic characteristics of the hydrogeologic units, which include water-bearing and non-water-bearing rocks and sediments (aquifers) and confining units, respectively.

In a simplified hydrogeologic setting in a humid environment, the groundwater table forms a subdued replica of surface topography with groundwater flow from high altitude areas of recharge to low altitude areas of discharge.[69] The surficial contributing area may be delineated from digital elevation models (DEMs) derived from ~~high-resolution~~ LiDAR, ~~if available,~~ or ~~alternately the lower resolution~~ 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 ~~a first-order~~an approximation of the potential area of recharge, but may not be valid in heterogeneous rocks and sediments with ~~more~~ complex topography, ~~and~~ depositional history, ~~and~~ or deformational environments.

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

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

- Remotely-sensed land cover data ~~is~~ available nationally at a spatial resolution of 30 meters from the U.S. Geological Survey's National Land Cover Database~~. In addition, land cover data is available for Washington State through the DNR Forest Resource Inventory System.~~;
- Geologic maps for ~~provide~~ providing a basis for delineating the areal extent, orientation, and stratigraphic ~~relations,and thickness~~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 ~~describing~~ 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~~, and information may be lacking in~~ rather than the forested environment.
- Hydrogeologic frameworks, which define the groundwater recharge environment and the subsurface environment in which groundwater occurs, have been developed from mapped geologic units, driller's logs, and hydrologic data at regional scales such as Puget Sound[70] and the Columbia Plateau[71]. However, it is also important to understand groundwater movement at smaller local scales. ~~Hydrogeologic frameworks have been developed from mapped geologic units, driller's logs, and hydrologic data at regional scales such as Puget Sound[72] and the Columbia Plateau[73], to local scales for sites across Washington State.~~ Hydrogeologic reports are available from sources such as the U.S. Geological Survey and the Department of Ecology.

~~6~~5.3.2 ~~Qualified Expert's~~ Field Assessment for Groundwater Recharge Areas

~~A groundwater recharge area of a deep-seated landslide is the area up-gradient of a landslide that can contribute water to the landslide. In simple terms, the groundwater recharge area is the~~

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[69] Freeze and Cherry, 1979.

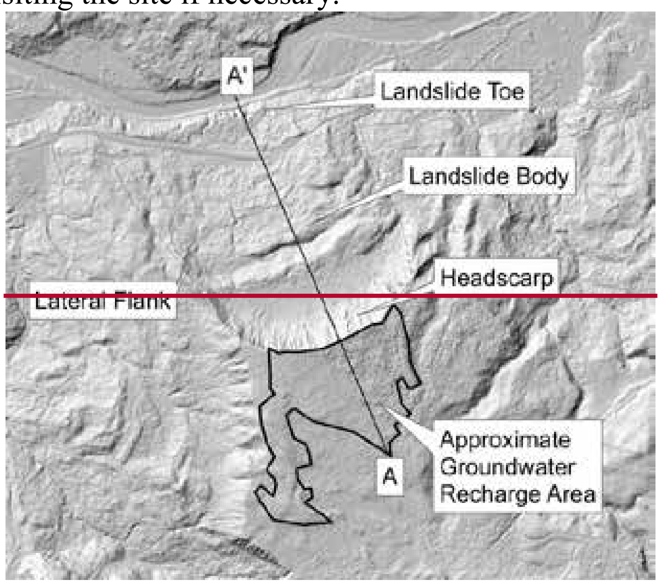
[70] Vacarro et al., 1998.

[71] Bauer and Hansen, 2000.

~~[72] Vacarro er al., 1998.~~

~~[73] Bauer and Hansen, 2000.~~

~~topographic or hillslope area that is at a higher elevation and capable of delivering water into the landslide.~~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 ~~of the initial groundwater recharge area map will be necessary to confirm that surface topography is a reasonable approximation of the groundwater recharge area delineation. 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. Topography developed from high resolution DEM generated from LiDAR is preferred as the most accurate tool available for mapping surface topography. Figure 25(a) shows the approximate groundwater recharge area for a landslide based on upslope topographical delineation. The cross section shown in Figure 25(b) illustrates the approximate stratigraphy through the groundwater recharge area and landslide body. After the initial designation by the qualified expert of the groundwater recharge area, a field assessment should be conducted in order~~ to determine if the initial designation accurately reflects the recharge area topography, including the topography up-gradient of the landslide. ~~Depending on the available topographic data for the site in question, examination of the boundaries of the mapped groundwater recharge area will be necessary to ensure that the hillslope morphology displayed by the DEM is accurate. For the purpose of groundwater recharge delineation, collecting~~It is helpful to collect GPS waypoints along the topographic boundaries of the groundwater recharge area ~~is helpful~~ for mapping and ~~for~~ revisiting the site if necessary.



~~*Figure 25a. Glacial deep-seated landslide. The black-lined polygon is an approximate upslope contributing groundwater recharge (DNR, 2014).*~~

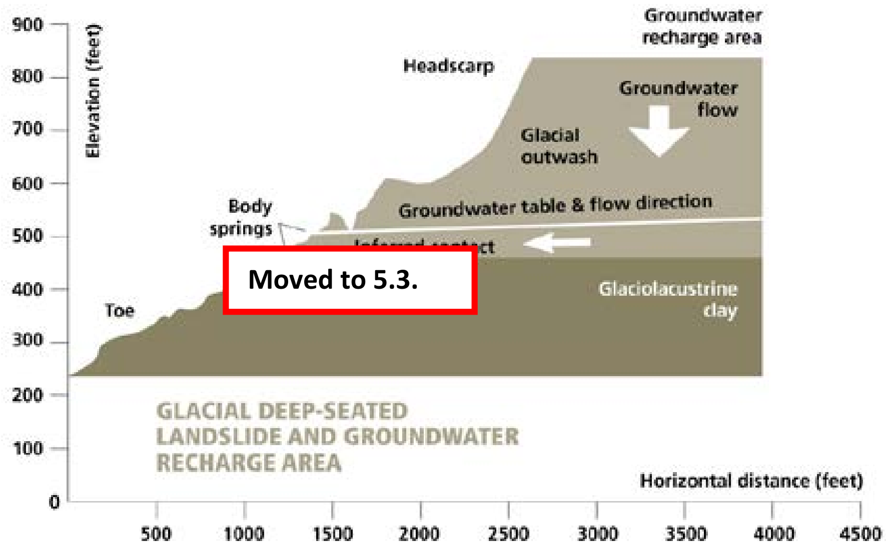


Figure 25b. Hillslope cross-section derived from 2-meter DEM of a glacial deep-seated landslide showing groundwater recharge area, geologic units, and generalized groundwater flow paths (DNR, 2014).

After the qualified expert has identified the groundwater recharge area, furtherThe field inspection should identify drainage patterns and surface water influencing the landslide areainclude the following. : Stream drainages on or adjacent to the deep-seated landslide should also be identified, mapped, and assessed for the potential to contribute water to the recharge area and landslide.

- During a field assessment it is important to examineExamining 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 those mapped for the location of interestmaps examined during the office review. In some cases, published soil and geologic data in forested areas may be mapped on a scale far less detailed for specific areasinaccurate at the scale of an FPA activity map.
- Mapping the stratigraphic units that compose the hillslope (i.e., the distribution of geologic units or horizons with depth below the groundwater recharge area) should be done 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.
- Exposures of Examining observable strata within the groundwater recharge area may be examined in exposures along marginal streams on the edges of the groundwater recharge area, or in head scarps at the top of the landslide. The distribution of geologic units with increasing depth below the surface may also be available from well driller's logs or other subsurface information such as geologic mapping and reports.

- Human activitiesMapping and evaluating infrastructure such as road construction of road networks and installation of drain fields can direct surface and groundwater towards or away from deep-seated landslides and/or contribute relatively large volumes of water within a groundwater recharge area. The location of such infrastructure should be mapped and evaluatedand landings with respect to possiblerelative water volumes likely to be contributed to flowing to or from a landslide or groundwater recharge area.
- StreamIdentifying surface water and stream drainages on or adjacent to the deep-seated landslides should also be identified, mapped, and assessed for the assessing the potential to contributeof water flowing to or away from the recharge area and a landslide and recharge area.

Excavation When conditions warrant, excavating of test pits, driving soil probes, drilling monitoring wells, or using other geophysical techniques such as seismic or electric resistivity methods should be considered in order to accurately better characterize and reduce any uncertainties about subsurface groundwater conditions where topographic indicators are uncertaininconclusive. See Part 6.4 for further discussion on quantitative field review methods.

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.

Human activities such as construction of road networks and installation of drain fields can direct surface and groundwater towards or away from deep-seated landslides and/or contribute relatively large volumes of water within a groundwater recharge area. The location of such infrastructure should be mapped and evaluated with respect to possible water volumes likely to be contributed to a landslide.

6.4 Quantitative Field Assessment Methods for Qualified Expert's Subsurface Investigations

If an unstable or potentially unstable landform with a potential to deliver sediment to public resources or threaten public safety is identified during the office review and field assessment, additional field analysis by a qualified expert may be needed to more quantitatively assess the hazard. This is generally accomplished with a subsurface investigation. The subsurface investigation should be designed to gather data necessary to evaluate the landslide in accordance with the evapotranspiration, recharge, groundwater flow, and slope stability modeling (see Part 7).

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, and limitations of budget and time. Subsurface exploration to assess landslides is generally described by McGuffey et al. (1996) as summarized in the following paragraphs:

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

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

~~*Drive Probe*. A simple hand probe can be used to estimate soil density and the depth to dense soil. The Williamson Drive Probe (WDP)[74] was developed as an inexpensive and portable alternative for determining soil relative densities and groundwater table elevations. Sections of hardware pipe are coupled and driven into the ground manually with a sliding hammer. The number of blows, in even distance increments, required to drive the probe is used to describe soil conditions. Blow-count data theoretically can be correlated with the Standard Penetration Test (American Society for Testing and Materials, 2014).~~

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

~~*Drill Rigs*. Borings constitute a common 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.). 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 can be an economical method of collecting 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.~~

~~A qualified expert should be present in the field during the completion of a subsurface investigation so that the field activities are properly executed and the desired results can be achieved.~~

PART ~~7~~ 6 ~~LANDSLIDE ACTIVITY ASSESSMENT~~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 the following guidance:

~~[74] Williamson, 1994.~~

- Landslide Activity Assessment (6.1)
- Glacial Deep-Seated Landslide Assessment (6.2)
- Quantitative Field Assessment Methods for the Qualified Expert's Subsurface Investigations (6.3)
- Water Budget and Hydrologic Contribution to Glacial Deep-Seated Landslides (6.4)
- Computational Slope Stability Assessment Methods (6.5)
- Delivery Assessment (6.6)

~~7~~6.1 Landslide Activity Assessment

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

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.[75] The *state of activity* refers to the timing of landslide movements and ranges from active (~~currently moving~~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). ~~When an active landslide stops moving, it becomes classified as suspended, and if it remains stationary for more than one annual cycle, it becomes inactive.~~ If the conditions that contributed to prior movement are still present even though the landslide is ~~inactive~~dormant, ~~the landslide is considered dormant because~~ it may become reactivated at a later time. ~~If~~ The landslide may be considered stabilized if the conditions promoting failure have naturally changed to promote stability~~, the landslide is considered abandoned, while~~ if human intervention has protected against future movement ~~the landslide is considered stabilized~~.

Interpretation of vegetation cover, surface morphology, and toe modification by a stream, if present, all aid in determining the state of activity based on local knowledge of typical rates of biologic and geomorphic processes.[76] ~~Although based on a Rocky Mountain- type climate, the framework~~ The characteristics described by Keaton and DeGraff (1996) ~~has~~ have been successfully applied in the Pacific Northwest. A modified version is presented in Table 2. New vegetation generally begins to colonize a landslide's scarp, lateral flanks, or other areas of disturbed ground once the landslide becomes dormant and progresses to mature vegetation cover according to the local climate. The scarp, flanks, and internal hummocky morphology of the landslide also tend to become increasingly subdued with time after the landslide becomes dormant, and the internal drainage network of the landslides tends to become more connected and organized. If the toe of the landslide enters a stream, that stream progressively modifies the toe as recorded by terraces and the establishment of a floodplain comparable to reaches unaffected by landslide activity.

The *distribution of activity* refers to the geometry and spatial pattern of landslide movements and how these patterns may change with time. One key distinction is if the landslide is advancing by

[75] Cruden and Varnes, 1996.
[76] Keaton and DeGraff, 1996, Table 2.

extending downslope in the main direction of movement, or retrogressing headcutting by extending in the upslope in the direction opposite movement. A landslide can also widen or narrow in the direction perpendicular to movement, and more generally can be enlarging or diminishing if its total volume is increasing or decreasing.

The *style of landslide activity* will be one of the movement types shown in Table 1, Landslide Classification. Many landslides involve different styles of landslide activity, and. movements Movements should be described as "complex" if they happen in succession, or as "composite" if they happen simultaneously at different parts of the landslide. Many landslides may reactivate repeatedly over time and their movements are noted 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.

Table 2. Guidelines for estimating deep-seated landslide activity level based on vegetation and morphology in Rocky Mountain-type climates
(modified from Keaton and DeGraff, 1996)

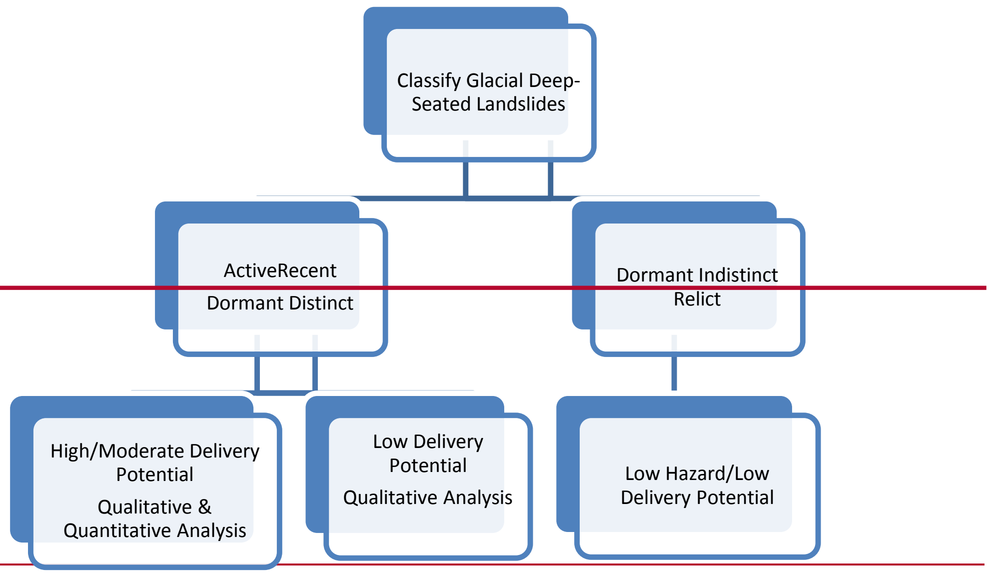
Active State	Main Scarp	Lateral Flanks	Internal Morphology	Vegetation +	Toes Relationships	Estimated Age (Years)
Active/recent* reactivated, or suspended; dormant-historic	Sharp; unvegetated	Sharp; unvegetated streams at edge	Undrained depressions; hummocky topography; angular blocks separated by scarps	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	< 100 (historic)
Dormant-youngdistinct	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	100 to 5,000 (Late Holocene)
Dormant-matureindistinct	Smooth; vegetated	Smooth; vegetated; tributaries extend onto body of slide	Smooth, rolling topography; disturbed internal drainage network	Different type or density than adjacent terrain butby same age	Terraces covered by slides debris; modern stream not constricted but wider upstream floodplain	5,000 to 10,000 (Early Holocene)
Dormant-old or rRelict	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	> 10,000 (Late Pleistocene)

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

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

~~Decision flow chart~~

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



~~*Figure 26. Decision pathway for implementing qualified expert investigations of groundwater recharge area harvests for glacial deep-seated landslides (DNR, 2001).*~~

6.2 Glacial Deep-Seated Landslide Assessment

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

1. Identify ~~and map~~ the glacial deep-seated landslide~~s~~ and associated groundwater recharge area~~s~~.
2. Classify landslide~~s~~ activity using the ~~Landslide Hazard Zonation (LHZ)~~ protocol (modified from Keaton and DeGraff, 1996) for deep-seated landslides as:
   - active;
   - dormant/distinct;
   - dormant/indistinct; or
   - relict.
3. ~~Calculate areas for the mapped~~Map the glacial deep-seated landslide and ~~the~~ associated groundwater recharge area.
4. Evaluate delivery potential if the landslide were to move for:

- public safety (e.g., houses~~,~~ and public roads~~, etc.~~); and
- public resources (water~~ quality and~~, fish~~ habitat~~, wildlife, and capital improvements).

5. If the landslide is relict or dormant/indistinct, and ~~has low delivery potential,~~the potential for reactivation of any portion of the landslide by harvest within the groundwater recharge area is highly unlikely, then additional analysis may not be necessary. Documentation of this analysis may be provided by a letter, memo, or other appropriate form.
6. If the landslide is active/recent or dormant/distinct with a low delivery potential, perform a qualitative assessment of factors contributing to landslide movement including natural disturbance, channel influences, and historic patterns of timber harvesting within the groundwater recharge area~~ and~~. Recent evidence of landslide movement may be detected from aerial photographs, LiDAR, and other screening methods.
7. If the landslide is active/recent or dormant/distinct and has moderate or high delivery potential, in addition to a qualitative assessment ~~of historic pattern of timber harvesting and landslide movement~~ described in (6), ~~if appropriate, perform a quantitative assessment of~~additional analyses may be conducted such as assessing whether a potential increase in groundwater recharge from timber harvest ~~and~~ will ~~effect~~ affect ~~on~~ the stability of the landslide.
8. Design appropriate landslide mitigation measures commensurate with delivery potential and hazard.

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

~~If an unstable or potentially unstable landform with a~~Where the potential to deliver sediment to public resources or threaten public safety is identified during the office review and field assessment, additional field analysis by a qualified expert may be needed to more quantitatively assess the hazard. ~~This is generally accomplished with a subsurface investigation.~~ 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. ~~The s~~Subsurface investigations~~ should~~can be designed to gather data necessary to evaluate the landslide in accordance with the evapotranspiration, recharge, groundwater flow, and slope stability modeling ~~(see Part 7)~~.

The qualified expert's selection of exploration methods should be based on the study objectives, size of the landslide area, geologic and hydrogeologic conditions, surface conditions and site access, ~~and~~ limitations of budget and time, and risk potential. Subsurface exploration to assess landslides is generally described by McGuffey et al. (1996) as summarized in the following paragraphs:

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

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

Drive Probe. A simple hand probe can be used to estimate soil density and the depth to dense soil. The Williamson Drive Probe (WDP)[77] was developed as an inexpensive and portable alternative for

[77] Williamson, 1994.

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 ~~theoretically can be~~ has been empirically correlated with the Standard Penetration Test (American Society for Testing and Materials, 2014).[78]

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

Drill Rigs. Borings constitute a ~~common~~ 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.). ~~A~~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 ~~can be an economical method of collecting~~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.

A qualified expert should ~~be present in the field during the completion of a~~supervise the subsurface investigation so that the field activities are properly executed and the desired results can be achieved.

~~7.2~~6.4 Water Budget and Hydrologic Contribution to ~~Slope Stability~~Glacial Deep-Seated Landslides

~~To further inform the landslide activity assessment involving groundwater recharge,~~When the preceding assessments indicate a potential influence from a forest practice, it is recommended that the qualified expert evaluate components of the water budget. The water budget of a groundwater/surface-water system describes the input, movement, storage, and output of water from a hydrologic system. Water enters a ~~hydrologic~~ hydrogeologic system through precipitation in the form of rainfall, ~~and~~ snowmelt, and other confined/unconfined groundwater sources. ~~Some of this water~~Not all precipitation, however, becomes groundwater, some is intercepted by vegetation or surface duff/debris and evaporates before reaching the ground or sublimates from the snowpack (see 6.4.1). Water that reaches the ground may run off directly as surface flow or shallow~~,~~ ~~sub~~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

78 Adams et al., 2007.

subsurface depends on the hydraulic properties of subsurface material as well as the distribution of groundwater recharge.

These fFurther assessments for calculating waterevaluating the influence of water to a glacial deep-seated landslide may be necessary when preliminary assessments suggest that the proposed forest practices activities have indicated an increase in the potential for contributing to movement to potentiallyof unstable slope or landforms. The extent of the analysis depends on site-specific geological and hydrogeological conditions. Such assessments and modeling should be consideredmay be useful when uncertainties remain regarding landslide movement or when the riskthere is potential for damage delivery of sediment or debris to public resources or threats to public safety are elevated. The following discussions of evapotranspiration and groundwater flow may aid the qualified expert during the landslide activity assessment involving a groundwater recharge area. Such assessments and modeling should be considered when uncertainties remain regarding landslide movement or when the risk for damage to public resources or threats to public safety are elevated. These further assessments for calculating water influence to a deep-seated landslide may be necessary when proposed activities have indicated an increase in the potential for contributing movement to potentially unstable slope or landforms.

7.2.16.4.1 Modeling Evapotranspiration

Modeling evapotranspiration is a data intensive exercise that requires regional and/or site-specific information regarding precipitation types and rates, wind speed, relative humidity, temperature, solar energy, and plant community stand characteristics.[79] The goal of evapotranspiration modeling is to derive estimates of the potential increase in water available to the groundwater recharge area from changes in energy balances, wind speeds, and plant community characteristics (i.e., aerodynamic roughness) after forest harvest.

Effects of evapotranspiration on the soil water budget can be partitioned as follows: (1) canopy interception of rainfall or snow and subsequent evaporation loss to the atmosphere; (2) transpiration of infiltrated water to meet the physiological demands of vegetation; and (3) evaporation from the soil or litter surface. Different vegetation covers have different balances of these fundamental water loss processes. The effects of evaporation on soil water budgets are relatively small compared with canopy evapotranspiration and interception.[80]

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.[81]

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

[79] Jassal et al., 2009.
[80] Bosch and Hewlett, 1982.
[81] Campbell, 1986.

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.[82]

Interception by vegetation cover controls both the amount and timing of precipitation reaching the soil surface. The interception capacity of vegetation types is important because intercepted water has a high surface area to volume ratio that promotes efficient evaporation by convection. Intercepted rainfall is mostly stored on the surface of foliage and stems, while intercepted snowfall bridges between gaps in tree crowns, facilitating an accumulation of snow over large surface areas of the canopy. Interception and subsequent evaporation of water from vegetation cover is particularly significant in coniferous forests[83]; snow or rain losses from these dense canopies can account for up to 30 to 50 percent of gross annual precipitation[84]. Moore and Wondzell (2005) estimated that interception loss in Pacific Northwest conifer forests ranged from 10 to 30 percent. Dingman (2002) reported similar values for Pacific Northwest plant communities, ranging from 21 to 35 percent, based on canopy characteristics and climate conditions. Hanell (2011) reported hydrologic modeling[85] that predicts a 27 percent decrease in evapotranspiration resulting from forest conversion to shrub for a site on the western Olympic Peninsula, Washington.

The proportion of rainfall intercepted by forest canopies is inversely related to both antecedent wetness and rainfall intensity. Gentle, short-duration rainfall may be almost totally intercepted, while interception may account for as little as 5 percent of precipitation during intense winter storms.[86]

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.

~~7.2~~6.4.2 Groundwater Recharge and Groundwater Flow Modeling

Groundwater recharge is difficult to measure directly, but several empirical and numerical methods exist for estimating recharge within the surface-water, unsaturated zone, and saturated zone, including physical, tracer, and numerical-modeling techniques.[87] 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

[82] Hanks and Ashcroft, 1980.
[83] Link et al., 2004.
[84] Dingman, 1994.
[85] DHSVM; Wigmosta, Njssena and Stork, 2002.
[86] Ramirez and Senarath, 2000.
[87] Scanlon et al., 2002.

Model[88], Precipitation Runoff Modeling System[89], and the Variable Infiltration Capacity Model[90]. 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.[91] 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.

~~7.3~~6.5 Computational Slope Stability Assessment Methods

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

Limit-equilibrium analysis calculates a factor of safety for sliding along a critical failure surface, which is expressed as a ratio of the shear strength of the earthen material resisting slope failure to the shear stresses driving instability. Relative stability is defined by a factor of safety exceeding a value of one. A two-dimensional limit-equilibrium analysis method may be applied to deep-seated landslides but can also be useful for smaller local site situations. Computation of the most critical failure surface is an iterative process generally supported by commercially available or public-domain software.[92] 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 ~~inputting~~ the following information to define an initial state of stability:

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

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[88] Bauer and Vaccaro, 1987.
[89] Leavesley et al., 1983.
[90] Liang et al., 1994.
[91] Harbaugh et al., 2000.
[92] e.g., LISA, DLISA, STABL, SLOPE-W.

The potential effects of the proposed forest practices activities on slope stability can then be evaluated by modifying the initial model with the expected condition based on the proposed activities, such as placement of fill for road construction or elevating groundwater levels (pressures) due to forest canopy removal. Limit-equilibrium models also allow the analyst to reconstruct pre-failure slope conditions of existing landslides by varying the input parameters (e.g., surface topography, engineering geologic unity 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 also can be used to evaluate downslope material impacts to ~~natural~~ public resources and threats to public safety, as well as upslope impacts in situations where retrogressive failure mechanisms are suspected. Turner and Schuster (1996), as well as 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.

~~7.~~46.6 Delivery Assessment

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

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

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

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

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

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

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

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

~~7.5~~PART 7 SYNTHESIS OF RESULTS, ~~PRIOR TO PREPARATION OF GEOLOGIC~~ EVALUATION~~S~~ AND GEOTECHNICAL REPORTS

This step is generally reserved for qualified experts when preparing geologic evaluations. The following questions and ~~recommendations~~ guidance are provided to ~~guide~~ assist the qualified expert ~~in their synthesis~~when synthesizing the information assembled in the office review and field assessment, and can be useful when preparing a geologic evaluation or report. ~~(see Part 8 for geotechnical report guidelines):~~

~~What are the project objectives (e.g., timber harvest unit evaluation, road construction or abandonment, landslide mitigation)?~~

~~Which types of unstable slopes and landforms have been identified (see Part 5)?~~

~~What are their spatial and temporal distributions (see Part 5)?~~

~~Which office and field methods were used to identify and delineate unstable slopes and landforms (see Part 6)?~~

7.1 Synthesis and Evaluation

Consideration of the following questions may help to synthesize findings:

- Based on an analysis of available information (see Parts 7.1, 7.2, 7.3), 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 identifications, delineation, and interpretion of unstable slopes and landforms?
- What is the potential for material delivery from each identified relevant unstable slope and landform to areas of public resource sensitivity or where public safety could be threatened (see Parts 7.4)?
- 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?

Documentation of the project analysis may include annotated images (e.g., LiDAR-derived hillshades, aerial photos), geologic or topographic profiles, maps, sketches, results of subsurface investigations, summaries of computational or simulation modeling, summaries of available (i.e., previously published) information and remotely sensed or field-derived data and text to explain the concrete evidence and logical train-of-thought for the conclusions and recommendations that will be presented in the geotechnical report.

It is recommended that field observation and sampling locations used in project analysis be displayed on a map in the geotechnical report. Descriptive, photo, or data-sampling observation points should be geo-referenced (i.e., with GPS waypoints). Mapped GPS track locations for field traverses also are recommended, so it is clear which portions of the project site were evaluated. In addition, field-derived cross sections and geologic profile locations should be geo-referenced.

Models such as those for slope stability and sensitivity (see Parts 7.2 and 7.36.5) may be used to support analyses of potentially unstable slope and landform characteristics and mechanics. If models 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.

It is recommended that theThe analytical methods and processes used to identify, delineate, and interpret unstable slopes and landforms can be described, in the geotechnical report, along with information sources, data processing techniques, and the meaning and limitations of analysis results. Geotechnical rReports 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. Geotechnical rReports may also should 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.

The report 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. Report 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.

It is helpful to provide a concise statement of confidence in and limitations of the slope stability analysis and its conclusions. 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 natural public resource, public safety, and liability risks associated with implementing a project.

Documentation of the project analysis may include: annotated images (e.g., LiDAR-derived hillshades, aerial photos),; geologic or topographic profiles,; maps,; sketches,; results of subsurface investigations,; summaries of computational or simulation modeling,; summaries of available (i.e., previously published) information; and remotely sensed or field-derived data and text to explain the concrete evidence and logical train- of- thought for the conclusions and recommendations that will be presented in the geotechnical report.

The geotechnical report 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. The qualified expert also might be asked by the landowner to provide or evaluate possible mitigation measures for destabilized slopes or landforms.

PART 87.2. Geotechnical Reports

The qualified expert is encouraged to consult with DNR Region geologists when preparing geotechnical report to ensure all important elements are covered. Region contact information can be found on DNR's web site at www.dnr.wa.gov.

When harvesting timber or building roads on potentially unstable slopes, a geotechnical written report is required to be part of the FPA to explain how 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." If the FPA is classed as a "Class IV-Special", the applicant must also submit to DNR a SEPA checklist and additional information as described in WAC 222-10-030. The geotechnical report must be prepared by a qualified expert and the report 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

~~submit to DNR a~~ include a SEPA checklist and additional information ~~as described~~listed in WAC 222-10-030.

~~Effective July 1, 2002,~~ ~~qualified~~ 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 ~~on~~ about the geologist licensing process, refer to WACs 308-15-010 through 308-15-150, or ~~visit~~ see the Geologist Licensing Board's web site at (www.dol.wa.gov/business/geologist). The education and field experience on forest lands ~~will still be~~ is required, in addition to the appropriate geologist license.

~~**In addition to the considerations described in Part 7.5, the following elements should be included in geotechnical reports prepared by qualified experts:**~~The report should be as detailed as necessary to ~~answer~~address these and any other relevant ~~questions.~~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, relevant weather conditions~~, and the locations visited with GPS coordinates if possible~~.

(b) *Describe the geographic, geologic, and soil conditions of the area in and around the application site*. Include a legal description of the proposal area, the county in which it is located, and where appropriate the distance and direction from the nearest municipality, local landmarks, and named water bodies. Provide elevations and aspect. Describe the underlying parent materials, including their origin (i.e., glacial versus bedrock); the name(s) of any rock formations and their associated characteristics; and geologic structure relevant to slope stability. Describe soils and rocks on site based on existing mapping, field observations, and any available local information. Describe soil and rock texture, depth, and drainage characteristics typically using standard soil and rock classification systems.[93]

(c) *Describe the potentially unstable landforms within and around the site*. Include a general description of the topographic conditions of the site. ~~It may be appropriate to provide GPS coordinates for locations of site observations and other important features such as borings, trenches, and outcrops.~~ 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 ~~dominant~~ mass wasting processes associated with each identified landform, as well as detailed observations of past slope movement and indicators of ~~instability~~potential future landslide activity. ~~It is recommended that~~Relevant field observations, important features, and sampling locations used in project analysis can be displayed on a map in the geotechnical report. Descriptive, photo, or data-sampling observation points should be geo-referenced (i.e., with GPS waypoints)~~.~~ ~~Mapped~~and mapped GPS track locations ~~for~~of field traverses ~~also are~~can be ~~recommended, so it is clear~~used to clarify 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 ~~and/~~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 ~~on or~~within the groundwater recharge area

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

of a glacial deep-seated landslide, specifically discuss the probable direct and indirect impacts to groundwater levels and those impacts to the stability of the glacial deep-seated landslide.

(d) *Analyze the possibility that the proposed forest practice will cause or contribute to movement on the potentially unstable slopes*. Explain the proposed forest management activities on and adjacent to the potentially unstable slopes and landforms. Clearly illustrate the locations of these activities on the site map, and describe the nature of the activities in the text. Discuss in detail the likelihood that the proposed activities will result in slope movement (separate activities may warrant separate evaluations of movement potential). The scope of analysis should be commensurate with the level of resource and/or public risk. Include a discussion of both direct and indirect effects expected over the short- and long-term. For proposals involving operations on or in the groundwater recharge area of a glacial deep-seated landslide, conduct an assessment of the effects of past forest practices on landslide/slope movement. Explicitly state the basis for conclusions regarding slope movement. Conclusions may be based on professional experience, field observations, unpublished local reports, watershed analyses, published research findings, and/or slope stability model output. Input parameters, model assumptions, and methods should be fully substantiated within the report.

(e) *Assess the likelihood of delivery of sediment and/or debris to any public resources, or to a location and in a manner that would threaten public safety, should slope movement occur*. Include an evaluation of the potential for sediment and/or debris delivery to public resources or areas where public safety could be threatened. Discuss the likely magnitude of an event, if one were to occur. Separate landforms may warrant separate evaluations of delivery and magnitude. Explicitly state the basis for conclusions regarding delivery. Conclusions may be based on professional experience, field observations, unpublished local reports, watershed analyses, published research findings, and/or landslide runout model results, which should have site-specific data. Input parameters, model assumptions, and methods using best available data should be fully substantiated within the report.

(f) *Suggest possible mitigation measures to address the identified hazards and risks*. Describe any modifications necessary to mitigate the possibility of slope movement and delivery due to the proposed activities. If no such modifications are necessary, describe the factors inherent to the site or proposed operation that might reduce or eliminate the potential for slope movement or delivery. For example, an intact riparian buffer down slope 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. ~~The~~ 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. ~~The qualified expert also might be asked by the landowner to provide or evaluate possible mitigation measures for destabilized slopes or landforms.~~

~~The report should be as detailed as necessary to answer these and any other relevant questions. In particular, examination of aerial photographs (preferably taken over many years), LiDAR-derived products, and other screening tools would be appropriate to evaluate the stability characteristics of the area and the effects of roads or previous logging on the subject or similar sites. Field observations will usually be necessary to define the local geology, landforms, etc. Quantitative estimates of site stability produced using SHALSTAB, XSTABL, or other slope-stability models may be useful.~~ ~~The report c~~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. ~~Report~~ ~~c~~Conclusions might also include a description of the suitability of the proposed activity for the site, and likely direct and indirect effects of the activity on the geologic environment and processes. Conclusions should be substantiated by the evidence presented and the expert's logical thought processes during analysis and synthesis.

GLOSSARY

Aquifer Saturated permeable geologic unit that can transmit significant quantities of water under ordinary hydraulic gradients.

Aquitard A less permeable bed in a stratigraphic sequence.

Confined aquifer An aquifer that is confined between two aquitards. Confined aquifers occur at depth.

Debris avalanche The very rapid and usually sudden sliding and flowage of incoherent, unsorted mixtures of soil and weathered bedrock.

Discontinuity Sudden or rapid change with depth in one or more of the physical properties of the materials constituting the earth.

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 Non-sorted, non-stratified sediment carried or deposited by a glacier.

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.

~~**Lahar** A mudflow composed chiefly of volcaniclastic materials on the flanks of a volcano.~~

LiDAR (Light Detection and Ranging) A detection system that works on the principle of radar, but uses light from a laser.

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.

Seismic method A geophysical method using the generation, reflection, refraction, detection and analysis of seismic waves in the earth to characterize the subsurface.

Soil An aggregate of solid particles, generally of minerals and rocks, either transported or formed by the weathering of rock in place.

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.

~~**Vadose zone** The unsaturated zone below the land surface and above the zone of saturation or water table.~~

Water table The surface on which the fluid pressure in the pores of a porous medium is exactly atmospheric. The location of this surface is revealed by the level at which water stands in a shallow well open along its length and penetrating the surficial deposits just deeply enough to encounter standing water at the bottom.

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APPENDIX B – LANDSLIDE PROVINCES IN WASHINGTON

2.4 Geographic Distribution of Landslides in Washington

Landsliding is a widespread geomorphic process which actively modifies the varied topography and diverse underlying geologic materials present throughout theWashington sState. 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.

The Puget Lowlands-North Cascade Foothills is a

This region that 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.[94] 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.[95] Thick, deeply weathered loess deposits are sources for shallow

[94] Tabor and Cady, 1978; Badger, 1993.
[95] Gerstel and Badger, 2002.

landslides, debris flows, and avalanches.[96] These deposits are prevalent along the lower Columbia River valley, as well as other areas where colluvial deposits have accumulated on slopes and in drainages underlain by strong and relatively unweathered rock.

Cascade Range

The Cascade Range is generally divided on the basis of rock types into northern and southern provinces occurring geographically in the vicinity of Snoqualmie Pass. Strong crystalline rocks intensely scoured by alpine glaciations occur to the north. Weaker volcanic flows, typically pyroclastic and volcaniclastic rocks occur to the south, much of which was beyond the reach of the last continental glaciation. Rockfalls and complex rock slides are dominant in the steep bedrock slopes in the North Cascades. In the South Cascades and Columbia Gorge, weak interbeds control large translational failures in the Chumstick and Roslyn Formations[97], the Columbia River Basalts and other volcanic flow rocks, and Cowlitz Formation and Sandy River Mudstone[98]. Shallow landslides generating debris avalanches and flows are common on steep slopes and drainages.

Okanogan Highlands

Pleistocene glacial sediments that mantle the mostly crystalline core of the Okanogan Highlands are prone to both shallow and deep-seated landslides. The debris flows in this region can be a hazard during intense thunderstorms, usually moving through the area during late spring to late summer. Deep-seated landslides are most common in the areas surrounding Lake Roosevelt and landslide movement usually occurs in areas where relict to dormant deep-seated landslides exist. Rockfalls and rock slides are common from the many steep bedrock exposures in the region.

Columbia Basin

This province is largely composed of thick sequences of lava flows known as the Columbia River Basalts. Catastrophic flood events scoured the soils and a portion of the bedrock in much of this region before re-depositing it in watersheds along the edges of the main floodway. Landslides include slope failures in bedrock along the soil interbeds and in the overlying flood sediments and loess deposits. Bedrock slope failures are most common in the form of very large deep-seated translational landslides, deep-seated slumps or earth flows. The Blue Mountains in southeastern Washington also have experienced recurring and widespread shallow landsliding and debris flows related to storm events.[99]

[96] Thorsen, 1989.
[97] Tabor et al., 1987.
[98] Wegmann, 2003.
[99] Harp et al., 1997.

APPENDIX A – MEASUREMENT OF SLOPE GRADIENTS

PART 3. MEASUREMENT OF SLOPE ANGLES

The forest practices rules contain specific slopes gradients (degrees and percent) for potentially unstable slope or landform descriptions. Part 3 provides guidance in determining slope gradients when evaluating the feature on site. 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.

3.1 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 (Figure 4a).

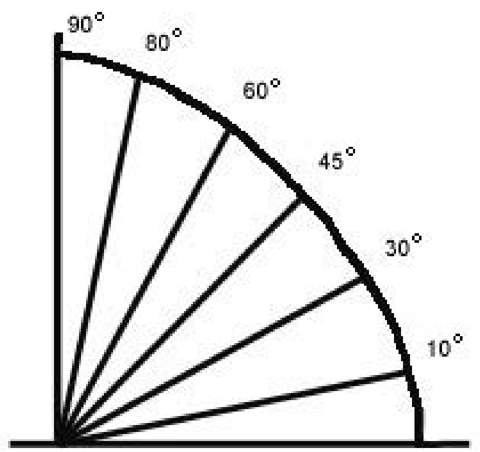


Figure 4a. Angles in degrees.

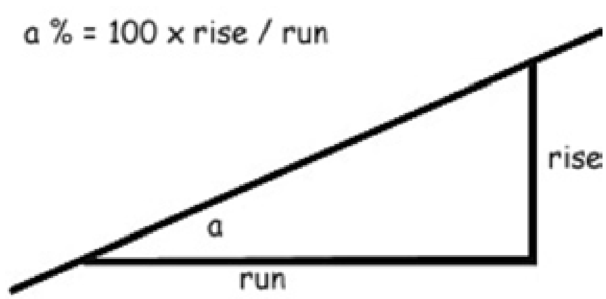


Figure 4b. Angles in percent.

3.2 Percent

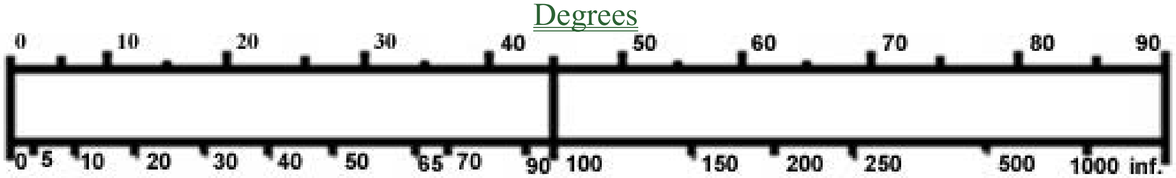
In Figure 4bthe figure directly above, the horizontal distance between two points (distance between the points on a map) is called the run. The vertical distance (difference in elevation) is called the rise. The gradient can be expressed as the ratio of rise divided by run, a fraction that is the tangent of angle α. When multiplied by 100, this fraction is the percent slope.

~~3.3~~ 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.

~~Figure 5~~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.

Degrees



Percent

~~Figure 5.~~ Slope gradients in degrees and percent.

APPENDIX ~~A~~ C – MAPS AND SURVEYS

Map and survey data resources available to the qualified expert include:

Multi-disciplinary map and survey data resources:

- Washington State Geologic Information Portal – create, save, and print custom digital maps of Washington State or download map data for GIS applications; includes a variety of base layer selections with interactive Geologic Map, Seismic Scenarios Catalog, Natural Hazards, Geothermal Resources, Subsurface Geology Information, and Earth Resource Permit Locations; available on Washington Dept. of Natural Resources website.
- Forest Practices Application Review System (FPARS) – online mapping tool with a variety of digital map base layer selections including topography, surface water (streams, water bodies, wetlands), soils, transportation network, forest site class, and potential slope instability (designed for shallow landslide susceptibility mapping only). Available on the DNR website.
- County interactive GIS map viewers – create, save, and print custom digital maps with some combination of the following data: topography (LiDAR and/or U.S. Geological Survey (USGS) DEM), surface water, soils, wetlands, sensitive areas, 100-year floodplain designations, transportation systems, property ownership and structure location. Available online at select county websites (e.g., King County iMAP).
- Washington State Coastal Atlas Map – interactive map utility for shoreline areas with multiple data layers including shoreline geomorphology (coastal slope stability and landforms), biology (plant communities), land and canopy cover, beaches and shoreline modifications, wetlands and estuaries, historic shoreline planforms, assessed waters, and Shoreline Management Act (SMA) designations; see Department of Ecology website.
- DNR surface mining permits.

Topographic maps:

- USGS topographic 7.5 minute quadrangle maps. Available from a number of government and non-government online vendors and free downloadable websites.
- LiDAR-based topographic maps (LiDAR-derived DEM (LDEM), typically 1- to 3- meter resolution); see Appendix C for LiDAR map and data sources.

Geologic maps:

- Geologic maps of various scales, in print and compiled by DNR, Division of Geology and Earth Resources as Map Series, Open File Reports, Bulletins, and Information Circulars; see most recent "Publications of the Washington Division of Geology and Earth Resources"; this publication and a status map of 7.5 minute quadrangle geologic mapping efforts (USGS STATEMAP program) are available on the Division of Geology and Earth Resources website with links to online publications where available.
- Geologic maps, various scales, out-of-print or historic; all sources including dissertations and theses. See catalog of the Washington Geology Library, available through the DNR website with links to online publications where available.
- Geology digital data; small-scale geology coverage in ArcGIS shapefile format, available on the Division of Geology and Earth Resources website.
- Geologic maps, various scales, available via The National Geologic Map Database (NGMDB); compiled by USGS and Association of American State Geologists; see NGMDB website catalog) and USGS Online Store (paper and digital copies).

Geologic hazards and landslide inventory maps:

- Washington State Geologic Information Portal, referenced previously.
- Landslide Hazard Zonation (LHZ) Project – mapped existing and potential deep-seated landslides and landforms in select watersheds; hazard classifications provided with supporting documentation for completed projects. Available on the DNR website.
- Landslide inventory and Mass Wasting Map Unit (MWMU) maps contained in Watershed Analysis reports prepared under chapter 222-22 WAC – mapped landslides (including deep-seated and earthflows) for select Watershed Administrative Units (WAU); Adobe pdf versions of DNR-approved Watershed Analysis Reports are available through the DNR website.
- Modeled slope stability morphology (SLPSTAB, SHALSTAB, SINMAP) output maps.
- U.S. Forest Service watershed analyses – available from US Forest Service offices for select watersheds; some documents and maps are available online.
- Washington State tribal watershed analyses – available from tribal agency offices; some documents and maps are available online;
- Washington State Coastal Atlas Map – slope stability maps developed prior to 1980, based on aerial photography, geologic mapping, USGS topographic quadrangle map, and field observations. Maps have not been updated with landslide data since 1980 but are used currently in land-use planning and in the Department of Ecology interactive Coastal Map tool; read data limitations on Department of Ecology's website.
- Qualified expert reports on deep-seated landslides in glaciated and non-glaciated terrain, for select timber harvest units or other forest management projects regulated by the Washington Forest Practices Act. Often contain mapped landslides.
- TerrainWorks (NetMap) – provides digital landscape and analysis tools for slopes stability data/analysis and risk assessments.

Soil surveys:

- Natural Resources Conservation Service (NRCS) soil survey maps and data – online soil survey, map and database service; historical soil survey publications (CD or paper copies); NRCS website administered through the U.S. Department of Agriculture.
- Geochemical and mineralogical soil survey map and data – USGS Mineral Resources Program, open-file report available online (Smith et al., 2013) in Adobe pdf.
- National Cooperative Soil Survey Program (NCSS), Washington State – online soil survey data and link for ordering in-print surveys not available electronically. See NRCS website.

APPENDIX ~~B~~ 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 C E – LiDAR: PROCESSING, APPLICATIONS, AND DATA SOURCES FOR LIDAR DATA

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.[100] 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.[101] 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.[102]

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.[103] 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.[104] 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.[105] 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

[100] Carter et al., 2001.
[101] For a review of filtering techniques, see Liu, 2008.
[102] Van Den Eeckhaut et al., 2007.
[103] Corsini et al., 2007; Delong et al., 2012; Daehne and Corsini, 2013.
[104] Burns et al., 2010.

[105] Tarolli, 2014.

displacement and sediment transport[106]; (2) ortho-rectified historical aerial photographs to map earthflow movement and calculate sediment flux[107]; (3) GIS-based algorithms for LiDAR derivatives (e.g., hillslope gradient, curvature, surface roughness) to delineate and inventory deep-seated landslides and earthflows[108]. ;and (4) subsurface investigations[109].

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 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.

[106] Roering et al., 2009; Handwerger et al., 2013; Scheingross et al., 2013.
[107] Mackey and Roering, 2011.
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[109] Travelletti and Malet, 2012.

APPENDIX ~~D~~ 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 http://www.dnr.wa.gov/ResearchScience/Topics/WatershedAnalysis/Pages/fp_watershed_analysis.aspx (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 ~~E~~ 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 ~~F~~ 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.

APPENDIX G - ADDITIONAL RESOURCES

The following literature list provides additional resources not directly cited in this Board Manual section. They are listed topically according to the scientific study/research.

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Section 16
Guidelines for Evaluating
Potentially Unstable Slopes and Landforms

PART 1. INTRODUCTION

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

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

The intended audience is:

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

The current rules related to potentially unstable slopes and landforms were developed to avoid an increase over natural background rates from forest practices on high-risk sites at a landscape scale. The rules apply when it is determined that proposed forest practices activities may contribute to the *potential* for sediment and debris delivery to a public resource or cause a threat to public safety. When the potential for slope instability is recognized, the likelihood of damage must be considered. Other factors in determining this likelihood could include initial failure landslide volume, the nature of the landslide, potential landslide runout distance, and slope or channel conditions.

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

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

- Parts 2, 3, and 4 contain general background information for all readers on how to recognize the various landslide types in Washington State (Part 2), how to recognize slope form (Part 3), and how to recognize potentially unstable slopes and landforms for purposes of identifying them in the area of a proposed forest practices activity (Part 4).
- Parts 5, 6, 7 contain procedures and resources, as applicable, 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 remainder of Part 5 and all of Parts 6 and 7 give guidance to the work of **qualified experts** to conduct expert-level office reviews and field assessments, and to prepare geotechnical reports.

- It ends with a glossary of terms that may not be familiar to many readers; a list of the references cited throughout the document; and several appendices containing lists of resources that any reader may find informative or useful.

PART 2. LANDSLIDE TYPES IN WASHINGTON

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

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

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

[1] e.g., Reeves et al., 1995; Geertsema and Pojar, 2007; Restrepo et al., 2009.
[2] Robinson et al., 1999; Turner et al., 2010.

2.1 Landslide Types and Effects

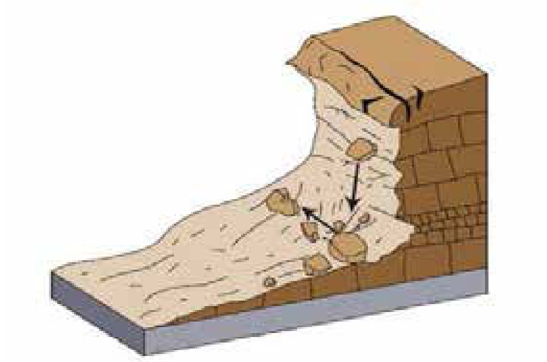
Several classification schemes are used by geologists, engineers, and other professionals to identify and describe landslides. The classification scheme of Varnes (1978), as modified by the U.S. Geological Survey (2004) and Hungr et al. (2001) is used for the purposes of this Board Manual section (see 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. 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. In the forested environment where coarse materials including wood are common, the terms under “Predominately Fine” are seldom used.

Table 1. Landslide Classification

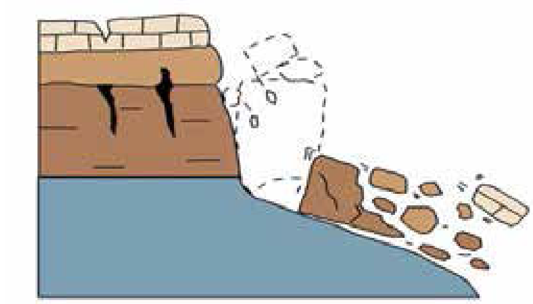
Based on Varnes (1978) as modified by U.S. Geological Survey (2004) and Hungr (2001).

<table>
<tr><th colspan="2" rowspan="3">Type of Movement</th><th colspan="3">Type of Material</th></tr>
<tr><th rowspan="2">Bedrock</th><th colspan="2">Soils</th></tr>
<tr><th>Predominately Coarse</th><th>Predominately Fine</th></tr>
<tr><td colspan="2">Falls</td><td>Rock Fall</td><td>Debris Fall</td><td>Earth Fall</td></tr>
<tr><td colspan="2">Topples</td><td>Rock Topple</td><td>Debris Topple</td><td>Earth Topple</td></tr>
<tr><td rowspan="2">Slides</td><td>Rotational</td><td rowspan="2">Rock Slide</td><td rowspan="2">Debris Slide</td><td rowspan="2">Earth Slide</td></tr>
<tr><td>Translational</td></tr>
<tr><td colspan="2">Lateral Spreads</td><td>Rock Spread</td><td>Debris Spread</td><td>Earth Spread</td></tr>
<tr><td colspan="2">Flows-Confined</td><td>Rock Flow</td><td>Debris Flow</td><td>Earth Flow</td></tr>
<tr><td colspan="2">Flows-Unconfined</td><td>Rock Avalanche</td><td>Debris Avalanche</td><td>Debris Flood</td></tr>
<tr><td colspan="2">Complex</td><td colspan="3">Combination of two or more principal types of movement</td></tr>
</table>

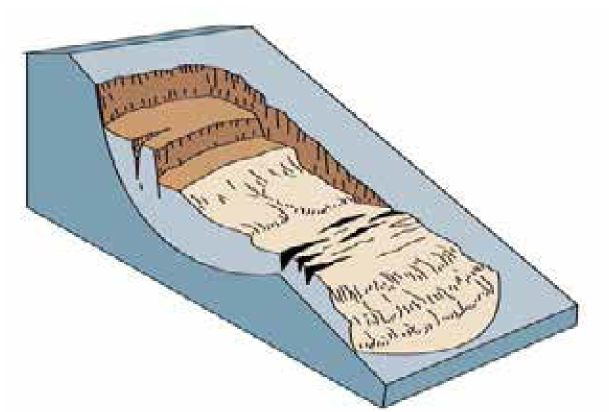
Materials in a landslide mass are either rock or soil (or both) and may include organic debris. In this context, soil is composed of sand-sized or finer particles and debris is composed of coarser fragments. The types of landslides commonly found in forested areas in Washington are slides, flows, and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



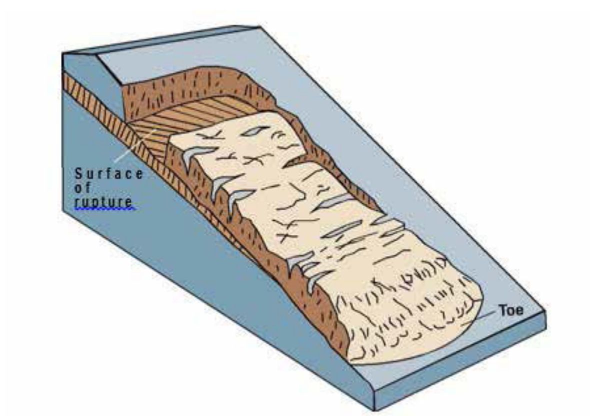
Falls: Falls occur when a mass of rock or soil detaches from a steep slope or cliff, and are often caused by the undercutting of the slope. The failure is typically rapid to very rapid. The fallen mass may continue down the slope until the terrain flattens.



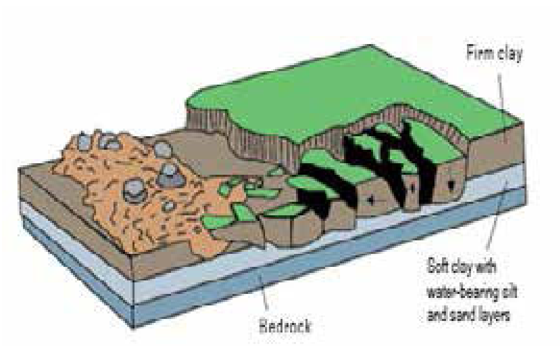
Topples: Landslides where the forward rotation of a mass of rock or soil breaks away or 'topples' from the slope. Their failure rates range from extremely slow to extremely fast.



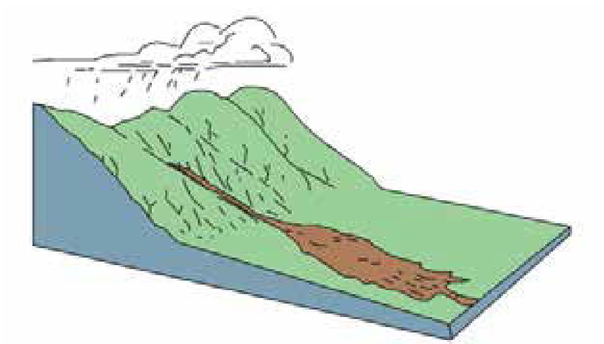
Rotational slides: Landslides where the surface of rupture is concave-up and the slide movement is rotational about an axis that is parallel to the contour of the slope. Glacial deep-seated landslides can be rotational slides developed in glacial sediments common in the Puget Sound area, but they can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



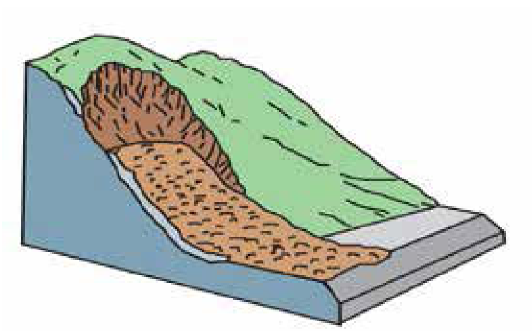
Translational slides: Landslides where the surface of the rupture is roughly planar with a surface roughly parallel to the ground surface. These are called rock slides, block glides, slab slides, or debris slides.



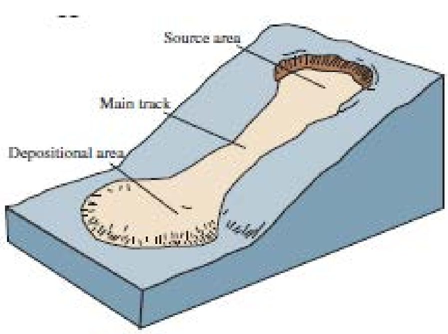
Lateral spreads: Landslides that generally occur on very gentle or level slopes and are caused by subsidence of a fractured mass of cohesive material into softer, often liquefied underlying material.



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



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



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

Figure 1. Illustrations of the major types of landslide movement (all from Highland and Bobrowsky, 2008, except "earth flows" is from U.S. Geological Survey, 2004).

2.2 Shallow Landslide Types

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

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

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

Figure 2. Debris flow (DNR, 2000).

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

[3] Pierson and Scott, 1985.
[4] Iverson and Reid, 1992.

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

Dam break floods are a subset of flow-type landslides defined as very rapid surging flows of water, heavily charged with debris, in a steep channel.[5] They contain a mixture of water and sediment (dominantly sand-sized), and organic debris with solids that range between 20% and 60% by volume.[6] 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.[7] Such floods can rise higher than normal rainfall- or snowmelt-induced flows along relatively confined valley bottoms, driving flood waters, sediment, and wood loads to elevations high above the active channel, and the active floodplain if present.

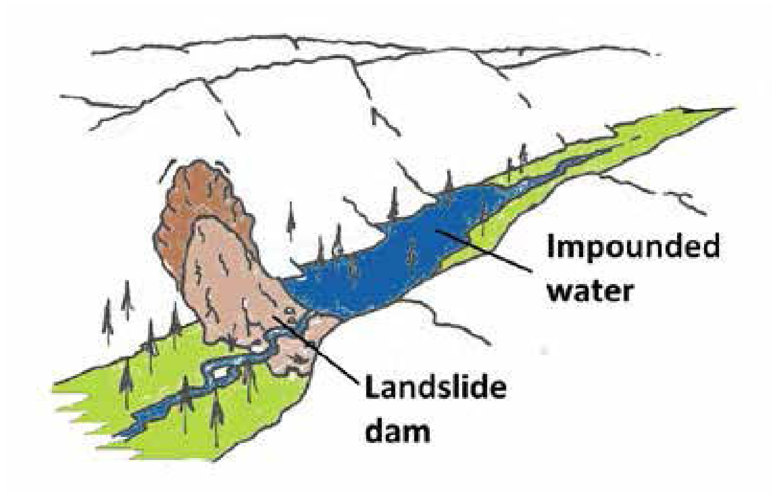


Figure 3. Impounded water caused by landslide dam.

Debris flows and dam break floods can occur in any unstable or potentially unstable terrain with susceptible valley geometry. In natural systems, debris flows and dam break floods are responsible for moving sediment and woody debris from hillslopes and small channels down into larger streams. They can also scour channel reaches, disturb riparian zones, dump debris onto salmonid spawning areas, elevate turbidity, and adversely affect water quality downstream and threaten public safety (Figure 3).

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[5] Hungr et al., 2001.
[6] Pierson and Scott, 1985.
[7] Johnson, 1991.

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

The photo on the left in Figure 4 shows debris flows that coalesced and, after exiting the confined channel at the base of the mountain, formed a new debris flow spreading across a 1,000-foot wide swath for a distance of 2,000 feet before entering the South Fork Nooksack River. Between the base of the mountain and the river, the debris flow affected (if not severely damaged) a county road, farmyard, house sites, and more than 60 acres of cultivated farm fields. The photo on the right shows the same hillslope after harvest with leave tree areas in the slide-prone inner gorges.

2.3 Deep-Seated Landslides

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

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

Deep-seated slides may respond to rainfall events over periods of days to weeks, or weather patterns over months to years or even decades.[8] The larger deep-seated landslides can usually be identified

[8] Washington State Department of Emergency Management, 2013.

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.

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 odd ways due to differential movement of discrete landslide blocks. The parts of deep-seated landslides that are most susceptible to shallow landslides and potential sediment delivery are steep scarps (including marginal stream side slopes) and toe edges.

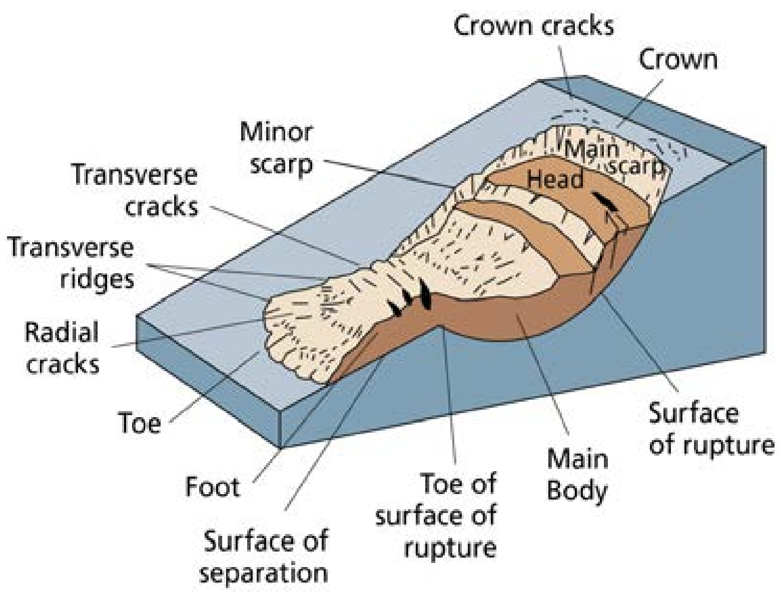

Figure 5. Rotational deep-seated landslide. Rotational displacement of blocks of soil commonly occur at the head of the landslide (adapted from USGS, 2004).

Movement of deep-seated landslides can be complex, ranging from slow to rapid, and may include numerous small to large horizontal and vertical displacements triggered by one or more failure mechanisms.[9] Deep-seated landslides often are part of large landslide complexes that may be intermittently active for hundreds of years or more.[10] The bodies and toes of deep-seated landslides and earth flows are made up of incoherent collapsed materials that were weakened from previous movement of the materials, and therefore may be subject to debris flow initiation. As a result, sediment delivery can occur from shallow landsliding on steep stream-adjacent toes of deep-seated landslides and from steep side slopes along marginal stream channels within the bodies of deep-seated landslides.

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

[9] Roering et al., 2005.
[10] Bovis, 1985; Keefer and Johnson, 1983.

activities such as excavating for land development.[11] 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.[12] Initiation or reinitiation of such landslides has also been associated with increases in groundwater levels[13] due to individual storms or in response to seasonal accumulation from rainfall or snow melt, depending on soil and bedrock properties, and the degradation of material strength through natural processes. When subsurface water is assumed to influence the movement of a deep-seated landslide, the methods used to identify groundwater recharge areas associated with glacial deep-seated landslides may apply to other (e.g., non-glacial) deep-seated landslides.

The loss of tree canopy interception of moisture and the reduction in evapotranspiration through timber removal on areas up-gradient of the slide may also initiate movement of the slide. However, many deep-seated landslides are not hydrogeologically connected to groundwater sources up-gradient.[14] Generally, avoiding the following practices will avoid reinitiating or accelerating deep-seated landslide movement: removing material during road construction or quarrying at the toe; overloading slopes by placing spoils on the upper or mid-scarp areas, changing subsurface hydrology by excessive soil compaction; and directing additional water into the slide from road drainage or captured streams.

PART 3. SLOPE FORM

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

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

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11 Schuster and Wieczoreck, 2002.
12 Cronin, 1992.
13 van Asch et al., 2005.
14 van Asch, et al., 2009.

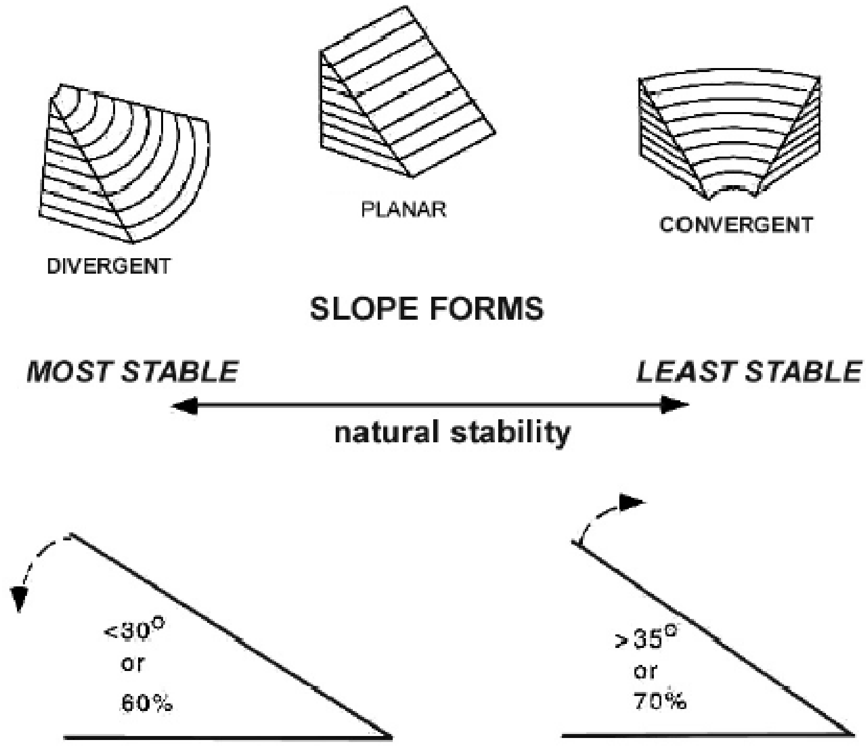

Figure 6a. Slope configurations as observed in map view.

Figure 6a shows three major slope forms (divergent, planar, and convergent) and their relative stability. These slope form terms are used in reference to contour (across) directions on a slope. Typically, convergent areas with slope gradients equal to or greater than 35 degrees (70%) are at a higher risk of sliding.[15]

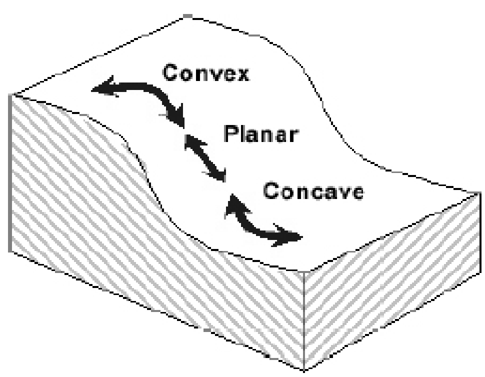

Figure 6b. Slope configurations as observed in profile: convex, planar, and concave. These terms are used in reference to up and down directions on a slope (Drawing: Jack Powell, DNR, 2004).

[15] 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);[16]
B. Toes of deep-seated landslides with slopes steeper than 33 degrees (>65 %) (see 4.2);
C. Groundwater recharge areas for glacial deep-seated landslides (see 4.3);
D. Outer edges of meander bends along valley walls or high terraces of an unconfined meandering stream (see 4.4); or
E. Any areas containing features indicating the presence of potential slope instability which cumulatively indicate the presence of unstable slopes (see 4.5).

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

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

4.1 Bedrock Hollows, Convergent Headwalls, Inner Gorges

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

[16] See Appendix A for guidance on determining slope gradients.

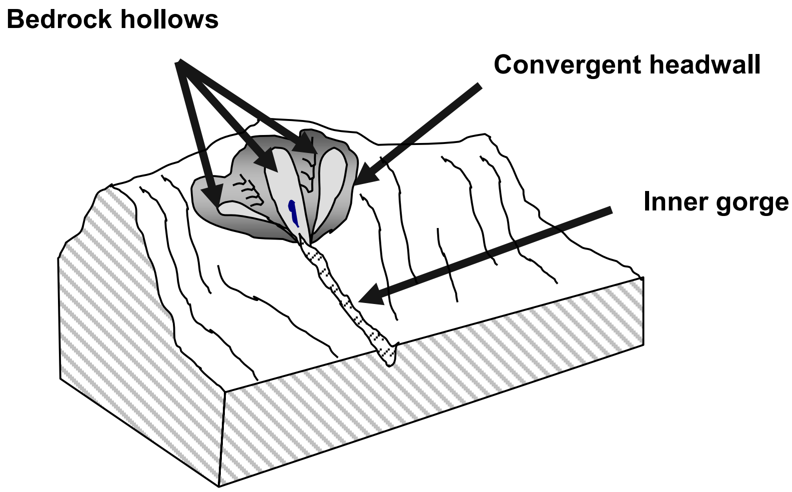

Figure 7. Typical hillslope relationships between bedrock hollows, convergent headwalls, and inner gorges (Drawing: Jack Powell, DNR, 2003).

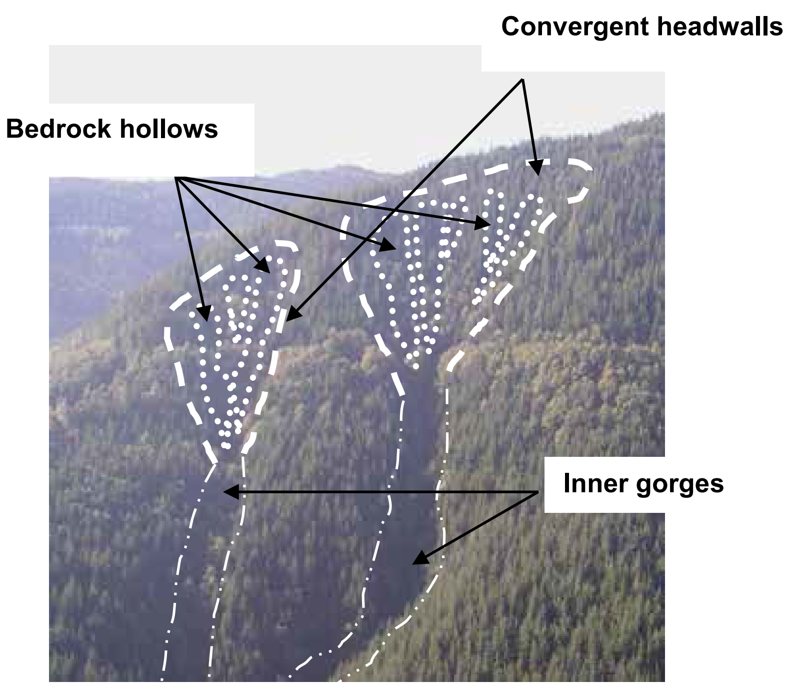

Figure 8. Common hillslope relationship: bedrock hollows in convergent headwalls draining to inner gorges (Photo and drawing: Jack Powell, DNR, 2003).

Bedrock hollows are also called colluvium-filled bedrock hollows, zero-order basins, swales, bedrock depressions, or simply hollows.[17] Not all hollows contain bedrock so the term "bedrock" hollow can be a misnomer. In the forest practices rule context, the "bedrock hollows" listed in category A are hollows formed in bedrock. However, hollows formed in other materials such as

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

glacial outwash without a bedrock substrate may also show signs of instability and would need evaluation similar to hollows containing bedrock. Such hollows that show signs of instability would fit into category E of the rule.

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

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

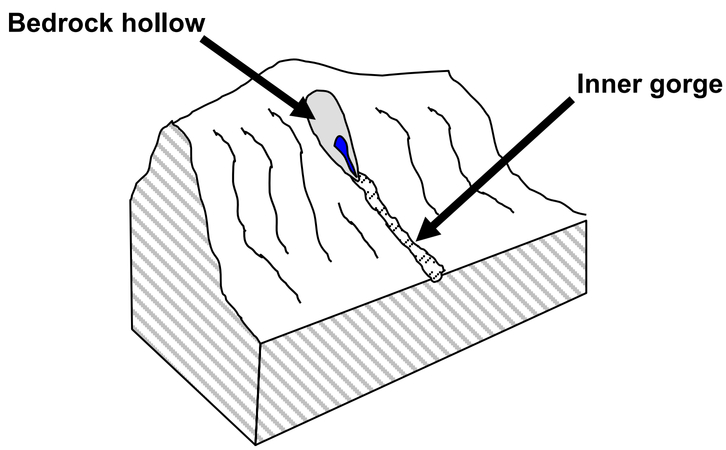

Figure 9. Bedrock hollow and relationship to inner gorges (Drawing: Jack Powell, DNR, 2003).

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

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

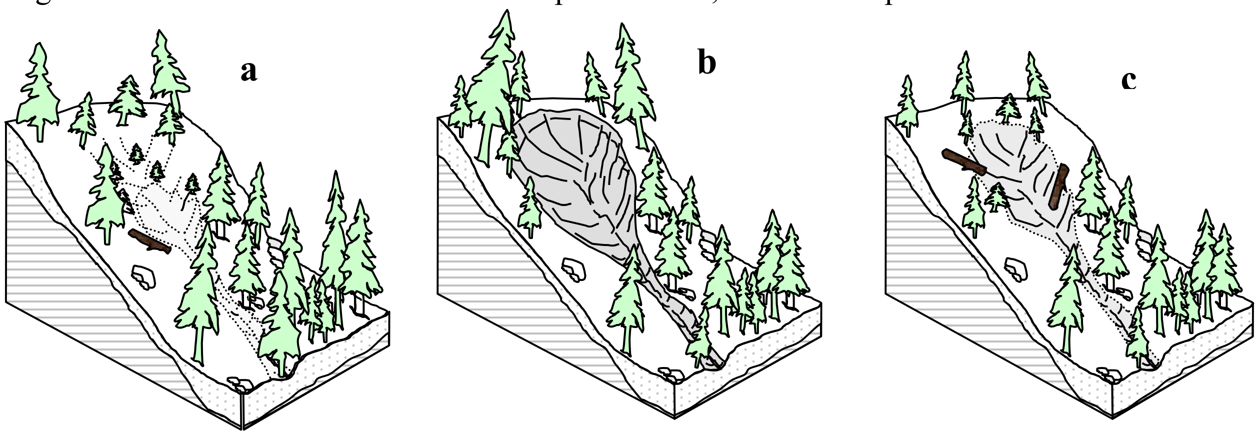

Figure 10. Evolution of a bedrock hollow following a landslide (adapted from Dietrich et al., 1988; drawing by Jack Powell, DNR, 2004).

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

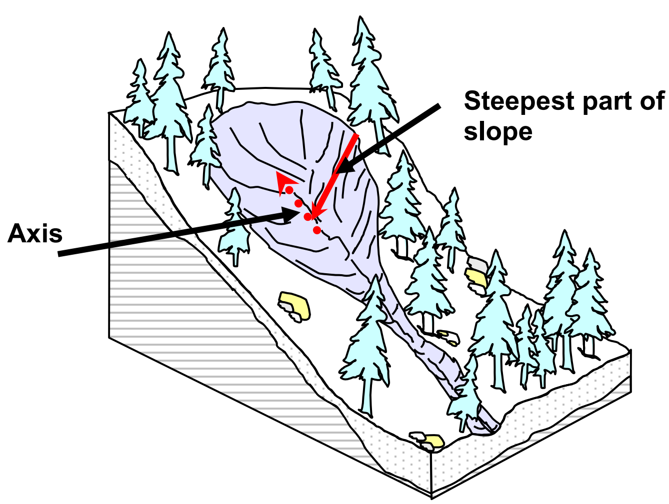

Figure 11. Bedrock hollow slopes are measured at the steepest part of the slope, rather than along the axis (Drawing: Jack Powell, DNR, 2004).

Vegetation can provide the critical cohesion on marginally stable slopes and removes water from the soil through evapotranspiration. Leaving trees in steep, landslide-prone bedrock hollows helps maintain rooting strength and should reduce the likelihood of landsliding (Figure 12).[18] 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 as well as to reduce the potential for landslides, include leaving wider strips, pruning or topping trees in the strips, or feathering the edges of reserve strips.

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

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

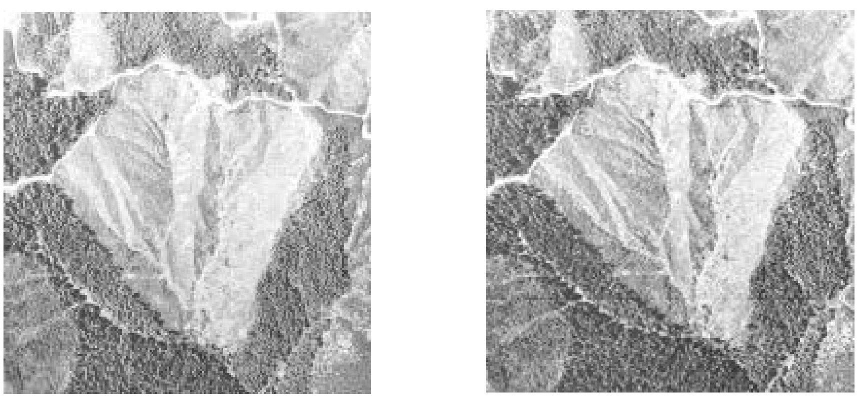

Figure 13. Stereo pair of a clearcut convergent headwall in Pistol Creek basin, North Fork Calawah River, Washington.

[18] Montgomery et al., 2000.

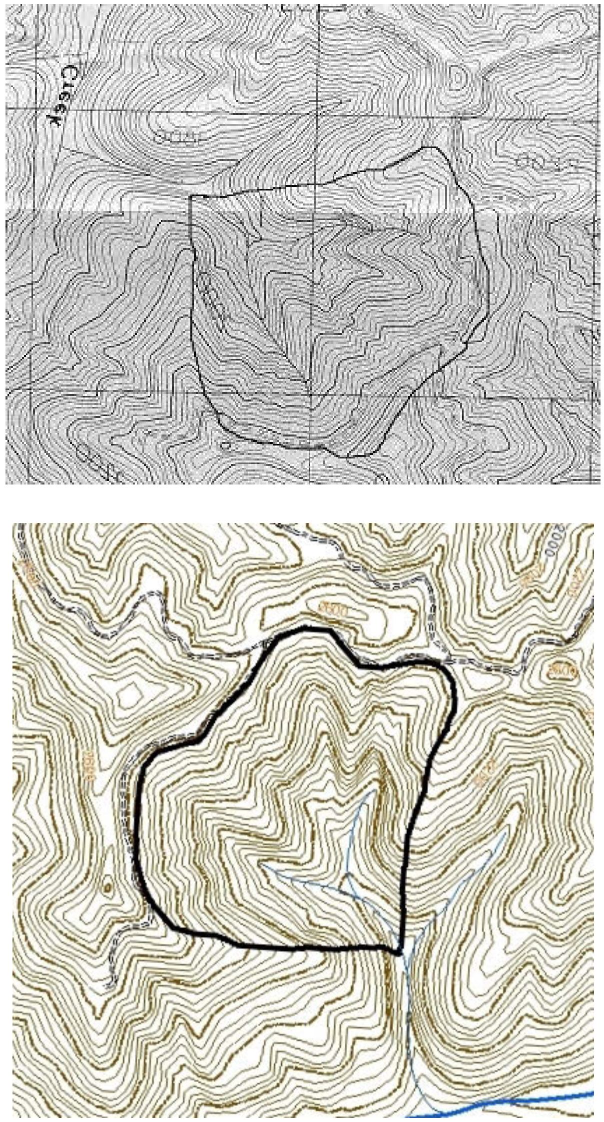

Figure 14. Rotated topographic map and outline of convergent headwall displayed in the stereo pair of Figure 12. Hunger Mountain and Snider Peak USGS 7.5' quadrangles.

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

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

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

Inner gorges are canyons created by a combination of stream down-cutting and mass movement on slope walls.[19] Inner gorges are characterized by steep, straight or concave sideslope walls that commonly have a distinctive break in slope (Figure 16). Debris flows, in part, shape inner gorges by scouring the stream, undercutting side slopes, and/or depositing material within or adjacent to the channel (Figure 17). Inner gorge side slopes may show evidence of recent landslides, such as obvious landslides, 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 exist of sufficient size to stop moving material exist along the gorge walls, but these are uncommon.

[19] Kelsey, 1988.

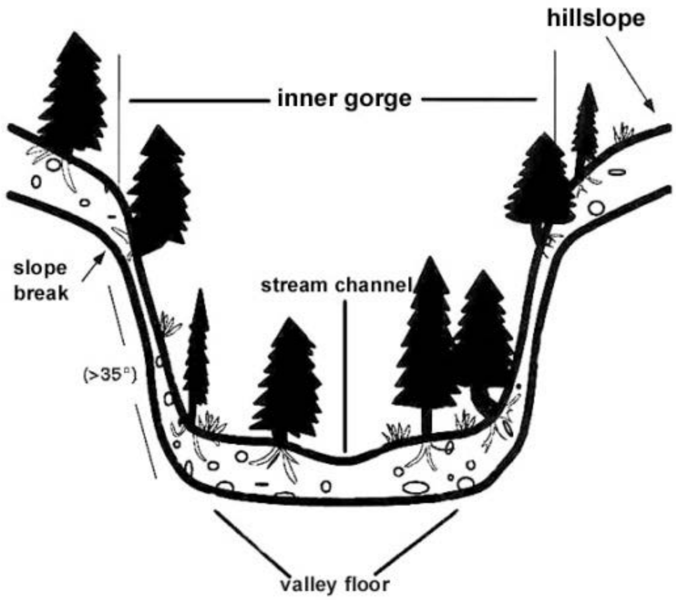

Figure 16. Cross-section of an inner gorge. This view emphasizes the abrupt steepening below the break-in-slope (Drawing: Benda et al., 1998).

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

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

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

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

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

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

4.2 Toes of Deep-Seated Landslides

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

Landslides with toe edges adjacent to streams have a high potential for delivery of sediment and wood to streams through natural processes. In such situations, streams can undercut the landslide toes and promote movement. Over-steepened toes of deep-seated landslides can also be sensitive to changes caused by harvest and road construction. The road shown in Figure 20 may have removed a portion of the toe, causing reactivation of the landslide. Resulting instability can take the form of shallow landslides, small-scale slumping, or reactivation of parts or the whole of a deep-seated landslide. Because deep-seated landslides are usually in weak materials (further weakened by previous movement), an angle of 33 degrees (65%) is the regulatory threshold used on the potentially unstable toe edges. Regardless of the surface expression of the toe, it is best to avoid disrupting the balance of the landslide mass by cutting into or removing material from the toe area.

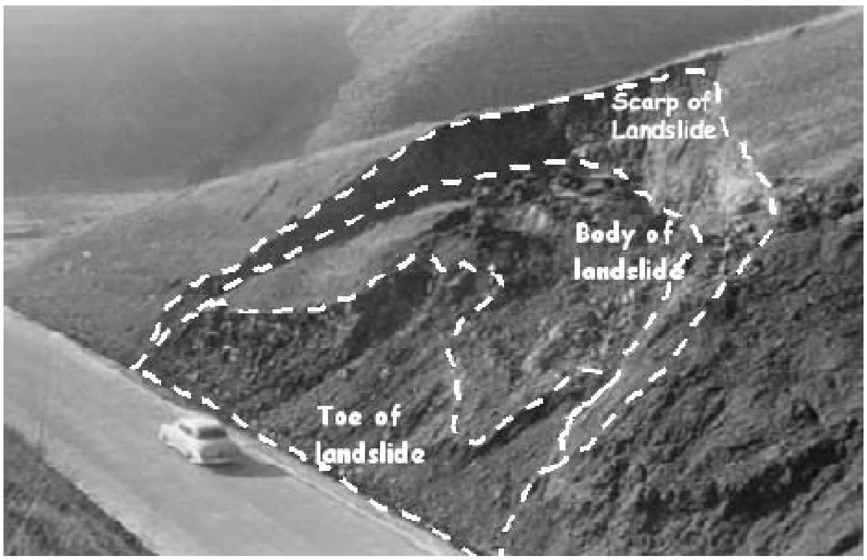

Figure 19. Deep-seated landslide showing the head scarp, side-scarps, body, and toe. Some of the toe has been removed in building and maintaining the highway (adapted from USGS photo).

4.3 Groundwater Recharge Areas for Glacial Deep-Seated Landslides

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

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

[20] Terzhagi, 1951.

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

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

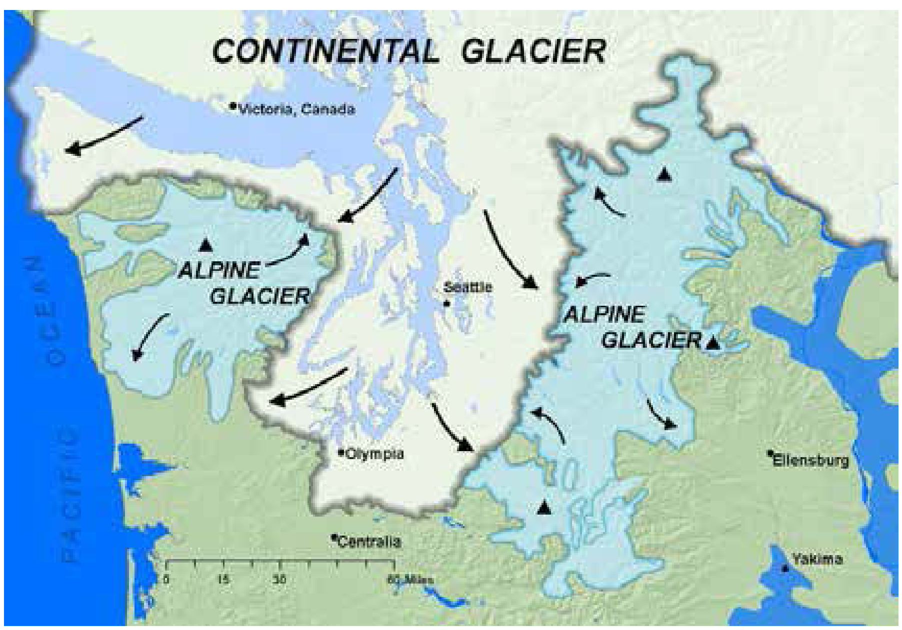

Figure 20b. Continental and alpine glaciation in western Washington (DNR, 2014).

Glacial deep-seated landslides can involve rotational and translational movement or flows, or a combination of movement types. They can occur in any type of glacial deposit including till, outwash, glaciolacustrine and glaciomarine silt and clay, or a mix of multiple glacial strata. During

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

interglacial periods, layers of loess (e.g., windblown silt and clay) and fluvial sediments may have been deposited on the surface of glacial deposits or become overlain by glacial deposits from successive glaciations.

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

Glacial deep-seated landslides can be affected by the hydrologic budget of an area (Figure 20). The hydrologic budget is the amount of groundwater present and is calculated based on precipitation (rain and snow), interception of precipitation by vegetation, evapotranspiration, surface storage, surface runoff, and groundwater recharge. Groundwater recharge is the component of a hydrologic budget that infiltrates into the subsurface below the vegetative rooting zone. The groundwater component is composed of water within the unsaturated and saturated zones.

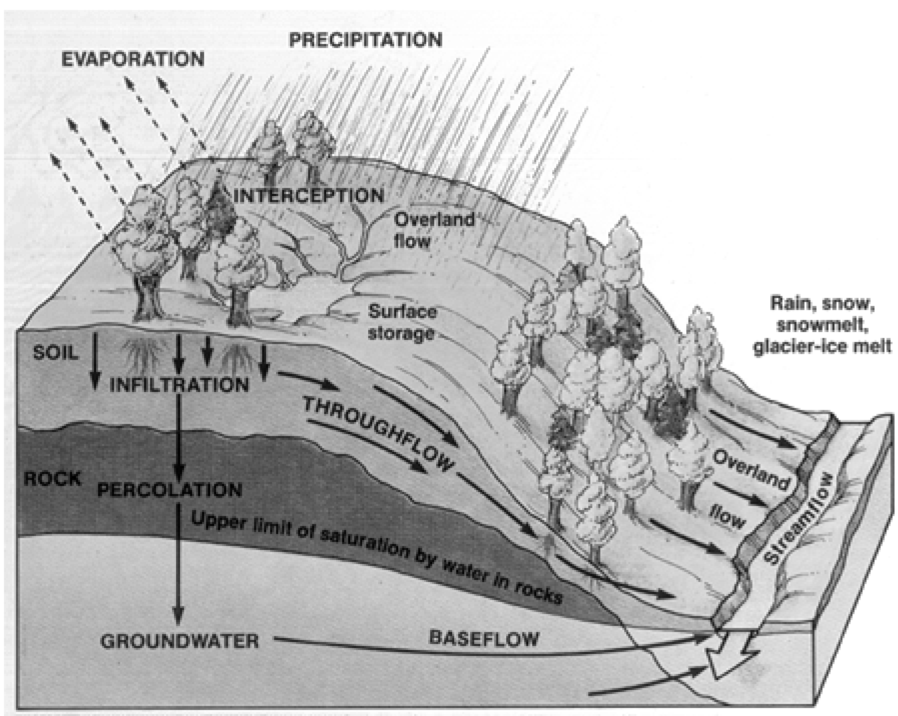

Figure 21. Hydrologic budget of a hillslope (University of Colorado).

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

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

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

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

[22] Bauer and Mastin, 1997; Vaccaro et al., 1998.
[23] Gerstel et al., 1997.
[24] Benda et al., 1988.

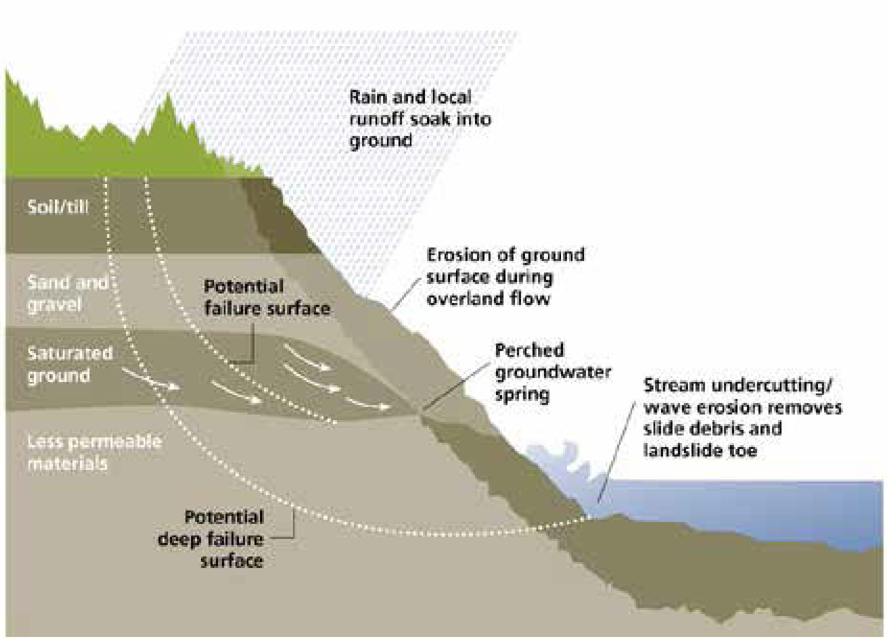

Figure 22. Diagram illustrating failure surface resulting from groundwater recharge to a glacial deep-seated landslide (DNR, 2014).

A classic example of a geologic setting where glacial deep-seated landslides are common is in the Puget Sound lowlands where the Esperance Sand or Vashon advance outwash overlies the Lawton Clay. In this setting, groundwater recharge from precipitation infiltrates downward within the hillslope until it encounters the relatively impermeable Lawton Clay. Because the water cannot infiltrate into the Lawton Clay at the same rate it is supplied from above, the water table rises vertically above the clay surface. The elevated water table increases the pressure within the Esperance Sand and forms a hydraulic gradient that causes water to flow horizontally along the sand-clay contact, resulting in springs where this contact is exposed at the surface.[25]

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

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

[25] Tubbs, 1974.

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 (see Figure 23).[26] The outer edges of meander bends are susceptible to deep-seated and shallow landsliding, including debris avalanching and small-scale slumping. They are less susceptible where mature trees exist on lower terraced slopes in riparian or channel migration zones. The roots and woody structure of riparian trees act to deflect erosive flows and lessen undercutting along the meander bend walls.

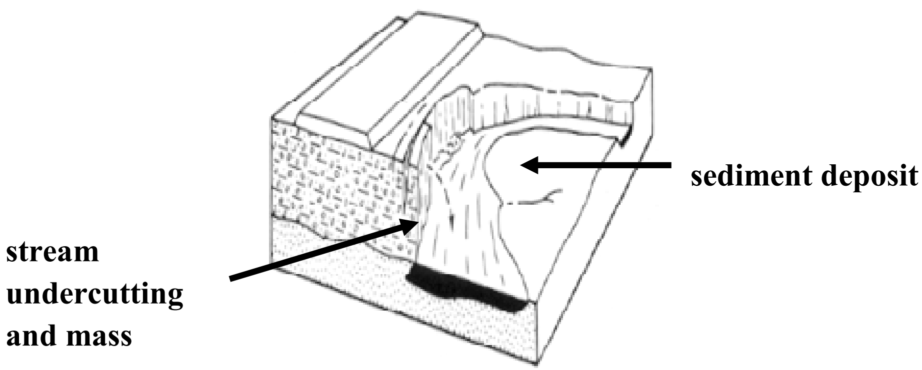

Figure 23. Outer edge of a meander bend showing mass wasting on the outside of the bend and deposition on the inside of the bend (adapted from Varnes, 1978).

4.5 Areas Containing Features Indicating the Presence of Potential Slope Instability

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

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

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

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

[26] Schuster and Wieczorek, 2002.

Topographic indicators

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

Hydrologic indicators

- Ponding of water in irregular depressions in undrained swampy or poorly drained areas on the hillslope above the valley floor. These conditions are often associated with hummocky topography which can be a signature of landslide activity.
- Seepage lines or spring and groundwater piping. These conditions often mark the contact between high permeability and low permeability soils.
- Sag ponds (ponded water in a tension crack or low depressions on a landslide body).
- Deflected or displaced streams (streams that have moved laterally to accommodate landslide deposits).
- Chaotic drainage patterns resulting from landslide activity.

Vegetative indicators

- Jack-strawed, back-rotated, or leaning trees and stumps. These are typically indicative of active or recently active landslides.
- Trees with curved-based lower stems and vertical upper boles may indicate slope movement stabilizing over time.
- Bowed, kinked, or pistol-butted trees. These are typically indicative of soil creep, but may indicate incipient land sliding, particularly if other indicators are present.
- Split trees and split old growth stumps. These may be associated with tension cracks.
- Hydrophytic (water-loving) vegetation (skunk cabbage, devil’s club, salmon berry, etc.) on slopes. These conditions may indicate the presence of groundwater seeps and associated hydrogeologic conditions.
- Other patterns of disturbed vegetation. Changes in stand composition (early seral stage or lack of mature trees within a hillslope) or small grouping 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 indicators 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 (Chatwin et al., 1994); Hillslope Stability and Land Use (Sidle et al., 1985); Landslides, Processes, Prediction and Land Use (Sidle and Ochiai, 2006); and Slope Stability Reference Guide for National Forests in the United States (USFS 1994).

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 for potentially unstable slopes and landforms. 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 review process typically includes the following components:

- office screening (Part 5.1); and
- field assessment and review (Part 5.2 and 5.3).

If desired by the landowner or required by rule, further geotechnical assessment may include:

- landslide/landform activity assessment (Part 6.1);
- glacial deep-seated landslide assessment (Part 6.2);
- quantitative field assessment methods for the qualified expert's subsurface investigations (Part 6.3);
- water budget and slope stability modeling assessments for glacial deep seated landslides (Part 6.4);
- slope stability sensitivity assessment (Part 6.5);
- delivery assessment (Part 6.6);
- synthesis and evaluation (Part 71); and
- geotechnical reports (Part 7.2).

While an appropriate investigation process cannot be defined by the rigid application of a set of procedural rules[27], Turner and Schuster (1996) suggest the following elements and sequence of the assessment:

1. Preliminary fact-finding to answer: What actions do the proposed forest practices activities include (e.g., partial cut, clear cut, road building, stream crossing)? In which landslide province (Appendix B) are the proposed forest practices activities located and what are the geologic conditions and types of landforms expected to be present? Are any site-specific resources available for review, such as previously completed geotechnical reports or watershed analysis reports?
2. Office review of geologic maps, topographic maps, aerial photographs, LiDAR data, and other information identified during the preliminary fact-finding phase.

[27] Turner and Schuster, 1996.

3. Field review to observe the site, confirm office review findings, and identify unstable and potentially unstable landforms not recognized during the office review. The field review may also involve a more detailed geologic investigation for collecting additional geologic data and hydrogeologic mapping.
4. Data analysis and assessment regarding the potential for landslide activity that could result from the proposed forest practices activity, and the potential for delivery of sediment to public resources or threats to public safety.

5.1 Office Review

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

A typical office review utilizes all pertinent site-specific and regional remote sensing data to help identify, delineate, and interpret potentially unstable slopes and landforms (e.g., aerial imagery, LiDAR, GIS-based model predictions of earth surface attributes derived from digital high-resolution topographic data). It may also include existing documents and databases (e.g., maps, geotechnical reports and studies, published and unpublished scientific literature, landslide inventories, local and regional databases containing meteorologic, hydrologic, and geologic information) to screen sites for potential slope stability concerns, identify public resource and public safety considerations, and make a determination regarding next steps in the site assessment. Please see appendices C through E for data sources, and 5.1.3 and 5.1.4 for information regarding remote sensing tools and topographic data.

5.1.1 General Practitioner's Office Review

The goals of the general practitioner's office review are to: identify and locate potential and existing areas of slope instability within or around proposed forest practices activities using descriptions provided in Part 4; locate areas of public resource sensitivity or public safety exposure in the area of the planned operations that could be adversely affected by mass wasting processes; and develop a strategy for assessing the landforms in the field.[28]

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).

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

- 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, the general practitioner may not be able to identify the full extent of a groundwater recharge area from topographic maps, or detect landslides under a mature forest canopy if using aerial photography exclusively. 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 screening process aids the general practitioner in targeting portions of the proposed harvest and construction area that may need further assessment in the field. A field assessment is typically conducted while performing reconnaissance and marking (flagging) the boundaries of the proposed harvest and construction area; see Part 5.2 for guidance on conducting field reviews. 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 in a manner that threatens 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 usually 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 site characteristics or physical features based on these data sources. The qualified expert determines the appropriate combination of assembled information based on the project objectives, requirements, and desired level of confidence in assessment products.

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

5.1.3 Remote Sensing Tools Available for Office Reviews

Common sources of remotely sensed information used in identifying, delineating, and interpreting landforms can be grouped broadly in two categories: (1) aircraft- or satellite-based earth imagery and photogrammetry; and (2) LiDAR and high-resolution topographic data. Previously prepared materials or documents often incorporate field and remotely sensed data; these sources include maps and surveys, technical reports, and other published/unpublished literature, and physical databases. Among the available remote sensing technologies, LiDAR has proven to be a valuable source of topographic data with distinct advantages over traditional analytical methods (e.g., aerial photo interpretation) for mapping landslides and interpreting landform characteristics (see Figure 24).[29] However, LiDAR is not a panacea; rather it complements traditional aerial photo interpretation and the analysis of both information sources are useful. For more information about LiDAR processing, applications, and data sources, see Appendix E.

5.1.4 LiDAR Use in Identifying Potentially Unstable Landforms

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

Hillshade, contour, and slope class maps derived from bare earth LiDAR DEMs are the most common LiDAR products used to identify landforms and landslides. A hillshade map is created by simulating sunlight shining on the topographic surface at a specified angle, while a slope map shows the magnitude of the topographic gradient, estimated by differencing the elevations of adjacent points in the DEM. Hillshade maps tend to have less contrast on slopes facing the incident sun angle and more contrast on slopes facing away from the incident sun angle, either of which can

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

obscure topographic features. Analyzing several hillshade maps generated with different sun angles or employing methods such as those described in Burns and Madin (2009) may minimize illumination and topographic shadowing effects (i.e., multi-directional oblique-weighted hillshade algorithm). Additional maps such as topographic curvature, surface roughness, and elevation contours can also be useful to identify deep-seated landslide features. Contours should be generated with spacing similar to the LiDAR data resolution and/or the scale of the geomorphic features of interest.

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

LiDAR hillshades can be used to delineate and interpret deep-seated and, with less certainty, shallow landslides, although some depositional surfaces (for example debris fans) can be identified. Various measures of surface roughness are commonly used to recognize and quantify deep-seated landslide morphology in landslide mapping studies.[30] Recent regional examples of deep-seated landslide mapping that used LiDAR-based protocols include Burns and Madin (2009), Schulz (2005, 2007), and Haugerud (2014).

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

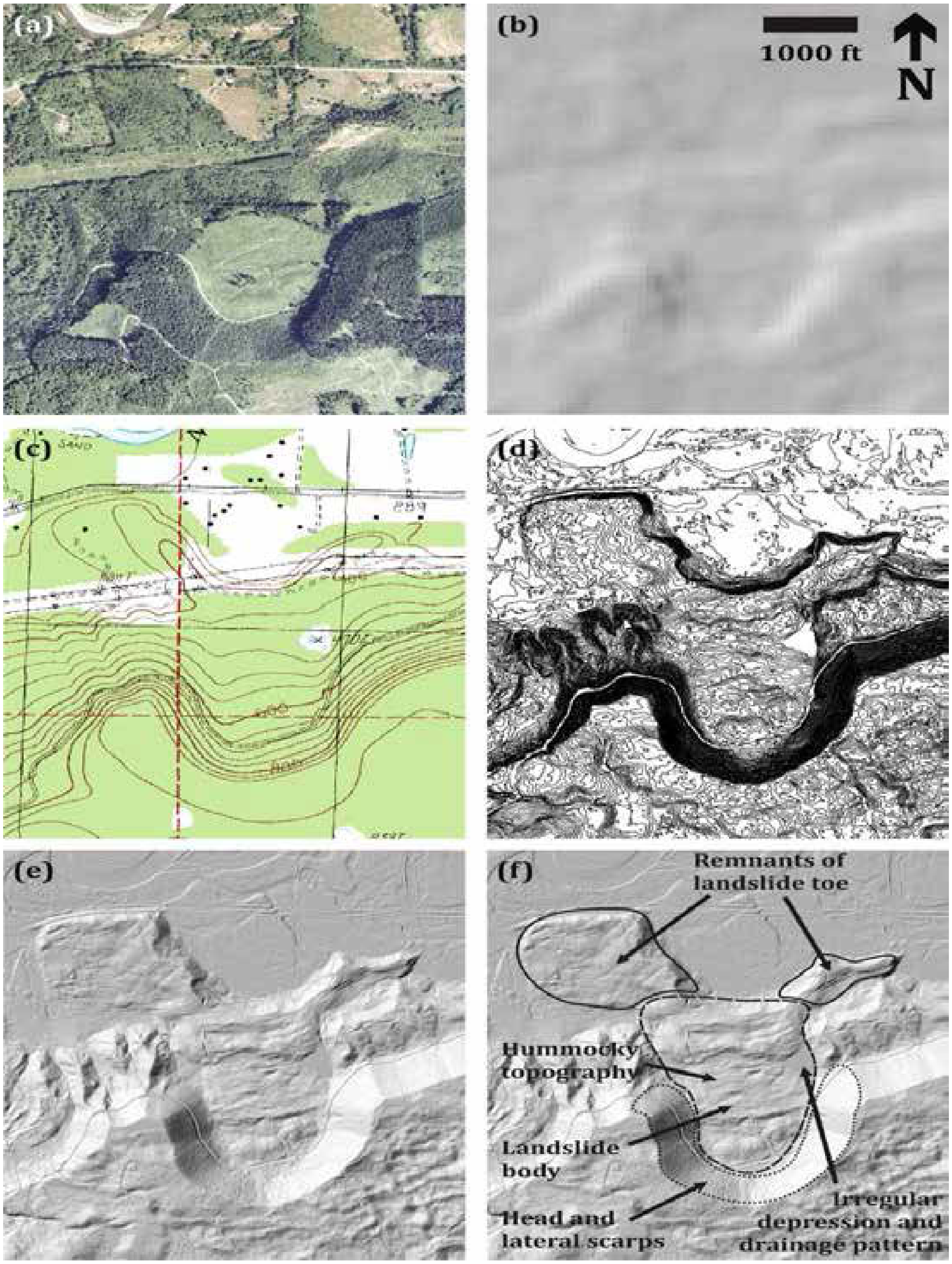

Figure 24. Example of a dormant glacial deep-seated landslide as seen in different types of remotely sensed data and in varying resolution quality:
(a) Digital Orthophoto Quadrangle, (b) hillshade map derived from 30-meter resolution ASTER Global Digital Elevation Model, (c) topographic map, (d) 6-foot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

5.2 Field Assessment

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

5.2.1 General Practitioner's Field Assessment

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

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

- The general practitioner does not identify any potentially unstable slopes or landforms within or around the planned area for the forest practices activities.
  - The landowner documents the finding in the slope stability sections of the FPA.
- The general practitioner identifies potentially unstable slopes or landforms in or around the planned operations area, and the landowner avoids timber harvest or construction on them.
  - The landowner documents the finding in the slope stability sections of the FPA, along with any additional required information DNR may have requested, and submits the FPA.
- The general practitioner identifies potentially unstable slopes or landforms in or around the planned operations area, and the landowner proposes timber harvest or construction activities on them.
  - The landowner retains a qualified expert to conduct geologic office and field reviews, and prepare a geotechnical reports (see Part 7.2) for information required in a geotechnical report.[31]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 Assessments

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

1. Refine any preliminary maps constructed during office reviews. This may include features not detected in the office review;

[31] 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.

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 Part 7.2 for information required 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 the landowner may ask the qualified expert to return to the field for an interdisciplinary team meeting if required by DNR. Depending on the analyst's level of confidence in potentially unstable landform identifications, delineations, and interpretations for any given site, the field assessment might range from qualitative to more quantitative in nature.

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

Preparation of a site-specific geomorphic map is helpful because most published geologic maps, although useful for understanding and locating bedrock and Quaternary sediment deposits, are insufficient to identify small-scale unstable 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.[32] To facilitate the review, geologic reports prepared for FPAs can include GPS locations of landforms and other relevant features with sufficient accuracy for others to identify the landforms in the field. It is also effective to include photographs of significant landforms, or their components if the spatial scales are compatible with ground-based photography. It is important to note indicators of potential slope instability or active movement during the field review. These include topographic, hydrologic, and vegetative indicators described in Part 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. Common results of a qualified expert's field assessment may include one of the following:

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

5.3 Delineating Groundwater Recharge Areas for Glacial Deep-Seated Landslides

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

Typically, once a landslide has been mapped, an initial designation of the topographic groundwater recharge area is a straightforward task that can be performed on a detailed topographic map of the area. The most accurate tool available for mapping surface topography is high resolution DEM

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

generated from LiDAR. Figure 25(a) shows the approximate groundwater recharge area for a landslide based on upslope topographical delineation. The cross section shown in Figure 25(b) illustrates the approximate stratigraphy through the groundwater recharge area and landslide body. The recharge, occurrence, and movement of groundwater through water-bearing units (aquifers), and confining units that inhibit groundwater movement, can have an effect on slope stability.

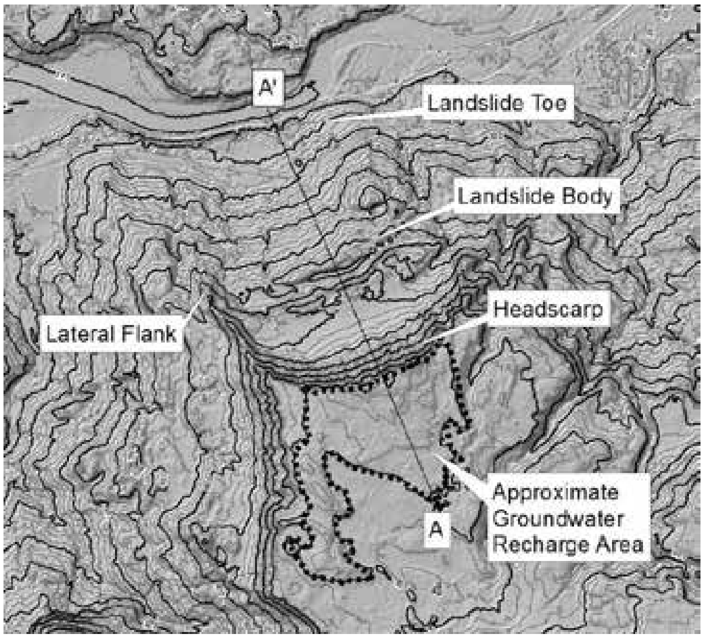

Figure 25a. Glacial deep-seated landslide. The dash-lined polygon is an approximate delineation of a groundwater recharge area based on LiDAR data (DNR, 2014).

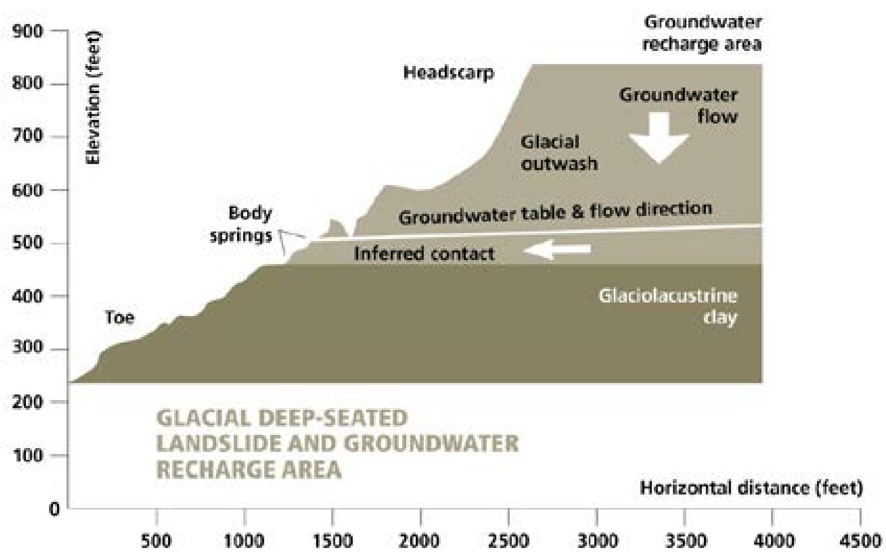

Figure 25b. Hillslope cross-section (A-A' in figure 25a) derived from 2-meter DEM of a glacial deep-seated landslide showing groundwater recharge area, geologic units, and generalized groundwater flow paths (DNR, 2014).

The recommended first step in delineating the groundwater recharge area is to evaluate its stratigraphic and/or topographic relationship to the landslide. When uncertainties remain as to the accuracy of the area boundary, further investigations and analysis are necessary. The results of these analyses provided by the qualified expert in a geotechnical report are used by DNR to determine the FPA classification and other decisions based on the applicant's proposed activity.

5.3.1 Office Review for Groundwater Recharge Areas

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

In a simplified hydrogeologic setting in a humid environment, the groundwater table forms a subdued replica of surface topography with groundwater flow from high altitude areas of recharge to low altitude areas of discharge.[33] 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 affect the amount of precipitation intercepted by foliage and leaf litter and the resultant through-flow that is available for recharge. In addition, land development and agricultural uses may influence groundwater recharge.

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

- Remotely-sensed land cover data available nationally at a spatial resolution of 30 meters from the U.S. Geological Survey's National Land Cover Database;
- Geologic maps for providing a basis for delineating the areal extent, orientation, and stratigraphic relationships of rocks and sediments that influence the occurrence and movement of groundwater. The U.S. Geological Survey, DNR, and others have published geologic maps at scales of at least 1:100,000 across Washington and locally at larger scales (1:24,000).
- Well logs and geotechnical borings may supplement geologic mapping by revealing the vertical extent of rocks and sediments and providing information about grain size distributions, sorting, and other physical properties that may influence the hydraulic characteristics of hydrogeologic units. The Washington State Department of Ecology maintains a searchable database of well logs for Washington State; however, subsurface data will generally be confined to developed areas rather than the forested environment.
- Hydrogeologic frameworks, which define the groundwater recharge environment and the subsurface environment in which groundwater occurs, have been developed from mapped geologic units, driller's logs, and hydrologic data at regional scales such as Puget Sound[34] and the Columbia Plateau[35]. However, it is also important to understand groundwater movement at

[33] Freeze and Cherry, 1979.
[34] Vacarro et al., 1998.
[35] Bauer and Hansen, 2000.

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

When conditions warrant, excavating test pits, driving soil probes, drilling monitoring wells, or using geophysical techniques such as seismic or electric resistivity methods should be considered in order to 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 the following guidance:

- Landslide Activity Assessment (6.1)
- Glacial Deep-Seated Landslide Assessment (6.2)
- Quantitative Field Assessment Methods for the Qualified Expert's Subsurface Investigations (6.3)
- Water Budget and Hydrologic Contribution to Glacial Deep-Seated Landslides (6.4)
- Computational Slope Stability Assessment Methods (6.5)
- Delivery Assessment (6.6)

6.1 Landslide Activity Assessment

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

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.[36] 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 if human intervention has protected against future movement.

Interpretation of vegetation cover, surface morphology, and toe modification by a stream, if present, all aid in determining the state of activity based on local knowledge of typical rates of biologic and geomorphic processes.[37] The characteristics described by Keaton and DeGraff (1996) have been successfully applied in the Pacific Northwest. A modified version is presented in Table 2. New vegetation generally begins to colonize a landslide's scarp, lateral flanks, or other areas of disturbed ground once the landslide becomes dormant and progresses to mature vegetation cover according to the local climate. The scarp, flanks, and internal hummocky morphology of the landslide also tend to become increasingly subdued with time after the landslide becomes dormant, and the internal drainage network of the landslides tends to become more connected and organized. If the toe of the landslide enters a stream, that stream progressively modifies the toe as recorded by terraces and the establishment of a floodplain comparable to reaches unaffected by landslide activity.

The *distribution of activity* refers to the geometry and spatial pattern of landslide movements and how these patterns may change with time. One key distinction is if the landslide is advancing by extending downslope in the main direction of movement, or headcutting by extending in the upslope direction. A landslide can also widen or narrow in the direction perpendicular to movement, and more generally can be enlarging or diminishing if its total volume is increasing or decreasing.

[36] Cruden and Varnes, 1996.

[37] Keaton and DeGraff, 1996, Table 2.

The *style of landslide activity* will be one of the movement types shown in Table 1, Landslide Classification. Many landslides involve different styles of landslide activity. Movements should be described as “complex” if they happen in succession, or as “composite” if they happen simultaneously at different parts of the landslide. Many landslides may reactivate repeatedly over time and 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.

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

(modified from Keaton and DeGraff, 1996)

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

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

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

6.2 Glacial Deep-Seated Landslide Assessment

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

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

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

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

The qualified expert's selection of exploration methods should be based on the study objectives, size of the landslide area, geologic and hydrogeologic conditions, surface conditions and site access, limitations of budget and time, and risk potential. Subsurface exploration to assess landslides is generally described by McGuffey et al. (1996) as summarized in the following paragraphs:

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

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

Drive Probe. A simple hand probe can be used to estimate soil density and the depth to dense soil. The Williamson Drive Probe (WDP)[38] was developed as an inexpensive and portable alternative for determining soil relative densities and groundwater table elevations. Sections of hardware pipe are coupled and driven into the ground manually with a sliding hammer. The number of blows, in even distance increments, required to drive the probe is used to describe soil conditions. Blow-count data has been empirically correlated with the Standard Penetration Test (American Society for Testing and Materials, 2014).[39]

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

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

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

A qualified expert should supervise the subsurface investigation so that the field activities are properly executed and the desired results can be achieved.

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

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

38 Williamson, 1994.

39 Adams et al., 2007.

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 activities increase the potential for contributing to movement of unstable landforms. The extent of the analysis depends on site-specific geological and hydrogeological conditions. Such assessments and modeling may be useful when there is potential for delivery of sediment or debris to public resources or threats to public safety. The following discussions of evapotranspiration and groundwater flow may aid the qualified expert.

6.4.1 Modeling Evapotranspiration

Modeling evapotranspiration is a data intensive exercise that requires regional and/or site-specific information regarding precipitation types and rates, wind speed, relative humidity, temperature, solar energy, and plant community stand characteristics.[40] The goal of evapotranspiration modeling is to derive estimates of the potential increase in water available to the groundwater recharge area from changes in energy balances, wind speeds, and plant community characteristics (i.e., aerodynamic roughness) after forest harvest.

Effects of evapotranspiration on the soil water budget can be partitioned as follows: (1) canopy interception of rainfall or snow and subsequent evaporation loss to the atmosphere; (2) transpiration of infiltrated water to meet the physiological demands of vegetation; and (3) evaporation from the soil or litter surface. Different vegetation covers have different balances of these fundamental water loss processes. The effects of evaporation on soil water budgets are relatively small compared with canopy evapotranspiration and interception.[41]

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.[42]

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.[43]

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

[40] Jassal et al., 2009.
[41] Bosch and Hewlett, 1982.
[42] Campbell, 1986.
[43] Hanks and Ashcroft, 1980.

has a high surface area to volume ratio that promotes efficient evaporation by convection. Intercepted rainfall is mostly stored on the surface of foliage and stems, while intercepted snowfall bridges between gaps in tree crowns, facilitating an accumulation of snow over large surface areas of the canopy. Interception and subsequent evaporation of water from vegetation cover is particularly significant in coniferous forests[44]; snow or rain losses from these dense canopies can account for up to 30 to 50 percent of gross annual precipitation[45]. Moore and Wondzell (2005) estimated that interception loss in Pacific Northwest conifer forests ranged from 10 to 30 percent. Dingman (2002) reported similar values for Pacific Northwest plant communities, ranging from 21 to 35 percent, based on canopy characteristics and climate conditions. Hanell (2011) reported hydrologic modeling[46] that predicts a 27 percent decrease in evapotranspiration resulting from forest conversion to shrub for a site on the western Olympic Peninsula, Washington.

The proportion of rainfall intercepted by forest canopies is inversely related to both antecedent wetness and rainfall intensity. Gentle, short-duration rainfall may be almost totally intercepted, while interception may account for as little as 5 percent of precipitation during intense winter storms.[47]

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

6.4.2 Groundwater Recharge and Groundwater Flow Modeling

Groundwater recharge is difficult to measure directly, but several empirical and numerical methods exist for estimating recharge within the surface-water, unsaturated zone, and saturated zone, including physical, tracer, and numerical-modeling techniques.[48] 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[49], Precipitation Runoff Modeling System[50], and the Variable Infiltration Capacity Model[51]. 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.[52] Groundwater-flow models are based on a hydrogeologic framework that

[44] Link et al., 2004.
[45] Dingman, 1994.
[46] DHSVM; Wigmosta, Njssena and Stork, 2002.
[47] Ramirez and Senarath, 2000.
[48] Scanlon et al., 2002.
[49] Bauer and Vaccaro, 1987.
[50] Leavesley et al., 1983.
[51] Liang et al., 1994.
[52] Harbaugh et al., 2000.

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 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, as well as to evaluate potential impacts of forest practices activities to public resources and public safety. This quantitative assessment may entail one or more methods. Limit equilibrium and numerical stability analyses may be used to evaluate the potential effects of increased groundwater recharge on glacial deep-seated landslides, but other methods may be necessary under certain conditions.

Limit-equilibrium analysis calculates a factor of safety for sliding along a critical failure surface, which is expressed as a ratio of the shear strength of the earthen material resisting slope failure to the shear stresses driving instability. Relative stability is defined by a factor of safety exceeding a value of one. A two-dimensional limit-equilibrium analysis method may be applied to deep-seated landslides but can also be useful for smaller local site situations. Computation of the most critical failure surface is an iterative process generally supported by commercially available or public-domain software.[53] Field-developed cross sections, back calculation of soil strength parameters, and estimation of groundwater elevations can be done where field accessibility is limited using the methods of Williamson (1994).

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

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

The potential effects of the proposed forest practices activities on slope stability can then be evaluated by modifying the initial model with the expected condition based on the proposed activities, such as placement of fill for road construction or elevating groundwater levels (pressures) due to forest canopy removal. Limit-equilibrium models also allow the analyst to reconstruct pre-failure slope conditions of existing landslides by varying the input parameters (e.g., surface topography, engineering geologic unity 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 also can 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

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

suspected. Turner and Schuster (1996), as well as 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 Delivery Assessment

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

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

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

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

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

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

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

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

PART 7 SYNTHESIS OF RESULTS, EVALUATION AND GEOTECHNICAL REPORTS

This step is generally reserved for qualified experts when preparing geologic evaluations. The following questions and guidance are provided to assist the qualified expert when synthesizing the information assembled in the office review and field assessment, and can be useful when preparing a geologic evaluation or report.

7.1 Synthesis and Evaluation

Consideration of the following questions may help to synthesize findings:

- Based on an analysis of available information, what is the geotechnical interpretation of physical processes governing unstable slope/landform movement, mechanics, and chronologies of each identified feature?
- What are the project limitations (e.g., quantity or quality of technical information, site access, project timeframe) that might influence the accuracy and precision of identifying, delineating, and interpreting unstable slopes and landforms?
- What are the scientific limitations (e.g., collective understanding in the scientific community of landform physical processes) that might influence the identification, delineation, and interpretation of unstable slopes and landforms?
- What is the potential for material delivery from each relevant unstable slope and landform to areas of public resource sensitivity or where public safety could be threatened?
- What are the relative roles of natural processes and land management activities in triggering or accelerating instability?
- What level of confidence is placed in the identification, delineation, and interpretation of unstable slopes and landforms? How does the confidence level impact any recommendations for unstable slope management and/or mitigation?

Models such as those for slope stability and sensitivity (see Part 6.5) may be used to support analyses of potentially unstable slope and landform characteristics and mechanics. If models 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.

The analytical methods and processes used to identify, delineate, and interpret unstable slopes and landforms can be described, along with information sources, data processing techniques, and the limitations of analysis results. Reports should describe all assumptions regarding input parameters or variables, such as groundwater surface elevation estimates employed in stability sensitivity analyses, as well as the reasoning for their use. Reports may also include an assessment of the sensitivity of the analytical method or model results to parameter variability. This is especially true where only a range of parameter values is available, or where input values are extrapolated or estimated from other locations or databases.

Confidence levels in the slope stability analysis and model results are influenced by many factors, including project complexity and objectives, site characteristics (e.g., acreage and accessibility), project timeframes, quantity and quality of available information (e.g., reports, databases) and remotely sensed data, accuracy and precision of field observations and collected data, and the rigor of available analytical methods and models. A discussion of the primary limiting factors will assist the landowner and report reviewer when evaluating the potential public resource, public safety, and liability risks associated with implementing a project.

Documentation of the project analysis may include: annotated images (e.g., LiDAR-derived hillshades, aerial photos); geologic or topographic profiles; maps; sketches; results of subsurface investigations; summaries of computational or simulation modeling; summaries of available (i.e., previously published) information; and remotely sensed or field-derived data and text to explain the concrete evidence and logical train of thought for the conclusions and recommendations that will be presented in the geotechnical report.

7.2. Geotechnical Reports

The qualified expert is encouraged to consult with DNR Region geologists when preparing geotechnical report to ensure all important elements are covered. Region contact information can be found on DNR's web site at www.dnr.wa.gov.

When harvesting timber or building roads on potentially unstable slopes, a written report is required to be part of the FPA to explain whether the proposed forest practices are likely to affect slope stability, deliver sediment and debris to public resources, or threaten public safety. For the purposes of this Board Manual section, such a report is called a "geotechnical report." The geotechnical report must be prepared by a qualified expert and the report 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 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, relevant weather conditions.

(b) *Describe the geographic, geologic, and soil conditions of the area in and around the application site*. Include a legal description of the proposal area, the county in which it is located, and where appropriate the distance and direction from the nearest municipality, local landmarks, and named water bodies. Provide elevations and aspect. Describe the underlying parent materials, including their origin (i.e., glacial versus bedrock); the name(s) of any rock formations and their associated characteristics; and geologic structure relevant to slope stability. Describe soils and rocks on site based on existing mapping, field observations, and any available local information. Describe soil and rock texture, depth, and drainage characteristics typically using standard soil and rock classification systems.[54]

(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. Descriptive, photo, or data-sampling observation points should be geo-referenced (i.e., with GPS waypoints)and mapped GPS track locations of field traverses can be used to clarify which portions of the project site were evaluated. In addition, field-derived cross sections and geologic profile locations should be geo-referenced. Assign a unique alphabetic or numeric identifier label to each landform or observation point relevant to the assessment and note these on a detailed site map of a scale sufficient to illustrate site landforms and features. Where the proposal involves operations within the groundwater recharge area of a glacial deep-seated landslide, specifically discuss the probable direct and indirect impacts to groundwater levels and those impacts to the stability of the glacial deep-seated landslide.

(d) *Analyze the possibility that the proposed forest practice will cause or contribute to movement on the potentially unstable slopes*. Explain the proposed forest management activities on and adjacent to the potentially unstable slopes and landforms. Clearly illustrate the locations of these activities on the site map, and describe the nature of the activities in the text. Discuss in detail the likelihood that the proposed activities will result in slope movement (separate activities may warrant separate evaluations of movement potential). The scope of analysis should be commensurate with the level of resource and/or public risk. Include a discussion of both direct and indirect effects expected over the short- and long-term. For proposals involving operations on or in the groundwater recharge area of a glacial deep-seated landslide, conduct an assessment

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

of the effects of past forest practices on landslide/slope movement. Explicitly state the basis for conclusions regarding slope movement. Conclusions may be based on professional experience, field observations, unpublished local reports, watershed analyses, published research findings, and/or slope stability model output. Input parameters, model assumptions, and methods should be fully substantiated within the report.

(e) *Assess the likelihood of delivery of sediment and/or debris to any public resources, or to a location and in a manner that would threaten public safety, should slope movement occur*. Include an evaluation of the potential for sediment and/or debris delivery to public resources or areas where public safety could be threatened. Discuss the likely magnitude of an event, if one were to occur. Separate landforms may warrant separate evaluations of delivery and magnitude. Explicitly state the basis for conclusions regarding delivery. Conclusions may be based on professional experience, field observations, unpublished local reports, watershed analyses, published research findings, and/or landslide runout model results, which should have site-specific data. Input parameters, model assumptions, and methods using best available data should be fully substantiated within the report.

(f) *Suggest possible mitigation measures to address the identified hazards and risks*. Describe any modifications necessary to mitigate the possibility of slope movement and delivery due to the proposed activities. If no such modifications are necessary, describe the factors inherent to the site or proposed operation that might reduce or eliminate the potential for slope movement or delivery. For example, an intact riparian buffer down slope from a potentially unstable landform may serve to intercept or filter landslide sediment and debris before reaching the stream. Discuss the risks associated with the proposed activities relative to other alternatives, if applicable. Some geotechnical reports might include recommendations regarding additional work needed to supplement the report, including but not limited to monitoring by the landowner or their designated qualified expert of geologic conditions (e.g., groundwater, slope movement) and review of plans and specifications.

Conclusions should include documentation of the outcomes of the slope stability investigation based on the synthesis of all geologic and hydrologic information and interpretations used in the office review and field assessment, qualitative information and data analyses, geo- and hydro-technical modeling, and evaluation of material deliverability. Conclusions might also include a description of the suitability of the proposed activity for the site, and likely direct and indirect effects of the activity on the geologic environment and processes. Conclusions should be substantiated by the evidence presented and the expert's logical thought processes during analysis and synthesis.

GLOSSARY

Aquifer Saturated permeable geologic unit that can transmit significant quantities of water under ordinary hydraulic gradients.

Aquitard A less permeable bed in a stratigraphic sequence.

Confined aquifer An aquifer that is confined between two aquitards. Confined aquifers occur at depth.

Debris avalanche The very rapid and usually sudden sliding and flowage of incoherent, unsorted mixtures of soil and weathered bedrock.

Discontinuity Sudden or rapid change with depth in one or more of the physical properties of the materials constituting the earth.

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 Non-sorted, non-stratified sediment carried or deposited by a glacier.

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.

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.
Seismic method	A geophysical method using the generation, reflection, refraction, detection and analysis of seismic waves in the earth to characterize the subsurface.
Soil	An aggregate of solid particles, generally of minerals and rocks, either transported or formed by the weathering of rock in place.
Strata	Plural of stratum.
Stratum	A section of a formation that consists throughout of approximately the same material. A stratum may consist of an indefinite number of beds, and a bed may consist of numberless layer. The distinction of bed and layer is not always obvious.
Stratification	A structure produced by the deposition of sediments in beds or layers (strata), laminae, lenses, wedges, and other essentially tabular units.
Unconfined aquifer	Aquifer in which the water table forms the upper boundary. Unconfined aquifers occur near the ground surface.
Water table	The surface on which the fluid pressure in the pores of a porous medium is exactly atmospheric. The location of this surface is revealed by the level at which water stands in a shallow well open along its length and penetrating the surficial deposits just deeply enough to encounter standing water at the bottom.

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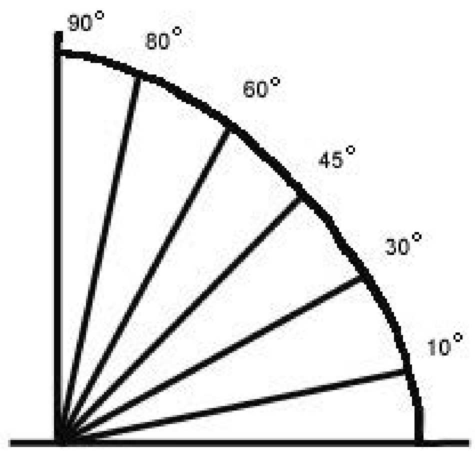
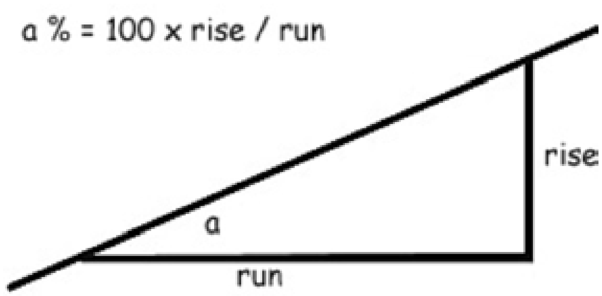
APPENDIX A – MEASUREMENT OF SLOPE GRADIENTS

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.

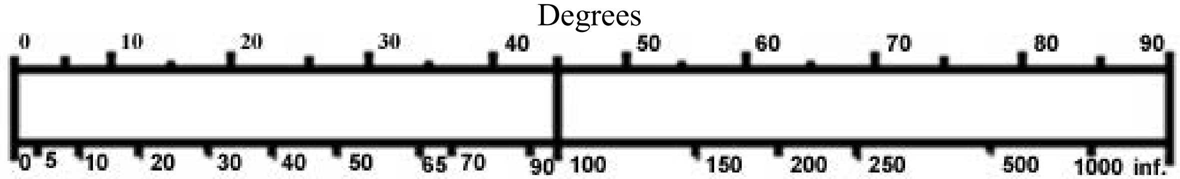
Percent
In the figure directly above, the horizontal distance between two points (distance between the points on a map) is called the run. The vertical distance (difference in elevation) is called the rise. The gradient can be expressed as the ratio of rise divided by run, a fraction that is the tangent 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.

Degrees



Percent

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.[55] 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.[56] Thick, deeply weathered loess deposits are sources for shallow landslides, debris flows, and avalanches.[57] These deposits are prevalent along the lower Columbia

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55 Tabor and Cady, 1978; Badger, 1993.
56 Gerstel and Badger, 2002.
57 Thorsen, 1989.

River valley, as well as other areas where colluvial deposits have accumulated on slopes and in drainages underlain by strong and relatively unweathered rock.

Cascade Range

The Cascade Range is generally divided on the basis of rock types into northern and southern provinces occurring geographically in the vicinity of Snoqualmie Pass. Strong crystalline rocks intensely scoured by alpine glaciations occur to the north. Weaker volcanic flows, typically pyroclastic and volcaniclastic rocks occur to the south, much of which was beyond the reach of the last continental glaciation. Rockfalls and complex rock slides are dominant in the steep bedrock slopes in the North Cascades. In the South Cascades and Columbia Gorge, weak interbeds control large translational failures in the Chumstick and Roslyn Formations[58], the Columbia River Basalts and other volcanic flow rocks, and Cowlitz Formation and Sandy River Mudstone[59]. Shallow landslides generating debris avalanches and flows are common on steep slopes and drainages.

Okanogan Highlands

Pleistocene glacial sediments that mantle the mostly crystalline core of the Okanogan Highlands are prone to both shallow and deep-seated landslides. The debris flows in this region can be a hazard during intense thunderstorms, usually moving through the area during late spring to late summer. Deep-seated landslides are most common in the areas surrounding Lake Roosevelt and landslide movement usually occurs in areas where relict to dormant deep-seated landslides exist. Rockfalls and rock slides are common from the many steep bedrock exposures in the region.

Columbia Basin

This province is largely composed of thick sequences of lava flows known as the Columbia River Basalts. Catastrophic flood events scoured the soils and a portion of the bedrock in much of this region before re-depositing it in watersheds along the edges of the main floodway. Landslides include slope failures in bedrock along the soil interbeds and in the overlying flood sediments and loess deposits. Bedrock slope failures are most common in the form of very large deep-seated translational landslides, deep-seated slumps or earth flows. The Blue Mountains in southeastern Washington also have experienced recurring and widespread shallow landsliding and debris flows related to storm events.[60]

[58] Tabor et al., 1987.
[59] Wegmann, 2003.
[60] Harp et al., 1997.

APPENDIX C – MAPS AND SURVEYS

Map and survey data resources available to the qualified expert include:

Multi-disciplinary map and survey data resources:

- Washington State Geologic Information Portal – create, save, and print custom digital maps of Washington State or download map data for GIS applications; includes a variety of base layer selections with interactive Geologic Map, Seismic Scenarios Catalog, Natural Hazards, Geothermal Resources, Subsurface Geology Information, and Earth Resource Permit Locations; available on Washington Dept. of Natural Resources website.
- Forest Practices Application Review System (FPARS) – online mapping tool with a variety of digital map base layer selections including topography, surface water (streams, water bodies, wetlands), soils, transportation network, forest site class, and potential slope instability (designed for shallow landslide susceptibility mapping only). Available on the DNR website.
- County interactive GIS map viewers – create, save, and print custom digital maps with some combination of the following data: topography (LiDAR and/or U.S. Geological Survey (USGS) DEM), surface water, soils, wetlands, sensitive areas, 100-year floodplain designations, transportation systems, property ownership and structure location. Available online at select county websites (e.g., King County iMAP).
- Washington State Coastal Atlas Map – interactive map utility for shoreline areas with multiple data layers including shoreline geomorphology (coastal slope stability and landforms), biology (plant communities), land and canopy cover, beaches and shoreline modifications, wetlands and estuaries, historic shoreline planforms, assessed waters, and Shoreline Management Act (SMA) designations; see Department of Ecology website.
- DNR surface mining permits.

Topographic maps:

- USGS topographic 7.5 minute quadrangle maps. Available from a number of government and non-government online vendors and free downloadable websites.
- LiDAR-based topographic maps (LiDAR-derived DEM (LDEM), typically 1- to 3- meter resolution); see Appendix C for LiDAR map and data sources.

Geologic maps:

- Geologic maps of various scales, in print and compiled by DNR, Division of Geology and Earth Resources as Map Series, Open File Reports, Bulletins, and Information Circulars; see most recent “Publications of the Washington Division of Geology and Earth Resources”; this publication and a status map of 7.5 minute quadrangle geologic mapping efforts (USGS STATEMAP program) are available on the Division of Geology and Earth Resources website with links to online publications where available.
- Geologic maps, various scales, out-of-print or historic; all sources including dissertations and theses. See catalog of the Washington Geology Library, available through the DNR website with links to online publications where available.
- Geology digital data; small-scale geology coverage in ArcGIS shapefile format, available on the Division of Geology and Earth Resources website.
- Geologic maps, various scales, available via The National Geologic Map Database (NGMDB); compiled by USGS and Association of American State Geologists; see NGMDB website catalog) and USGS Online Store (paper and digital copies).

Geologic hazards and landslide inventory maps:

- Washington State Geologic Information Portal, referenced previously.
- Landslide Hazard Zonation (LHZ) Project – mapped existing and potential deep-seated landslides and landforms in select watersheds; hazard classifications provided with supporting documentation for completed projects. Available on the DNR website.
- Landslide inventory and Mass Wasting Map Unit (MWMU) maps contained in Watershed Analysis reports prepared under chapter 222-22 WAC – mapped landslides (including deep-seated and earthflows) for select Watershed Administrative Units (WAU); Adobe pdf versions of DNR-approved Watershed Analysis Reports are available through the DNR website.
- Modeled slope stability morphology (SLPSTAB, SHALSTAB, SINMAP) output maps.
- U.S. Forest Service watershed analyses – available from US Forest Service offices for select watersheds; some documents and maps are available online.
- Washington State tribal watershed analyses – available from tribal agency offices; some documents and maps are available online;
- Washington State Coastal Atlas Map – slope stability maps developed prior to 1980, based on aerial photography, geologic mapping, USGS topographic quadrangle map, and field observations. Maps have not been updated with landslide data since 1980 but are used currently in land-use planning and in the Department of Ecology interactive Coastal Map tool; read data limitations on Department of Ecology's website.
- Qualified expert reports on deep-seated landslides in glaciated and non-glaciated terrain, for select timber harvest units or other forest management projects regulated by the Washington Forest Practices Act. Often contain mapped landslides.
- TerrainWorks (NetMap) – provides digital landscape and analysis tools for slopes stability data/analysis and risk assessments.

Soil surveys:

- Natural Resources Conservation Service (NRCS) soil survey maps and data – online soil survey, map and database service; historical soil survey publications (CD or paper copies); NRCS website administered through the U.S. Department of Agriculture.
- Geochemical and mineralogical soil survey map and data – USGS Mineral Resources Program, open-file report available online (Smith et al., 2013) in Adobe pdf.
- National Cooperative Soil Survey Program (NCSS), Washington State – online soil survey data and link for ordering in-print surveys not available electronically. See NRCS website.

APPENDIX D – EARTH IMAGERY AND PHOTOGRAMMETRY

The most common sources of imagery for landslide and landform identification, mapping, and photogrammetric analysis include:

- Aerial photography – historic and recent aerial photos produced in color or black and white and taken at various altitudes (typical scales in the 1:12,000 to 1:60,000 range). Aerial photos acquired by the U.S. Soil Conservation Service are available in some areas as early as the 1930s. Multiple flight years are required for chronologically reconstructing deep-seated landslide activity and developing time-constrained landslide inventories. Forest landowners typically purchased photos from regional vendors on a 2 to 10 year cycle until recently when other freely acquired imagery became available (e.g., Google Earth, ESRI World Imagery). Stereo-pair photos are highly valued for landslide detection and reconstruction because they allow stereoscopic projection in three dimensions and can display high-quality feature contrast and sharpness;
- Google Earth – map and geographic information program with earth surface images created by superimposing satellite imagery (DEM data collected by NASA's Shuttle Radar Topography Mission), aerial photos, and GIS 3D globe. Ortho-rectified, generally 1-meter resolution, three dimensional (3D) images are available for multiple years (Historical Imagery tool), allowing chronologic deep-seated landslide mapping. Google Earth supports desktop and mobile applications, including managing 3D geospatial data. See Google website for download information.
- Bing Maps Aerial View – part of Microsoft web mapping service; overlays topographic base maps with satellite imagery taken every few years. See Microsoft site for download information.
- ESRI World Imagery – ArcGIS online image service utilizing LandSat imagery based on the USGS Global Land Survey datasets and other satellite imagery, with onboard visualization, processing, and analysis tools that allow imagery integration directly into all ArcGIS projects. Requires ArcGIS capability; see ESRI website.
- NAIP (National Agriculture Imagery Program) aerial imagery – ortho-rectified, generally 1-meter resolution earth surface images taken annually during peak growing season ("leaf-on"), acquired by digital sensors as a four color-band product that can be viewed as a natural color or color infrared image. The latter are particularly useful for vegetation analysis. Data available to the public via the USDA Geospatial Data Gateway and free APFO viewing software, as well as through ESRI for ArcGIS applications; See USDA Farm Service Agency website;
- Washington State Coastal Atlas Map and Photos – oblique shoreline photos spanning 1976-2007; part of an interactive map tool; see Department of Ecology's website.
- United States Geological Survey EarthExplorer (http://earthexplorer.usgs.gov/) archive of downloadable aerial photos.

APPENDIX E – LiDAR: PROCESSING, APPLICATIONS, AND DATA SOURCES

The process to create high-resolution data begins with airborne LiDAR. LiDAR is a remote sensing technique that involves scanning the earth's surface with an aircraft-mounted laser in order to generate a three-dimensional topographic model.[61] 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.[62] 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.[63]

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.[64] 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.[65] 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.[66] 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

[61] Carter et al., 2001.
[62] For a review of filtering techniques, see Liu, 2008.
[63] Van Den Eeckhaut et al., 2007.
[103] Corsini et al., 2007; Delong et al., 2012; Daehne and Corsini, 2013.
[104] Burns et al., 2010.

[66] Tarolli, 2014.

displacement and sediment transport[67]; (2) ortho-rectified historical aerial photographs to map earthflow movement and calculate sediment flux[68]; (3) GIS-based algorithms for LiDAR derivatives (e.g., hillslope gradient, curvature, surface roughness) to delineate and inventory deep-seated landslides and earthflows[69];and (4) subsurface investigations[70].

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.

[67] Roering et al., 2009; Handwerger et al., 2013; Scheingross et al., 2013.
[68] Mackey and Roering, 2011.
[69] e.g., Ardizzone et al., 2007; Booth et al., 2009; Burns and Madin, 2009; Tarolli et al., 2012; Van Den Eeckhaut et al., 2012.
[70] 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 http://www.dnr.wa.gov/ResearchScience/Topics/WatershedAnalysis/Pages/fp_watershed_analysis.aspx (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.

Cultural Resource Roundtable TIMBER/FISH & WILDLIFE

July 22, 2015

MEMORANDUM

To: Forest Practices Board

From: Timber/Fish/Wildlife Cultural Resources Roundtable Co-Chairs

Jeffrey Thomas, Puyallup Tribe of Indians
Karen Terwilleger, Washington Forest Protection Association

RE: FY 2015 Annual Report of Timber/Fish/Wildlife Cultural Resources Roundtable

The Timber/Fish/Wildlife Cultural Resources Roundtable (Roundtable) is pleased to submit the FY2015 annual report to the Forest Practices Board.

We look forward to your August 11, 2015 meeting and answering any questions you may have. In the meantime, please do not hesitate to contact us:

jeffrey.thomas@puyalluptribe.com and (253) 405-7478/cell
KTerwilleger@wfpa.org and (360) 352-1500

FY2014 Annual Report to the Forest Practices Board

from the

Timber/Fish/Wildlife Cultural Resources Roundtable

July 22, 2015

<u>T/F/W Cultural Resources Roundtable Members:</u>
<u>Co-Chairs:</u>

- *Jeffrey P. Thomas, Puyallup Tribe of Indians*
- *Karen Terwilleger, Washington Forest Protection Association.*

<u>Active Members:</u>

- *Sherri Felix, Department of Natural Resources (DNR) Forest Practices Division*
- *Marc Engel, DNR Forest Practices Division*
- *Sara Palmer, DNR State Lands Archaeologist*
- *Gretchen Kaehler, Department of Archaeology and Historic Preservation (DAHP)*
- *Morgan McLemore, DAHP*
- *Katherine Kelley, Department of Fish & Wildlife*
- *David Powell, Yakama Nation*
- *Dave Burlingame, Cowlitz Tribe*
- *Gideon Cauffman, Jamestown S'Klallam Tribe*
- *Chad McCrea, Spokane Tribe of Indians*
- *John Sirois, Upper Columbia United Tribes (UCUT)*
- *Marc Gauthier, UCUT*
- *Susannah Spock, Hoh Tribe*
- *Justine James, Quinault Indian Nation*
- *Jim Peters, Squaxin Island Tribe*
- *Robert Bass, Hancock Forest Management*
- *Eric Beach, Green Diamond Resource Company*
- *Steve Barnowe-Meyer, Washington Farm Forestry Association*

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The Timber/Fish/Wildlife (T/F/W) Cultural Resources Roundtable is pleased to submit the FY2015 Annual Report to the Forest Practices Board, pursuant to WAC-222-08-160. Schedules for action items listed below are included in the attached spreadsheet.

<u>FY2015 Work Activities</u>

***<u>Review of WAC 222-20-120 Interpretations and DNR Forest Practices Application (FPA) Conditioning Authority</u>*:** The key topic worked on by the T/F/W Cultural Resources Roundtable (Roundtable) during FY2015 was WAC 222-20-120 interpretations and DNR FPA conditioning authority. At the March 2014 Roundtable meeting, the Yakama Nation had voiced concerns about recent DNR responses to their requests to condition FPAs to follow the Yakama-landowner agreed to protection plans, stating DNR no longer conditions FPAs to follow all aspects of the agreed upon plans and therefore has significantly reinterpreted WAC 222-20-120(4) without communicating this change to the Roundtable. DNR's FPA conditioning practices raised questions about the scope of DNR's legal authority to condition FPAs and communication between DNR and the Roundtable. During FY2015, this situation significantly affected working relationships within the Roundtable and consumed most of the Roundtable's time. In early 2015, the Roundtable resumed monthly meetings to deal with this issue. The major activities/events are summarized below:

- Correspondence between the Confederated Tribes and Bands of the Yakama Nation, the Department of Natural Resources (letter attached).

- Exchange of letters between the Confederated Tribes of the Umatilla Indian Reservation and the Commissioner of Public Lands (Chair of the Forest Practices Board) (letters attached).

- Presentation of flow charts by DNR and DAHP staff, at the April 2014 Roundtable meeting, describing the regulatory processes related to forest practices applications and cultural resources in each agency (flowcharts attached).

- Request by the co-chairs at the May 2015 meeting for the Forest Practices Board to fund a facilitator and note-taker. This request was made to assist the Roundtable to restore discussions. The Board adopted the following motion:

  TFW Cultural Resources Roundtable Report and Proposed Action Items
  Motion: Aaron Everett moved the Forest Practices Board recommend and request DNR to allocate funding from the Forests & Fish Support Account to retain professional facilitation and note taking services at TFW Cultural Resources Roundtable meetings.
  He further moved the Forest Practice Board direct the TFW Cultural Resources Roundtable to:
  • Continue work to resolve the FPA conditioning issues identified in the "draft discussion strategy" dated April 21, 2015; by o *Understanding the extent of DNR's conditioning authority, and the role of the Department of Archaeology and Historic Preservation in the FPA approval process;*
  o *Expanding the scope of the annual survey to collect more complete information on how the current system of cultural resource protection is working;*
  o *Reporting to the Board on its progress in a standing agenda item at each quarterly meeting; and*

  • At the August 2015 meeting, the report will include a strategy and a timeline for reaching resolution.

> *He further moved the Board request a short public memo from the Board's counsel on the extent and nature of DNR conditioning authority for cultural resource protection.*
> *2nd Bill*

- At the June 2015 Roundtable meeting, Assistant Attorney General Phil Ferester (Senior Counsel, Natural Resources Division) presented information to the Roundtable related to the forest practices application conditioning authorities of the Board and DNR. (memorandum attached).

- At the June Roundtable meeting, members recommitted to the TFW archeology and cultural resources goals.

> "We, the participants of the Timber/Fish/Wildlife Cultural Resources Roundtable commit to the Archaeological and Cultural goals of the February 17, 1987 TFW Agreement: "**to develop a process to inventory archaeological/cultural spaces in managed forests; and to inventory, evaluate, preserve and protect traditional cultural and archaeological spaces and assure tribal access**". We reaffirm the Timber/Fish/Wildlife Cultural Resources Roundtable's purpose as spelled out in our 2011 Charter to facilitate "**the identification, protection, and management of cultural resources that are significant to the history and cultures of the people of Washington State, and which are located on the state's non-federal forest lands. The Roundtable supports improved tribal access to traditional tribal cultural resources."**

- During the July 2015 Roundtable meeting, members began discussing options offered by various members. Discussion of this list, as well as, additional tasks related to questions raised during the July meeting will continue throughout FY2016. Potential options suggested by TFW participants for next steps and further actions (party suggesting option):

    - Restore WAC 222-20-120(4) with the "may" changed to "shall". Instruct all Regions to consistently make plans agreed to between Tribes and landowners an FPA condition when requested. (Yakama)
    - Instruct all Regions to consistently require meetings under WAC 222-20-120(2) when Tribes appropriately use WAC 222-16-050(5)(k) to identify cultural resources. (Yakama)
    - Insert incidental discovery language into every approved FPA. (Yakama)
    - Use the DAHP predictive model to screen every FPA. High risk and Very high risk areas shall trigger a required professional survey to "inventory archaeological/cultural spaces". Consultation with local Tribes will be required. (Yakama)
    - When archaeological and cultural sites are discovered professionals shall "inventory, evaluate" and make recommendations to "preserve and protect" in consultation with local Tribes. (Yakama)

- "Assure Tribal access" to Tribally significant areas in "managed forests" through binding consultation between affected Tribes and landowners. (Yakama)
- Clarify existing regulatory authority process. (WFPA)
- Develop additional tools for Tribes and landowners to use during landowner – Tribal planning meetings. (WFPA)
- Use CRR survey to identify specific areas where 222-20-120 works well/doesn't work. (WFPA, Forest Practices Board)
- Develop additional guidance for landowners. (WFPA)
- Develop Board Manual Section for protecting cultural resources. (DNR)
- Develop SEPA guidance rule for protecting cultural resources. (DNR)
- Develop additional cross-training opportunities for DNR staff, landowners and Tribal staff. (WFPA, DNR)
- Develop locally based, tribal-run training opportunities for DNR staff and landowners. (Puyallup)
- Develop guidance for DNR staff to ensure consistency. (DAHP)
- Complete the biennial review required under the Cultural Resources Protection and Management Plan. (WFPA)
- Begin formal evaluation of cultural resources program. (Puyallup)
- Eliminate the SEPA off-ramp. (DAHP)
- Develop legislation defining cultural resources as public resources. (Yakama, UCUT, DAHP)
- Funding. (All)

***Roundtable Outreach & Education (incl. Forest Practices Board Reports)*:** The Roundtable prepared and provided quarterly reports to the Board (in the form of the Roundtables monthly/quarterly action items list), and prepared and provided the FY2013 annual report as expected. The Roundtable co-chairs presented their quarterly report briefings at each quarterly meeting of the Board, as needed.

***WAC 222-20-120 & Cultural Resources Protection and Management Plan/Use and Effectiveness Survey Project*:** Due to the controversy related to interpretations of WAC 222-20-120, the Roundtable did not conduct a survey during FY2015 to assess how well WAC 222-20-120 *Notice of forest practices that may contain cultural resources to affected Indian tribes* and the techniques of the Forest Practices Board's Cultural Resources Protection and Management Plan (CRPMP) are working.

Anticipated Activities for FY 2016:

In FY2016, the Roundtable plans to continue reviewing the questions related to about WAC 222-20-120 interpretation and DNR's conditioning authority. While we have not outlined a full schedule of activities, we've begun the planning process. The Roundtable appreciates the funding provided for facilitation and note-taking; these resources will greatly assist in resolving issues. A Roundtable subcommittee will review applications and making recommendations to the full Roundtable in the next month.

Roundtable members have been diligently working to improve communication and consensus. The true dedication of each of the active members and their employers has enabled the Roundtable members to successfully work toward resolving these delicate and sensitive issues during 2016. We sincerely thank you for your genuine interest and honest attention.

T/F/W Cultural Resources Roundtable					7/21/2015	Changes from the previous report are in Red or Italics
Project Priority		**Action Items**	**Lead**	**Status**	**Next Action**	**Relationship to the CRPMP**
High	1	~~Review DNR's FPA conditioning authority~~ Continue to review WAC 222-20-120 interpretations and DNR conditioning authority and develp recommendations for implementation. The Roundtable will begin with the following tasks:	Jeffrey, Karen, David, Sherri	~~Beginning~~ Ongoing	*Identify specific issues and policy framework*	
		Presentations on 3 Models and Cultural Module	David, Robert Morgan Jeffrey	Scheduled	*Presentations at August meeting, determine next steps*	
		Review DNR's suggested Inadvertent Discovery language	Sherri, Marc	Scheduled	*Review language at August meeting*	
		Review additional watershed models	Jeffrey, Karen,	Beginning	*Discuss what additional models to review in August.*	
High	2	Seek funding and staff support for the Roundtable's work		*Roundtable will bring a request to the FPB in May*	*Identify needs and potential resources*	
High	3	Prepare the cultural resource guidance documents and tools as agreed to in the CRPMP		Target completion date: *2015*		Educational Program and Commitments
		Scope the guidance/manual project to develop a detailed description and outline of the proposed guidance or manual.		Complete		
		Work products:1) Guidance for T/F/W stakeholders, 2) Guidance specific to forest landowners, and 3) Guidance specific to Tribes.	Jesse and Gretchen	In progress	Schedule work group in April to review completed drafts; prepare drafts on remaining sections	
		Post Roundtable guidance documents and other information and training material on the DNR Forest Practices web site		On going		

T/F/W Cultural Resources Roundtable					7/21/2015	*Changes from the previous report are in Red or Italics*
Project Priority	**Action Items**		**Lead**	**Status**	**Next Action**	**Relationship to the CRPMP**
High	4	Investigate opportunities to develop training workshop curricula *and presentation* for private industrial foresters.	Jeffrey Karen	Planning	*Schedule work group in 2014*	An education component of the CRPMP
Medium	5	Develop a Logo for the Cultural Resources Roundtable	Jeffrey *and dAVe*	In progress	Draft logo under review	Publicity
Medium	6	CRPMP amendments to consider and further discuss:	All	Scoping	Members of the Roundtable will provide suggestions for amendments after the guidance document task is completed.	CRPMP Support
		Regarding MOUs, consider adding a statement specifying when DNR has a role in implementing MOUs and if there is a role, specifying its nature.				
		Under "Education Program and Commitments," modify #2 to recognize that agreements are often executed at the field level without the need for higher level contacts				
		Reference a role for the CRPMP in Forest Practices ID team deliberations and preparation of SEPA documents for Class IV Special FPAs	Jeffrey			
Low	7	Prepare a report to the Forest Practices Board on the impact to cultural resource protection and management when forest land is converted to another use and regulatory responsibility passes to local government (county or city)	Jeffrey and Karen	On hold	Wait for other higher priority items to be addressed	

T/F/W Cultural Resources Roundtable					7/21/2015	*Changes from the previous report are in Red or Italics*
Project Priority		**Action Items**	**Lead**	**Status**	**Next Action**	**Relationship to the CRPMP**
On-Going Tasks	1	The Roundtable will: (a) meet quarterly; (b) Report- to the FP Board at each regular meeting; (c) Review the CRPMP each year; (d) Report to the FP Board each August on progress of the CRPMP and implementation of WAC 222-20-120 during the previous FY *(e) suggest recommendations for modification to CRPMP*.	Co-Chairs	FPB meeting report due		Annual & quarterly obligation
	2	Give a CRPMP presentation at Regional TFW meetings as new CRPMP support material is released.	All	Next opportunity for TFW presentations after the 20-120 rule and supporting manual is passed by the FPB		Communication
		Create a Roundtable presentation about the CRPMP and Roundtable activities with a singular message and bullet points	Jeffrey and Jesse			
	3	Maintain an annual calendar of recurring Roundtable tasks and functions and post on DNR's website. Include FP Board report due dates, DNR regional TFW meetings and upcoming training opportunities. Emphasize accomplishments when communicating progress on implementing the CRPMP. Post examples of successes and cooperative opportunities on the DNR Forest Practices web site.	Jeffrey	Planning	Select calendaring software	CRPMP Support; Communication
	4	Contact individual FP Board members to "champion" CR Roundtable issues	All	Collaborate with current FP Board members regarding cultural resources issues coming to the Board.		Advance the Roundtable's work
	5	Individual caucuses will continue to support funding for a **full time** position at DAHP for the maintenance of CR data in support of the forest practices risk assessment tool.	Individual Caucuses	Currently the position has 1/2 time funding	Next opportunity is the *2014* Legislature	DNR Forest Practices Program support
	6	Seek funding for a CR Module pilot project		On hold	Waiting for the next opportunity	Board Manual Section 11 Appendix J

T/F/W Cultural Resources Roundtable					7/21/2015	Changes from the previous report are in Red or Italics
Project Priority		**Action Items**	**Lead**	**Status**	**Next Action**	**Relationship to the CRPMP**
Completed Items	1	Cultural Resource Protection and Management Plan (CRPMP)		Completed 2003		
	2	Forest Practices Board adopted the rules recommended in the CRPMP		Completed 2005		
	3	Statutory exemption for sensitive cultural resource information gathered during a watershed analysis CR module or stand-alone CR module		Completed 2005		
	4	Updates to the CRPMP		Completed 2008		
	5	Recommendation to DNR staff and the Board for changes to the historic site definitions in Class III and Class IV Special definition to correct long standing interpretation issues		Completed 2008		
	6	A recommendation to include a cultural resource question on the Phase II 15-year small landowner permit application.		Completed Spring 2009		
	7	Draft a motion for the Forest Practices Board to request that the staff create a CR page on the Department's forest practices website		Complete (Board action was unnecessary)		
	8	With the support of the Commissioners Office, a Charter for the Timber/Fish/Wildlife Cultural Resources Roundtable (formerly known as TFW Cultural Resources Committee) delivered to the Forest Practices Board		Completed 2011		
	9	Consensus recommendation on changes to WAC 222-20-120 delivered to the Forest Practices Board		Completed 2011		
	10	As requested by the FPB, review and comment on a suggestion to amend 222-20-120 Sub-Section (3)(c))(i)		Completed 2011	Recommendation adopted by the Board in Feb, 2012	
	11	Prepare a streaming video of Lee Stilson's lecture on cultural resources that typically may be found in Washington's managed forests		Completed May 2012		

T/F/W Cultural Resources Roundtable					7/21/2015	*Changes from the previous report are in Red or Italics*
Project Priority		**Action Items**	**Lead**	**Status**	**Next Action**	**Relationship to the CRPMP**
	12	In time for the FY 2012 report to the FPB, develop a method for formally assessing the performance CRPMP in accomplishing its purposes as stated on page 1 of the plan.		Completed June 2012		
	13	Two new cultural resource links have been added to the DNR Forest Practices webpage. Roundtable agendas, notes and action item list are on the Forest Practices Board's webpage		Completed September 2012		
	14	Improve knowledge, understanding and use of the GLO, historic and current USGS quad maps and other publicly available information to identify historic features recognized during 19th century land surveys.		Completed October 2012		Making available tools to improve identification and recognition of cultural resources in the field
	15	Update the instructions for question 7 of the forest practices application.	Sherri	Completed October 2013	Draft submitted to DNR for inclusion in the next update of FPA Instructions.	This would be an edit to Appendix B of the Cultural Resources Protection and Management Plan
	16	Follow the State Environmental Policy Act rule making by the Department of Ecology to draft rules to increase categorical exemptions.	Gretchen	Completed November 2014	*Ecology is recommending that Cultural Resource be considered as one of three top priorities for Phase 2 rulemaking.*	

Confederated Tribes and Bands
of the Yakama Nation

Established by the
Treaty of June 9, 1855

March 23, 2015

Washington State Forest Practices Board
1111 Washington Street SE
P. O. Box 47012
Olympia, WA 98504-7012

Subject: WDNR Forest Practices implementation of WAC 222-20-120

Dear Commissioner Goldmark and Forest Practices Board Members:

I would like to bring to your attention a significant issue that has surfaced regarding protection of cultural resources. I understand you were informed about part of the issue at your September 3, 2014 Board meeting. Beginning in February 2014 the Washington Department of Natural Resources (WDNR) Forest Practices began informing the Yakama Nation that they do not have the authority to condition applications with plans agreed to between the landowner and tribe to protect archaeological or cultural resources as authorized by WAC 222-20-120(4). In response to our May 21, 2014 declaration of areas to contain cultural value across the ceded and traditional use lands we received a response informing us to update our FPARS profiles. Our staff has had FPARS profiles since the program began and they do not require updating. It is clear the Forest Practices Division has an inconsistent understanding of the implementation of WAC 222-20-120 and the archaeological and cultural goals of the Timber, Fish and Wildlife (TFW) Agreement.

It is imperative that all members of the Forest Practices Board understand the history of WAC 222-20-120 and the TFW Agreement to appreciate the problems presented with an inconsistent application of the rule. The background is necessary to be able to adopt measures to correct the problems and direct a reasonable solution.

The TFW Agreement goes back to February 17, 1987. The Forest Practices Rules were in place addressing some TFW goals by January 1, 1988. These rules included WAC 222-20-120 requiring a Tribal-landowner meeting to agree on a plan for protecting cultural values and the department's authority to make the plan a condition of the forest practices application (FPA) (p. 23). The Yakama Nation has used Forest Practices Rules in cooperation with landowners to protect 100s of archaeological and cultural sites.

The Forests and Fish Report (FFR) was presented to the Forest Practices Board (FPB) February 22, 1999. It was a response to multiple species being listed under the Endangered Species Act (ESA). The FPB requested that the TFW Cultural Resources

Committee (now the Roundtable) reconvene and take up the task of addressing the cultural resources components of the FFR. This effort resulted in the Cultural Resources Protection and Management Plan (CRPMP) in 2003, a voluntary process.

In June 2006 the National Marine Fisheries Service and the U.S. Fish and Wildlife Service (Services) approved the Forest Practices Habitat Conservation Plan (FPHCP), which included a 50-year Incidental Take Permit (ITP) under the ESA. The Services did not meet their section 106 responsibilities under the National Historic Preservation Act (NHPA). The Services said the state laws, rules and voluntary processes were equivalent to section 106. They are not.

From late 2008 to February 2012 the Roundtable worked on issues concerning WAC 222-20-120. Consensus language was reached in February 2011. Legal rule amendments were adopted February 14, 2012 and became effective March 19, 2012.

The Yakama Nation was dismayed in February 2014 when we learned the Forest Practices Division had reinterpreted and eliminated the rule for making a plan a condition of a FPA. Even though the exact language of WAC 222-20-120(4) is in the 1988 and 2015 Forest Practices Rules, and there is proof of its use going back to 1998, Forest Practices says it was eliminated in 2007. That is just a year after the Services failed to comply with the NHPA erroneously claiming that state laws, rules and voluntary processes were equivalent to section 106. It is also before over three years of negotiations and discussions from 2008 - 2012 that led to the legal rule amendments benefitting landowners.

The Yakama Nation has used WAC 222-16-050(5)(k) in 1995, 1999 and 2014 to identify areas that have cultural value. This declaration should trigger the required meeting under WAC 222-20-120(2) but Forest Practices has only honored the 1995 declaration. The failure to honor the 1999 and 2014 declarations has resulted in approximately 15,000 violations of WAC 222-20-120(2).

The Yakama Nation's TFW archaeologist, David Powell, provided a presentation at the March 17, 2015 TFW Cultural Resources Roundtable meeting describing the history, problems and solution with Forest Practices reinterpretation of WAC 222-20-120 and the archaeological and cultural goals of the 1987 TFW Agreement. I am attaching his detailed outline for your information. The Yakama Nation concurs with the facts and the proposed solution that Mr. Powell has presented.

The Yakama Nation therefore respectfully requests that the FPB adopt the provisions to implement the archaeological and cultural goals of the TFW Agreement: 1) Restore WAC 222-20-120(4) with the "may" changed to "shall". Instruct all Regions to consistently make plans agreed to between Tribes and landowners a FPA condition when requested. 2) Instruct all Regions to consistently require meetings under WAC 222-20-120(2) when Tribes appropriately use WAC 222-16-050(5)(k) to identify cultural resources. 3) Insert incidental discovery language into every approved FPA. 4) Use the DAHP predictive model to screen every FPA. High Risk and Very High Risk areas shall trigger a required professional survey to "inventory archaeological/cultural spaces". Consultation with local Tribes shall be required. 5) When archaeological and cultural sites are discovered professionals shall "inventory, evaluate" and make recommendations to "preserve and protect" in consultation with local Tribes. And 6) "Assure Tribal access" to Tribally significant areas in "managed forests" through binding consultation between affected Tribes and landowners.

The Yakama Nation hereby formally requests that the FPB include the TFW archaeological and cultural resources goals in their work plan until rules are in place that accomplishes the goals. The FPB should propose and support legislation that insures the Forest Practices Division has the authority to protect cultural and archaeological resources information as a public resource as well as other legislation that is needed to meet the TFW goals.

Thank you for your time and immediate consideration of this serious matter. I look forward to having our staffs work together to implement the TFW goals for resource protection. If there are any questions regarding this request, please feel free to contact Superintendent Philip Rigdon at (509) 865-5121 ext. 4655 or Jim Matthews at (509) 865-5121 ext. 6311 or David Powell at (509) 865-5121, ext. 6312.

Sincerely,

Ruth Jim, Chairwoman
Cultural Committee
Tribal Council

cc: Yakama Nation Tribal Council Cultural Committee
Yakama Nation Tribal Council TFW Committee
Johnson Meninick, Cultural Program
Kate Valdez, THPO
Patrice Kent, OLC
Dawn Vyvyan, OLC
Allyson Brooks, Director DAHP
Lenny Young, WDNR Department Supervisor
Aaron Everett, WDNR Deputy Supervisor
Chris Hanlon-Meyers, WDNR Forest Practices Division Manager
YN TFW files

Enclosure

TFW Cultural Resources Roundtable
March 17, 2015
Hosted by Dept. of Archaeology and Historic Preservation
Comments by David Powell for the Yakama Nation on
Forest Practices Rules for Cultural Resources Protection
And the TFW Agreement

- Thanks to everyone for allowing me to provide a summary and background of the reinterpretation of WAC 222-20-120 and the TFW Agreement.
- I have worked for the Yakama Nation Timber, Fish and Wildlife Program for 20 years.

TFW Agreement

- The Timber/Fish/Wildlife (TFW) Agreement goes back to February 17, 1987. The archaeological and cultural goals are "to develop a process to inventory archaeological/cultural spaces in managed forests; and to inventory, evaluate, preserve and protect traditional cultural and archaeological spaces and assure tribal access" (pp. 2-3).
- The Forest Practices Rules were in place addressing some TFW goals by January 1, 1988. These rules included WAC 222-20-120 requiring a Tribal-landowner meeting to agree on a plan for protecting cultural values and the department's authority to make the plan a condition of the forest practices application (FPA) (p. 23).

Forest Practices Rules

- Many rules have been added over the years – now the rulebook is 3 inches thick.
- But all the rules for protecting cultural resources fit on only two pages.
- I have used these tools in cooperation with landowners to protect 100s of archaeological and cultural sites.

Forest and Fish Report

- February 22, 1999 the Forests and Fish Report (FFR) was presented to the Forest Practices Board (FPB). It was a response to multiple species being listed under the Endangered Species Act (ESA). The FFR "committed to the original TFW agreement" (p. 3). There were cultural resources components of the FFR. Only an informal coalition of Tribes met the legislature's timeline for addressing the cultural resources components.
- The FPB requested that the TFW Cultural Resources Committee (now the Roundtable) reconvene and take up the task of addressing the cultural resources components with representatives of all stakeholders. This effort resulted in the Cultural Resources Protection and Management Plan (CRPMP) in 2003, a voluntary process.

FPHCP

- In June 2006 the National Marine Fisheries Service and the U.S. Fish and Wildlife Service (Services) approved the Forest Practices Habitat Conservation Plan (FPHCP), which included a 50-year Incidental Take Permit (ITP) under the ESA. A federal permit is defined as an "undertaking" [36 CFR 800.16 (y)] in the National Historic Preservation Act (NHPA). The Services admitted that they had section 106 responsibilities in issuing the ITP and would decide how best to meet their section 106 responsibilities. The

Services did not meet their section 106 responsibilities. They failed to consult with the Yakama Nation or to comply with the NHPA.

- NHPA requires that in issuing the ITP the Services needed to make a reasonable and good faith effort to identify historic properties in all areas where the permit applies – the private and state lands in Washington. NHPA requires the Services develop a strategy to physically look for, document and evaluate all sites that are on or eligible for inclusion in the National Register of Historic Places. They said the state laws, rules and voluntary processes were equivalent to section 106. They are not.
- Although the Services never consulted with the Yakama Nation, we commented on every draft and final Environmental Impact Statements for nearly three years. We recommended a reasonable strategy to make a condition of the ITP be a requirement for professionally reasoned cultural resources surveys on a project-by-project basis using predictive models. Instead the Services relied on state laws, rules and voluntary processes as a substitute for the NHPA.

Legal Rule Amendments to WAC 222-20-120

- In late 2008 dAVe burlingame, Cowlitz Tribe, brought an issue to the Roundtable because WAC 222-20-120 directed Tribes to meet with a landowner. Washington has no authority to direct a Tribe to do anything. The Cowlitz Tribe recommended inserting, "at the discretion of the Tribe". The Roundtable took up the issue. The simple fix was accepted but other improvements were discussed and approved.
- In March 2010 Steve Griswold, Plum Creek Timber Company, brought another issue with WAC 222-20-120 to the Roundtable. When a Tribe did not respond with their efforts to meet under the rule, their FPA was denied. The Roundtable took up their issue and worked on it for another year.
- In February 2011 we had consensus on language allowing the documentation of efforts to meet to fulfill the requirements and have the FPA approved. The Forest Practices Division made the final recommendation to keep the exact language: "The department may condition the application in accordance with the plan". The revisions went through the legal rule-making process with Tribal and public comment and testimony. The rule was adopted February 14, 2012 and became effective March 19, 2012.

Reinterpretation of WAC 222-20-120(4)

- The Yakama Nation was dismayed in February 2014 when we learned the Forest Practices Division had reinterpreted and eliminated the most successful rule for cultural resources protection: making a plan a condition of a FPA.
- Beginning March 3, 2014 I tried to resolve the problem with Sherri Felix who took it to her supervisors. I was promised a response daily but none came.
- March 14, 2014 at 8 a.m. I sent out "What Tribes can expect from Forest Practices" when a plan is agreed to because the next Roundtable meeting was March 18th.
- Joenne McGerr called within 5 minutes saying she had to retract my statement. I forwarded her all of the e-mails and attachments between Sherri and I. At 5:30 she forwarded Chris Hanlon-Meyer's statement that Forest Practices "honors and implements all provisions of WAC 222-20-120" to 45 people. My statement is still true. Chris' statement is still not true and it has not been retracted.
- Even though the exact language is in the 1988 and 2015 Forest Practices Rules, and there is proof of its use going back to 1998, SE Region has been directed to never use it!

- July 2014 the Roundtable was told the reinterpretation happened in 2007 but no one was told. That is just a year after the Services violated the NHPA erroneously claiming that state laws, rules and voluntary processes were equivalent to section 106. It is before over three years of negotiations and discussions of legal rule amendments.
- The reinterpretation benefits no one. I do not accept the explanations or rationale.

Contradictory Interpretation of WAC 222-20-120(2)

- The Yakama Nation has another major issue with Forest Practices contradiction of implementation of rules for protection of cultural resources concerning the 1995, 1999 and 2014 Yakama Nation declarations of areas to contain cultural values.
- In 1995 the Yakama Nation identified to Forest Practices areas to contain cultural value in Kittitas County citing WAC 222-16-050(5)(k). That declaration triggers the required meeting between the landowner and the Tribe under WAC 222-20-120(2). Southeast Region has appropriately implemented that declaration for nearly 20 years.
- In 1999 the Yakama Nation expanded the area identified to Forest Practices that contain cultural values to the ceded and traditional use lands again appropriately citing WAC 222-16-050(5)(k). That declaration has never been implemented resulting in approximately 15,000 violations of WAC 222-20-120(2).
- May 21, 2014 the Yakama Nation again identified areas to Forest Practices that contain cultural values in the ceded and traditional use lands citing WAC 222-16-050(5)(k). Commissioner Goldmark responded July 31, 2014, saying the Yakama Nation needs to update their FPARS profile. This response demonstrates Forest Practices employs contradictory interpretations of WAC 222-16-050(5)(k) between the 1995, 1999 and 2014 declarations and continues to violate WAC 222-20-120(2).
- The contradictory interpretation of rules further demonstrates that Chris Hanlon-Meyer's assertion that "DNR continues to honor and implement all provisions of WAC 222-20-120 regarding forest practices that may contain cultural resources" is not accurate.

The Problem

- Forest Practices reinterpretation of WAC 222-20-120(4) did not go through a legal rule amendment process requiring Tribal and public scrutiny. It removes a Tribal cultural resources protection tool that has been in the rules for over 27 years.
- The Services relied on rules, including WAC 222-20-120(4), as a substitute for section 106 of the NHPA when they approved the FPHCP. They have not been informed of the reinterpretation of WAC 222-20-120(4) out of existence in the annual reports.
- WAC 222-20-120(2) requires that a landowner shall meet with affected Tribes. Forest Practices has inconsistently applied the rule with thousands of violations where FPAs have been approved without the required meeting.
- TFW is built on trust between all participants. The failure to reveal the 2007 reinterpretation of WAC 222-20-120(4) is a huge betrayal of trust. It demonstrates a disregard for the TFW agreement. How will Forest Practices restore trust?
- There has never been an effort to fully implement the 28-year-old archaeological and cultural goals of the TFW Agreement.

The Solution

- To serve on the TFW Cultural Resources Roundtable participants must commit to the Archaeological and Cultural goals of the 1987 TFW Agreement: "to develop a process to inventory archaeological/cultural spaces in managed forests; and to inventory, evaluate, preserve and protect traditional cultural and archaeological spaces and assure tribal access". If you will not commit to these goals, what are you doing on the Roundtable? Why are you here? What will do to assure tribal access to managed forests?
- Implementation of the Archaeological and Cultural goals of the TFW Agreement requires an honest commitment from all participants. A voluntary process has been tried for a dozen years and failed.

Provisions to Inventory, Preserve and Protect Cultural Resources
in Managed Forests and Assure Tribal Access:

1) Restore WAC 222-20-120(4) with the "may" changed to "shall". Instruct all Regions to consistently make plans agreed to between Tribes and landowners an FPA condition when requested.

2) Instruct all Regions to consistently require meetings under WAC 222-20-120(2) when Tribes appropriately use WAC 222-16-050(5)(k) to identify cultural resources.

3) Insert incidental discovery language into every approved FPA.

4) Use the DAHP predictive model to screen every FPA. High Risk and Very High Risk areas shall trigger a required professional survey to "inventory archaeological/cultural spaces". Consultation with local Tribes shall be required.

5) When archaeological and cultural sites are discovered professionals shall "inventory, evaluate" and make recommendations to "preserve and protect" in consultation with local Tribes.

6) "Assure Tribal access" to Tribally significant areas in "managed forests" through binding consultation between affected Tribes and landowners.

Confederated Tribes *of the*
Umatilla Indian Reservation
Department of Natural Resources
Administration

46411 Timíne Way
Pendleton, OR 97801

www.ctuir.org ericquaempts@ctuir.org
Phone 541-276-3165 Fax: 541-276-3095

August 29, 2014

Washington State Forest Practices Board
1111 Washington Street SE
P. O. Box 47012
Olympia, WA 98504-7012

Subject: WDNR Forest Practices reinterpretation of WAC 222-20-120(4)

Dear Commissioner Goldmark and Forest Practices Board Members:

The Confederated Tribes of the Umatilla Indian Reservation (CTUIR) has concerns with the way the Washington Department of Natural Resources (WDNR) Forest Practices Division (FPD) is protecting and managing cultural resources in accordance with Washington Administrative Code (WAC) 222-20-120, specifically in regards to forest practice applications in accordance with plans agreed upon between landowners and Tribes to protect archaeological and cultural resources.

Earlier this year the FPD stated they do not have the authority to condition forest practice applications in accordance with plans agreed upon between landowners and Tribes. The CTUIR disagrees with this. The FPD has conditioned applications in accordance with agreed upon plans going back as early as 1998 and the authority has been in the rules since January 1988. The Forest Practices Rules for Cultural Resources Protection, WAC 222-20-120 clearly states:

> (1) The department shall notify affected Indian tribes of all applications in geographic areas of interest that have been identified by such tribes, including those areas that may contain cultural resources.
> **(2) Where an application is within a tribe's geographic area of interest and contains cultural resources the landowner, at the tribe's discretion, shall meet with the affected tribe(s) prior to the application decision due date with the objective of agreeing on a plan for protecting the archaeological or cultural value.**
> (3) The department will consider the requirements in subsection (2) of this section complete if prior to the application decision due date:
> (a) The landowner meets with the tribe(s) and notifies the department that a meeting took place and whether or not there is agreement on a plan. The department shall confirm the landowner's information with the tribe(s); or
> (b) The department receives written notice from the tribe(s) that the tribe(s) is declining a meeting with the landowner; or
> (c) The tribe(s) does not respond to the landowner's attempts to meet and the landowner provides to the department:
> (i) Written documentation of telephone or e-mail attempts to meet with the tribe's designated cultural resources contact for forest practices; and
> (ii) A copy of a certified letter with a signed return receipt addressed to the tribe's cultural resources contact for forest practices requesting a meeting with the tribe; or
> (d) The department receives other acceptable documentation.
> **(4) The department may condition the application in accordance with the plan.**

WAC 220-20-120 (emphasis added.)

In March, participants of the Timber/Fish/Wildlife Cultural Resources Roundtable (Roundtable) were informed of the FPD's new interpretation of WAC 222-20-120(4). The Roundtable was asked to submit written questions and concerns regarding this issue. The FPD Manager, Chris Hanlon-Meyer, provided verbal explanations to the Roundtable's comments and concerns at the July 2014 Roundtable meeting in Olympia, Washington; however, he did not disclose how FPD came to their new interpretation of WAC 222-20-120.

The FPD did not consult with affected Tribes about this decision or reinterpretation of WAC 222-20-120. This decision does not demonstrate transparency or an interest in a cooperative working relationship between the agency and tribes, as per Commissioner's Order 201029 on Tribal Relations, or the Millennium Agreement for working with Tribes.

The CTUIR formally requests that the Forest Practices Board take action to ensure archaeological and cultural resources are adequately protected and managed by directing the WDNR and FPD to follow WAC 222-20-120(4) for all forest practice applications and conditioned in accordance with agreed upon protection plans between the landowners and Tribes. Furthermore, we would like to request the Forest Practices Board require a pre-assessment provision for all forest practice applications that incorporates the Department of Archaeology and Historic Preservation (DAHP) archaeological risk assessment model and an inadvertent discovery plan as a condition. This will ensure archaeological and cultural resources are being properly protected and managed, a duty of the State of Washington. Lastly, the Forest Practices Board is encouraged to propose and support legislation to protect cultural and archaeological resources information as a public resource.

Thank you for your time and immediate consideration of this serious matter. If there are any questions regarding this request, please feel free to contact Teara Farrow Ferman, Cultural Resources Protection Program Manager or Audie Huber, Intergovernmental Affairs Manager, at (541) 276-3447.

Respectfully,

Eric Quaempts, Director
Department of Natural Resources

cc: Chuck Sams, Communications Director, CTUIR
Lisa Ganuelas, Legislative Affairs, CTUIR
Allyson Brooks, State Archaeologist, DAHP
Chris Hanlon-Meyers, Forest Practices Division Manager, WDNR
Joenne McGerr, Tribal Liaison, WDNR

WASHINGTON STATE DEPARTMENT OF
Natural Resources
Peter Goldmark - Commissioner of Public Lands

Caring for
your natural resources
... now and forever

October 23, 2014

Eric Quaempts, Director
Department of Natural Resources
Confederated Tribes of the Umatilla Indian Reservation
Nixyáawii Governance Center
46411 Timine Way
Pendleton, OR 97801

Subject: August 29, 2014 Letter to Washington State Forest Practices Board "WDNR Forest Practices reinterpretation of WAC 222-20-120(4)"

Dear Mr. Quaempts:

I received your letter of concern regarding the Washington State Department of Natural Resources (DNR) conditioning forest practices applications for cultural resources plans under Washington Administrative Code (WAC) 222-20-120(4). This part of the cultural resources rule is specific to how forest practices applications are conditioned in accordance with agreed upon plans for cultural resources protection developed between the landowner and Tribe. I recognize the importance of this matter.

The Forest Practices Board (Board), at their September 3, 2014 meeting, was informed of this cultural resources conditioning issue during the FY2014 annual report presentation by our Timber/Fish/Wildlife Cultural Resources Roundtable (Roundtable). The Roundtable informed the Board they are working with DNR to gain a mutual understanding between Tribes and DNR of the cultural resources rule requirements and the DNR's conditioning authority under the Forest Practices Rules, Title 222 WAC. The Roundtable suggested the review of the conditioning authority for cultural resources under the forest practices rules be the basis for their collaborative deliberations and, if needed, recommendations to Board. The Board believes this approach is appropriate given the Roundtable's proven ability to reach consensus agreements on sensitive and complicated cultural resources issues, and record of consensus products that ensure protection of cultural resources.

To keep the Confederated Tribes of the Umatilla Indian Reservation (CTUIR) informed on the current efforts of the Roundtable, I will ask the Roundtable to add your email address to their contact list so you directly receive their meeting agendas and meeting notes. Additionally, Roundtable agendas and notes are posted on the Board's website at Timber/Fish/Wildlife Cultural Resources Roundtable.

1111 WASHINGTON ST SE ▮ MS 47001 ▮ OLYMPIA, WA 98504-7001
TEL (360) 902-1000 ▮ FAX (360) 902-1775 ▮ TTY (360) 902-1125 ▮ TRS 711 ▮ **WWW.DNR.WA.GOV**

DNR has been taking steps to ensure forest practices applications are properly conditioned in accordance with landowner – Tribe agreed to protection plans for cultural resources, including statewide meetings with region managers. DNR must be vigilant to not over-step or under-step the Board's authority. The Washington State legislature sets this authority via the laws of chapter 76.09 Revised Code of Washington (RCW) *Forest practices act.*

Additionally, DNR will continue to pre-screen proposed forest practices using the Washington Department of Archaeology and Historic Preservation's (DAHP) Archaeology and Historic Sites database to alert us of known cultural resources. DNR will continue to require review of proposed forest practices according to the State Environmental Policy Act, including screening with Bureau of Land Management Government Land Office (GLO) maps and U.S. Geologic Survey and Army Mapping Service maps. DNR will continue to require the landowner to meet with the Tribes pursuant to WAC 222 20-120 *Notice of forest practices that may contain cultural resources to affected Indian tribes*, including when a Tribe requests a meeting.

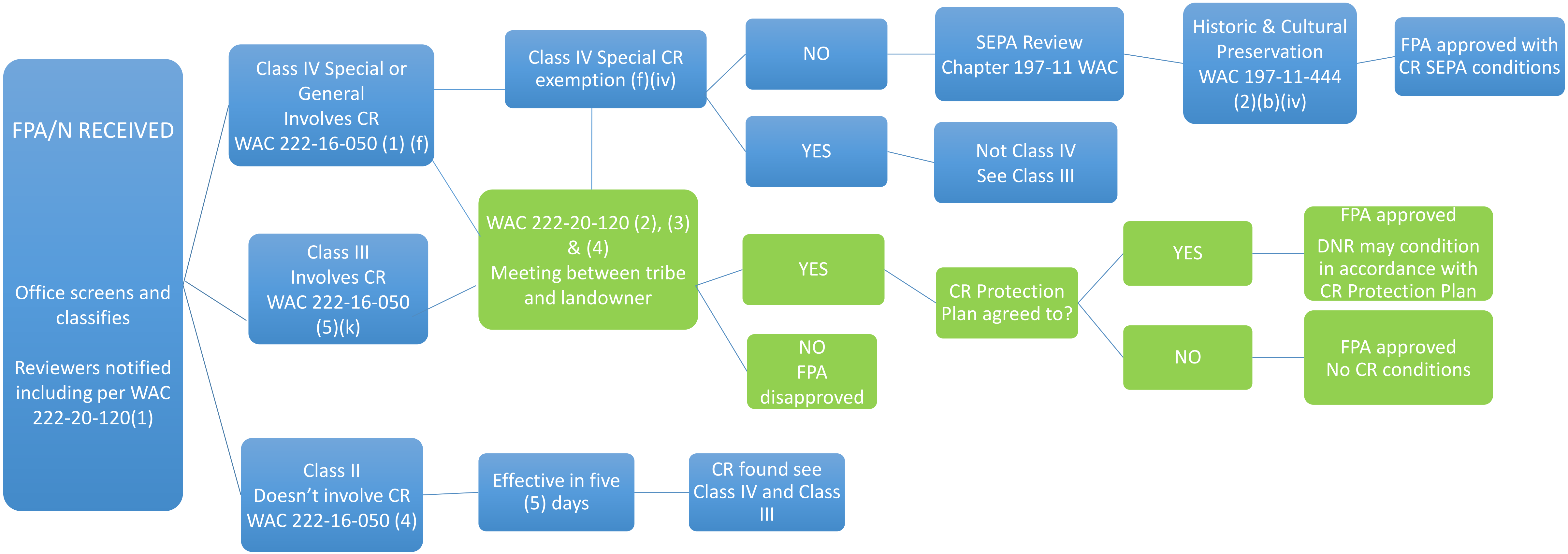
Thank you, Mr. Quaempts, for advising me and the Board of the CTUIR's concerns about conditioning forest practices applications for cultural resources plans under WAC 222-20-120 (4). I look forward to resolving this issue, transparently and cooperatively. Please do not hesitate to directly contact me at 360-902-1004 or peter.goldmark@dnr.wa.gov.

Sincerely,

Peter Goldmark
Commissioner of Public Lands

c: Lenny Young, Department Supervisor
Aaron Everett, Deputy Supervisor, Forest Practices and Federal Relations
Joenne McGerr, Tribal Liaison
Chris Hanlon-Meyer, Forest Practices Division Manager
Todd Welker, Southeast Region Manager
Loren Torgerson, Northeast Region Manager
Eric Wisch, Pacific Cascade Region Manager
Art Tasker, South Puget Sound Region Manager
Jean Fike, Northwest Region Manger
Sue Trettivik, Olympic Region Manager
Jeffrey Thomas, Co-chair, TFW Cultural Resources Roundtable
Karen Terwilleger, Co-chair, TFW Cultural Resources Roundtable
14-174

CULTURAL RESOURCES (CR) FPA/N PROCESS
Draft



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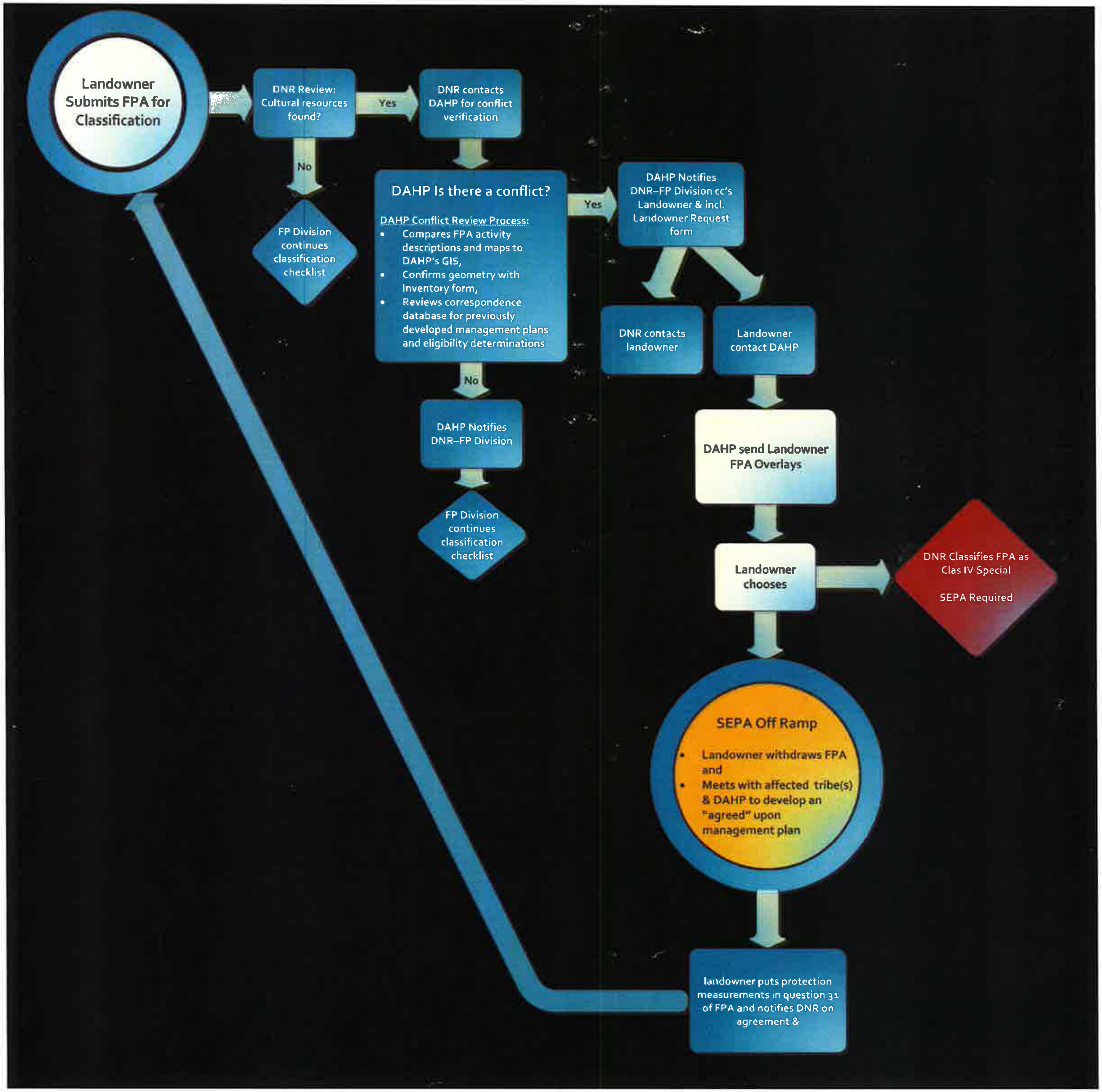

Landowner Submits FPA for Classification
DNR Review: Cultural resources found?
Yes
DNR contacts DAHP for conflict verification
No
FP Division continues classification checklist
DAHP Is there a conflict?
DAHP Conflict Review Process:
• Compares FPA activity descriptions and maps to DAHP's GIS,
• Confirms geometry with Inventory form,
• Reviews correspondence database for previously developed management plans and eligibility determinations
Yes
DAHP Notifies DNR–FP Division cc's Landowner & incl. Landowner Request form
DNR contacts landowner
Landowner contact DAHP
No
DAHP Notifies DNR–FP Division
FP Division continues classification checklist
DAHP send Landowner FPA Overlays
Landowner chooses
DNR Classifies FPA as Clas IV Special
SEPA Required
SEPA Off Ramp
• Landowner withdraws FPA and
• Meets with affected tribe(s) & DAHP to develop an "agreed" upon management plan
landowner puts protection measurements in question 31 of FPA and notifies DNR on agreement &

Bob Ferguson
ATTORNEY GENERAL OF WASHINGTON
Natural Resources Division
PO Box 40100 ● Olympia, WA 98504-0100

M E M O R A N D U M

DATE: June 10, 2015

TO: Stephen Bernath, Chair, and the Forest Practices Board

FROM: Philip M. Ferester, Senior Counsel
Natural Resources Division

SUBJECT: **Open Primer on Forest Practices Act Conditioning Authority**

INTRODUCTION

The Forest Practices Board (Board) passed a resolution at its May 12, 2015, quarterly meeting that requested a short, public memorandum on conditioning authorities under the Forest Practices Act. This request came about because of current issues before the Board's Cultural Resources Roundtable, and a proposal suggesting that the Board change "may" to "shall" in WAC 222-20-120(4).

This memorandum provides a brief open primer on Board rule making and DNR conditioning authority. The memorandum starts with general concepts of administrative law and the scope of administrative authority. That provides a foundation for reviewing past forest practices cases addressing conditioning and a foundation from which various entities might explore lawful ways to address cultural resource issues either through the Forest Practices Act structure or elsewhere.

While this memorandum reflects my own legal judgment as counsel to the Board, it is not an official opinion of the Attorney General's Office.

ANALYSIS

A. The Statutory Framework of the Forest Practices Act Establishes the Subjects That May Be Regulated By the Board and DNR.

A fundamental aspect pertaining to the authority of any administrative agency is the statutory structure under which they operate. "The Board has only those powers expressly granted to it and those powers necessarily implied from its statutory delegation of authority." Att'y Gen. Op. 1, at 5 (2015). An agency has implied authority to carry out a task "where an agency is charged with a specific duty, but the means of accomplishing that duty are not set forth by the Legislature." *Tuerk v. Dep't of Licensing*, 123 Wn.2d 120, 124-25, 864 P.2d 1382 (1994). From these general concepts, some key provisions in the Forest Practices Act (FP Act) will be explored.

1. Board's Forest Practices Act Authorities.

The Board's primary rule-making responsibilities are established in RCW 76.09.040(1)(a). The Legislature directed the Board as follows:

> *Where necessary to accomplish the purposes and policies stated in RCW 76.09.010*, and to implement the provisions of this chapter, the board shall adopt forest practices rules pursuant to chapter 34.05 RCW and in accordance with the procedures enumerated in this section that:
>
> (i) Establish minimum standards for forest practices; . . . [and]
>
> (iii) Set forth necessary administrative provisions; . . . .

RCW 76.09.040(1)(a)(i) and (iii) (emphasis added). RCW 76.09.010 thus directly bears upon the scope of the Board's rule-making authority. RCW 76.09.010(2) sets forth the purposes and policies of the Forest Practices Act:

> The legislature further finds and declares it to be in the public interest of this state to create and maintain through the adoption of this chapter a comprehensive statewide system of laws and forest practices rules which will achieve the following purposes and policies:
>
> (a) Afford protection to, promote, foster and encourage timber growth, and require such minimum reforestation of commercial tree species on forest lands as will reasonably utilize the timber growing capacity of the soil following current timber harvest;
>
> (b) Afford protection to forest soils and public resources by utilizing all reasonable methods of technology in conducting forest practices;
>
> (c) Recognize both the public and private interest in the profitable growing and harvesting of timber;
>
> (d) Promote efficiency by permitting maximum operating freedom consistent with the other purposes and policies stated herein;

> (e) Provide for regulation of forest practices so as to avoid unnecessary duplication in such rules;
>
> *(f) Provide for interagency input and intergovernmental and tribal coordination and cooperation*;
>
> (g) Achieve compliance with all applicable requirements of federal and state law with respect to nonpoint sources of water pollution from forest practices;
>
> (h) To consider reasonable land use planning goals and concepts contained in local comprehensive plans and zoning regulations;
>
> *(i) Foster cooperation among managers of public resources, forest landowners, Indian tribes and the citizens of the state*;
>
> (j) Develop a watershed analysis system that addresses the cumulative effect of forest practices on, at a minimum, the public resources of fish, water, and public capital improvements of the state and its political subdivisions; and
>
> (k) Assist forest landowners in accessing market capital and financing for the ecosystem services provided to the public as a result of the protection of public resources.

RCW 76.09.010(2)(a)–(k) (emphasis added). These policies establish the parameters for proper Board rule making. The two italicized provisions address working with Indian tribes on forest practices applications and promoting cooperation. The FP Act and rules strongly focus upon the protection of "public resources," pursuant to RCW 76.09.010(2)(b). "Public resources" includes "water, fish, wildlife, and capital improvements of the state or its political subdivisions." RCW 76.09.020(25).[1]

"Cultural resources" is a term not found in the FP Act. That means that cultural resources are not a regulatory focus that the Legislature assigned to the Board or to DNR, beyond promoting cooperation between landowners and Indian tribes.[2]

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[1] The protection of water quality through the protection of public resources carries extra significance as a regulatory purpose behind the FP Act because it provides the means of Washington's compliance with federal non-point source water pollution laws on forest lands. *See* RCW 90.48.420(1); RCW 77.85.180(2).

[2] Agreements like TFW inform the interpretation of many Board rules and promote cooperation among resources managers, landowners, and tribes. However, those agreements do not expand the regulatory authority of either the Board or DNR. That authority can only be set or established by the Legislature.

The Board must act within its statutory authority when it adopts rules. Rules adopted in excess of an agency's statutory authority may be stricken under the Administrative Procedure Act.[3]

2. DNR Forest Practices Act Conditioning Authorities.

DNR administers the regulatory programs created under the FP Act and rules. RCW 76.09.040(1)(c). DNR's conditioning authority is not exhaustively set forth in the FP Act. In RCW 76.09.050(4), the Legislature indicated that "forest practices shall be conducted in accordance with the forest practices regulations, orders and directives as authorized by this chapter or the forest practices regulations, *and the terms and conditions of any approved applications*." RCW 76.09.050(4) (emphasis added). This is a strong indication that the Legislature anticipated that applications may include some conditions.[4]

DNR also has important enforcement authority regarding issued permits that further emphasizes its conditioning authority to protect public resources. As will be discussed in greater detail below, the quasi-judicial agencies that review DNR's regulatory decisions under the FP Act have found that DNR's authority to issue Stop Work Orders or Notices to Comply to prevent actual or potential damage to public resources provides an additional statutory basis for site-specific application conditioning to protect public resources.[5]

Importantly, DNR's authority is limited to site-specific circumstances. DNR does not have the authority to adopt rules under the FP Act. That authority rests with the Forest Practices Board, as discussed above. Should DNR attempt to impose uniform conditions on all sites having a particular issue, that would be considered a rule under the Administrative Procedure Act, and conditions imposed in that manner would be invalidated.[6]

---

[3] RCW 34.05.570(2)(c); *Edelman v. State ex rel. Pub. Disclosure Comm'n*, 152 Wn.2d 548, 99 P.3d 386 (2004) (rule in excess of statutory authority invalid; agency cannot promulgate a rule that amends or changes a statute).

[4] Washington courts have expressly held that "'the power to disapprove a permit necessarily includes the power to condition an approval.'" *State v. Crown Zellerbach Corp.*, 92 Wn.2d 894, 899, 602 P.2d 1172 (1979), quoting *S. Pac. Co. v. Olympian Dredging Co.*, 260 U.S. 205, 208 (1922). *Crown Zellerbach* involved a criminal gross misdemeanor charge associated with the violation of conditions on a hydraulic project approval by the Department of Game for a timber harvest. The permit conditions required cut logs to be yarded over a fish-bearing stream named Williams Creek (in Pacific County). *Crown Zellerbach,* 92 Wn.2d at 897-98.

[5] DNR may issue Stop Work Orders under RCW 76.09.080 and Notices to Comply under RCW 76.09.090.

[6] RCW 34.05.010(16); *Failor's Pharmacy v. DSHS*, 125 Wn.2d 488, 495-98, 866 P.2d 147 (1994) (invalidation of action of general applicability when not based upon a rule adopted under the APA's process); *SDS Lumber Co. v DNR*, FPAB 92-27, Final Findings of Fact, Conclusions of Law, and Order, Conclusion Nos. 3-5 (1992) (reliance upon general guidance memorandum concerning Northern spotted owl as rule was improper).

While a permitting agency generally has the authority to condition its permit as discussed in note 4, this does not mean the agency has carte blanche to require *any* conditions. Rather, the conditions imposed must still be tethered to the agency's underlying regulatory purpose established by the Legislature. This concept will become more apparent in Section B of this memorandum.

3. DNR SEPA Authority.

Applications under the FP Act must go through the State Environmental Policy Act (SEPA) process if they fit the criteria for Class IV.[7] WAC 222-16-050(1)(f) designates some forest practices as Class IV-Special if they affect particular archaeologic or historic resources, as follows:

> (i) Archaeological sites or historic archaeological resources as defined in RCW 27.53.030; or
>
> (ii) Historic sites eligible for listing on the National Register of Historic Places or the Washington Heritage Register as determined by the Washington state department of archaeology and historic preservation; or
>
> (iii) Sites containing evidence of Native American cairns, graves, or glyptic records as provided for in chapters 27.44 and 27.53 RCW. The department of archaeology and historic preservation shall consult with affected Indian tribes in identifying such sites.

WAC 222-16-050(1)(f). Activities that would otherwise be Class IV-Special may avoid that designation and the SEPA process if the landowner voluntarily implements certain protection strategies. WAC 222-16-050(1)(f)(iv).

Applications subject to SEPA require additional information called a "SEPA Checklist," to help make what is called a "threshold determination."[8] The SEPA Checklist includes an area of inquiry into historic and cultural resource preservation.[9] If a proposal receives a threshold "determination of significance" because it will likely have significant adverse environmental impacts, an environmental impact statement (EIS) must be prepared to discuss the impacts,

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[7] RCW 76.09.050 (1); RCW 43.21C.037(3).

[8] WAC 197-11-310; WAC 197-11-315; and WAC 197-11-330(1). The SEPA Checklist is set forth in WAC 197-11-960.

[9] SEPA Checklist, question 13. Proposals subject to SEPA due to a different provision in WAC 222-16-050(1) or (2) must also complete this part of the SEPA Checklist.

alternatives to the proposal that might reduce the impacts, and ways that the impacts may be mitigated.[10]

If a particular forest practices proposal will cause significant adverse impacts, DNR has additional conditioning authority that it may exercise under SEPA to address the specific, adverse environmental impacts identified in the SEPA Checklist or EIS.[11] If the impacts can be mitigated to an insignificant level, a mitigated determination of non-significance may be issued in lieu of an EIS.[12] Some Forest Practices Board rules articulate how DNR should exercise its authority under SEPA for particular environmental issues.[13]

B. Decisions Addressing Conditioning Authority Find DNR Has Limited, Site-Specific Conditioning Authority to Protect Public Resources.

The Pollution Control Hearings Board (PCHB) has authority to review whether DNR appropriately conditioned or failed to condition any application.[14] Although WAC 222-20-120(4) indicates that DNR "may condition the application in accordance with the plan" negotiated between a landowner and tribe, no case interprets this requirement.[15]

The PCHB and its predecessor (the Forest Practices Appeals Board) have consistently held that DNR has conditioning authority to prevent material damage to public resources.[16] These precedents draw upon DNR's statutory authority to condition applications and issue orders that prevent

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[10] WAC 197-11-360(1); WAC 197-11-402.

[11] WAC 222-10-010(4); WAC 197-11-660.

[12] WAC 197-11-350.

[13] *See* WAC 222-10-030; WAC 222-10-035; WAC 222-10-040; WAC 222-10-041; and WAC 222-10-042.

[14] *Yakama Indian Nation v. DNR*, Order Granting Summary Judgment at 4-5, FPAB No. 01-017 (2002) (denying landowner's contention that the FPAB lacked jurisdiction to review appellant Yakama's conditioning claim). The conditioning claim here concerned wildlife reserve trees and green recruitment trees. The PCHB took over the duties of the Forest Practices Appeals Board (FPAB) in 2010. Laws of 2010, ch. 210, §§ 1, 19-25. The PCHB still cites and relies on the FPAB's decisions, however.

[15] The only case mentioning WAC 222-20-120 indicates that when an operator disturbs cultural resources and failed to get an approved application, DNR is not authorized to charge the operator with civil penalties for both harvesting without an application *and* for violating the WAC 222-20-120 meeting requirement. *T.J. Henderson v. DNR*, FPAB No. 95-9, Final Findings of Fact, Conclusions of Law, and Order, Conclusion No. V (1995).

[16] *See, e.g.*, *Long v. DNR*, FPAB No 94-005, Final Findings of Fact, Conclusions of Law, and Order, Conclusion III (1994); *Confederated Bands & Tribes of the Yakama Indian Nation v. DNR*, FPAB Nos. 96-38 and 97-11, Final Findings of Fact, Conclusions of Law, and Order, Conclusion No. II (1998); and *City of Bellingham v. DNR*, PCHB No. 11-125 and 11-130, Order Granting Summary Judgment to Respondents at 17 (2012).

material damage to public resources.[17] The PCHB or a court would likely consider these prior conditioning decisions in interpreting WAC 222-20-120(4), even though there is no statutory basis for conditioning to protect cultural resources.

A few cases indicate that DNR's ability to condition applications is limited, even for the protection of public resources. In one of the cases cited above, the appellant believed that permit approvals were inappropriate when the marking of wildlife reserve trees and green recruitment trees did not occur before application approval. The FPAB determined that the pre-approval marking was not warranted because doing so would have conflicted with the legislative mandate in RCW 76.09.010(2)(d) to "promote efficiency by permitting the maximum operating freedom" to landowners consistent with the other purposes and policies in the FP Act. Given this mandate, "*any restrictive condition that is not warranted by the facts should not be lightly disregarded*."[18]

This case highlights that the purposes and policies in the FP Act are many, and even though a strong focus on public resources exists, that does not necessarily trump other legislatively established policies under the FP Act. It also highlights that in order for conditions to be valid, there must be some reason for the conditions specific to the site in question.

In a different case, DNR added conditions by a Notice to Comply after an application's approval to protect pileated woodpeckers and northern goshawk. The landowner challenged these conditions, which the FPAB struck down. The FPAB applied a narrow interpretation of what constitutes "material" damage to public resources as it concerned woodpeckers and goshawks. The FPAB found that material damage to wildlife only occurs when there is actual or potential harm to a *species*, not an individual or a pair of individuals.[19] Importantly, the FPAB determined that:

> what is "material" [damage to public resources] will vary with the facts of each case and the species at issue. In this context, the paramount concern is to ensure that the statute is interpreted consistent with its underlying policy . . . "to afford

/ / /

/ / /

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[17] RCW 76.09.050(4); RCW 76.09.080(1)(c); and RCW 76.09.090. DNR's ability to condition will be at its zenith when it implements a statutory source of authority, such as protecting public resources. As the cases below reveal, however, even DNR's ability to condition for potential harm to public resources is limited.

[18] *Yakama Indian Nation v. DNR*, Order Granting Summary Judgment, FPAB No. 01-017 (2002) (emphasis added).

[19] *Confederated Bands & Tribes of the Yakama Indian Nation v. Boise Cascade, DNR, and WDFW*, Final Findings of Fact, Conclusions of Law, and Order, Conclusion Nos. VI and VII, FPAB No. 96-38 (1998).

> protection to . . . wildlife" in a manner that is "coincident with maintenance of a viable forest products industry."[20]

These cases illustrate that DNR has limited, site-specific conditioning authority even when addressing a "public resource," a key statutory focus under the FP Act. However, "cultural resources" are not a "public resource," and the FP Act does not directly provide for the regulation of "cultural resources."

WAC 222-20-120(2) contains one mandatory duty for landowners – they must make a good faith attempt to meet to discuss a tribe's cultural resource concerns with a proposed forest practice, with the objective of agreeing on a plan for protecting the archeological or cultural value at the site. WAC 222-20-120(2) does not require the landowner to agree to a plan. That is consistent with the policies in the FP Act that promote cooperation.[21]

Whether a plan negotiated between a tribe and a landowner would be amenable to DNR's conditioning authority under the FP Act depends on the plan's contents and whether it strays from the issues regulated under the FP Act. If the negotiated plans included agreements on issues that DNR does not regulate, such as for the landowner to provide access, for the landowner to survey for archaeological resources, or for a landowner to fund a tribe's archaeological exploration, DNR conditions on those points would likely be unenforceable. DNR's application conditions must be tethered to its regulatory responsibilities under the FP Act.[22] If the plans involved protecting areas by removing them from the proposed operational area covered by the permit, this would be a permit term or condition that DNR could enforce.[23]

Outside of the Class IV-Special SEPA requirements discussed above, the Board's remaining rule structure concerning cultural resources consists mostly of voluntary measures. The use of voluntary measures follows the policies established by the Legislature in RCW 76.09.010(2) to

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[20] *Id*. at Conclusion of Law IX. The FPAB thus balanced policies among those stated in RCW 76.09.010. The words "viable forest products industry" and "afford protection to . . . wildlife" appear in RCW 76.09.010(1) and are reflected in the purposes and policies in RCW 76.09.010(2) (e.g., (2)(b) pertains to protecting public resources, while (2)(c) recognizes the public and private interest in the profitable growing and harvesting of timber).

[21] RCW 76.09.010(2)(f) and (i). Additionally, a private agreement between a landowner and tribe may be enforceable in court as a contract. A contract has potential legal consequences should performance not occur, while not all agreements have legal consequences. *Corbit v. J.I. Case Co.*, 70 Wn.2d 522, 531-37, 424 P.2d 290 (1967).

[22] Conditions on DNR-approved applications must also address specific issues, be visible to all interested parties who may review the proposal, and contain definite terms that do not require future studies or assessments. *SDS Lumber Co. v. DNR*, FPAB No. 98-5, Order Granting Summary Judgment, Conclusions of Law III, IV, and VI.

[23] *T.J. Henderson v. DNR*, FPAB No. 95-9, Final Findings of Fact, Conclusions of Law, and Order, Finding Nos. IV, IX, and XIII, and Conclusion Nos. II and III (1995) (harvests beyond permitted areas lacked approved applications and were subject to civil penalty under RCW 76.09.170).

ensure cooperation among landowners, tribes, and other public resource managers. The policies in the FP Act do not support mandatory conditioning for cultural resources.

CONCLUSION

Hopefully, this memorandum provides some guidance regarding the DNR's and the Board's authorities under the FP Act to require application conditions and will help align parties' expectations with statutory roles. Once this occurs, several options may be discussed to bring clarity to the plans developed under WAC 222-20-120 as well as the parties' various roles.

PMF:kk

Timber, Fish & Wildlife Policy Committee
Policy Co-Chairs:
Adrian Miller, Olympic Resource Management
Chris Hanlon-Meyer, Department of Natural resources

July 21, 2015

TO: Forest Practices Board

FROM: Adrian Miller, Co-Chair
Chris Hanlon-Meyer, interim Co-Chair

SUBJECT: Policy Committee Type F Progress and Path Forward

The Timber, Fish, & Wildlife Policy Committee (Policy) continues to manage an increasing workload driven by both internal process deadlines as well as priorities directed by the Forest Practices Board. To accomplish this, Policy continues to rely on additional meetings, email communications between meetings and the creation of technical and policy subgroups to address specific issues and meet deadlines.

Policy developed an initial plan in early 2014 to accomplish the Board's motions from February 2014. Soon after, the tragedy at Oso occurred leading to a re-focusing of Policy's attention to respond to the Board's motions regarding unstable slopes. It was not until late November 2014 that Policy was able to come back to Type F. As Policy refocused its efforts to respond to Board motions on Type F, we completed the following:

Policy's accomplishments in response to Board motions:
Conducted Electro-fishing workshop – January 30, 2015
Conducted off-channel habitat field trips – March 2015 (westside) and April 2015 (eastside).

TFW Policy participants continue to recognize that the existing direction from the Forest Practice Board does not comprehensively address all caucus' issues surrounding water typing. At the same time, there is a recognition that the focus on the discrete issues of "off channel habitat" and "the use of electrofishing in conducting protocol surveys" has been helpful in moving the overarching issue forward. There remains a certain amount of uncertainty about how the specific policy responses to the FPB motion will tie together as part of a comprehensive resolution on water typing.

In an attempt to assuage this uncertainty, the Co-Chairs have developed a matrix (attached) that attempts to accomplish three tasks. First, it establishes a crosswalk between discrete elements of the Forest Practice Board's motion and specific TFW Policy actions. Second, it attempts to illustrate the specific process steps that are or will be taken to implement these TFW Policy actions, including timeframes. Third, serves as a tool to capture any additional issues not specifically addressed in the Forest Practice Board's motion, and to illustrate how those issues might be integrated into a more comprehensive solution. This is not intended to be a static document, and will be updated as TFW Policy makes decisions.

The Co-chairs will provide a verbal update on progress while presenting a newly developed Type F Matrix at the Board meeting in August and anticipate using this document as a means to demonstrate progress to TFW Policy Caucus' as well as the Forest Practice Board.

There has been a procedural issue raised with TFW Policy related to where we are at in our process and if we are still operating under a consensus decision making process. The Co-Chairs are assuming that since the Forest Practice Board directed TFW Policy to undertake the elements identified in the Board's motion, that this constituted initiation of Adaptive Management. Thus, we are operating consistently with the Adaptive Management Program's process, including decision making by consensus.

TFW Policy workload is heavy, yet we must remain sensitive to the changes in various timelines and to new issues as they come up. The capacity for Policy to accept any new work as assigned by the Forest Practices Board, or taken on for other reasons, could affect our progress toward Type F conclusion. Even more, the existing priorities may require scheduling additional Policy meetings. Currently, TFW Policy is not spending focused meeting time on the following issues, although individual caucuses are working on these issues outside formal meetings to varying degrees. If these conversations result in agreements that have the potential to move a specific issue forward or when CMER projects are forwarded to TFW Policy, we will consider how to integrate those issues into our workload priorities.

- The Policy monthly workplan for 2015 includes the review and action related to CMER studies. While we are unsure exactly when these studies will come to Policy, we expect the very large Type N Hard Rock Study to be submitted in December.

- The remaining element of completing our work on Type N surrounds the development of "wet season defaults" for identifying the upper most point of perennial flow.

- TFW Policy has formed a subgroup to respond to the proposal initiation related to a westside template for small forest landowners. This work is being conducted outside of TFW Policy meetings, however, we are receiving updates as a group.

DRAFT-----TFW Policy Committee----DRAFT

Type F Matrix - Board Motion to Completion

7/21/2015

Policy Priority in addition to Board Motion | Next Step/Pending | Final Action/Product/Target Date TBD | Completed | Policy Action/Decision

Board Motion Language		Board Motion/Task	Status/Plan/Assignee	Target Date	Intermediate Task/Assignee	Target Date	Outcome/Product/Decision maker	Process Informed	Target Date	Final Policy Recommendations	Target Date
1. Policy is directed to complete recommendations for options on a permanent water typing rule, beginning with two tasks to be completed and reported to the Board at the May, 2014 meeting:	1.a. Development of "best practices" recommendations regarding protocol survey electrofishing, including an evaluation of relevant literature, minimizing potential site-specific impacts to Incidental Take Permit covered species, and options for reducing the overall extent of the surveys' use.	Protocol E-fishing lit synthesis	Policy, with the support of the AMPA, convenes a technical group of practitioners with representation from caucuses to identify best practices regarding electrofishing within the context of protocol surveys (including a literature synthesis), including: • How to reduce site-specific impacts of practices of protocol survey electrofishing • How to reduce overall extent of the surveys' use.	Aug-15	Cochairs and AMPA present technical group product to Policy to include identification of any gaps in science and any areas of suggested focus in order to identify or address BMPs, methods to minimize survey's use and site specific impacts to ITP species.	Dec-15	Policy take action to propose rule change (may include a proposal initiation that results in new research, a look past research findings, or a policy analysis); guidance change (may include a change in guidance on protocol surveys or how e-fishing is used) or create new training.	Potential: Policy and/or science track (Proposal Initiation response from AMPA); Board Manual changes; training development		For each element moving through the adaptive management process, TFW Policy will have to decide first if we want to take action in response to the information provided by the adaptive management process. Presuming that TFW Policy agrees to take action in response to that information; this could include recommending rule changes, board manual guidance, agency process changes (with concurrence from the agency), additional scientific review, or any combination thereof. TFW Policy may also identify additional issues related to this topic outside of the scope of the original Board motion and will be developing a workplan for those issues consistent with the adaptive management program.	
		Evaluation of Lit Synthesis Protocol Survey E-Fishing BMPs Minimize potential site specific impacts to ITP species Options for reducing overall extent of survey's use	Policy reviews a draft technical group workplan whi will include a list of the documents that the technical group will review/consider and also those suggested by Policy that they consider irrelevant Policy will approve the technical group's workplan with any edits necessary.	Sep-15	Policy Consider recommendations from tech group and refine path forward for each (i.e. proposal initiation; propose Board Manual change; suggest areas of needed training	Feb-16					
		Understanding the use of protocol surveys/Electro Fishing	Conduct a TFW Policy electrofishing workshop to understand the current use of protocol surveys and how electrofishing is being used.	Feb-15							
			WDFW, USFWS, NOAA present the current scientific collection permit process and how E-fishing is permitted.	Jul-15	AMPA work with WDFW, USFWS, NOAA identify potential data sharing opportunities and process to get data from scientific collection permit reports to help develop, confirm, inform model, map and protocol development/assessment	Oct-15					
	1.a.i Not Part of Board Motion - Confirm Physical criteria as habitat and define Recoverable Habitat using physicals	Assess the accuracy and limitations of physical habitat defaults in predicting fish use	Create new technical workgroup; conduct literature review and field dicussions as needed	Nov-15	Identify potential data or research gaps; propose further action to fill gaps to Policy		Policy determine if physical criteria needs to change; determine if rule or Board Manual need to change;				
	1.b. An evaluation of the current rule process to identify off-channel habitat (OCH) under the interim water typing rule, including recommended clarifications in field implementation guidance, or rule language. The evaluation must be based, in part, on field review of approved FPAs and WTMFs.	Evaluate current rule process to id OCH	Policy field tours on westside and eastside to see OCH protection in practice;	Apr-15	DNR has developed a proposal review packet with discussion and input from Policy, to move OCH discussions into a formal procedure with timelines.		Policy conducts stage 2: development by track; administrator assessment and synthesis; Policy recommendations; Identify any need to initiate additional scientific review; Determine which proposed changes are unaffected by the need for additional scientific review and which require the creation of a TWIG to propose approach to answering specific Policy questions				
		Recommend clarifications in field implementation, guidance and/or rule	Policy review the existing guiding language in Act, Rule, and FFR establishing bankfull width and depth to calculate the edge of the stream and OCH, and the start of the riparian management zone	Oct-15							
		Field review of approved FPAs and WTMFs.	Perform field reviews of approved FPAs and water type mod. forms; visits to determine if this description adequately covers off channel habitat as currently described in rule.	Apr-15							
			Review the existing science based definitions of OCH connected at bankfull elevation as intended in the forest practices rules and the FFR	Oct-15							
			Review OCH description developed during Policy field site visits to determine if it adequately covers OCH as described in rule	Apr-15							
2. AMPA to scope and initiate a pilot project to re-run the existing hydrologic model using LiDAR data, including at least two watersheds (west and east). Objectives include:	2.a. Develop quantitative information about the "footprint" of the interim rule;	Work with GIS experts to develop a scope of work to compare a 10 m DEM and a 2 m DEM that is LiDAR based to evaluate potential improvements of a water typing model.	Execute a contract that compares the original water type model (10 m DEM) to a 2 m LiDAR based DEM in two basins (east and west).	Oct-15			Create Draft GIS hydrography map (based on an updated model) using best available data.	As determined: Develop, revise, and/or update a water-typing model in accordance with the HCP and on which to base the rule of identifying Type F waters.			
	2.b. Compare model-based water type designations to on-the-ground FPAs and WTMFs;		Execute a contract that compares the original model (10 m DEM) and LiDAR based 2 m DEM (see above) with biological survey results from WTMFs.	Oct-15			Identify the technical issues related to the use of the model and map. Twig/Technical group review of model/map issues.				
	2.c. Investigate additional model utility, such as detection of OCH, ability to predict physicals and assess footprint effects from using different physicals;		Test a LiDAR 2 m DEM in the two basins (east and west) to determine if OCH can be predicted. Follow up initial pilot work with field evaluation of physical habitat. Compare field data with remotely sensed data to determine if physical criteria can be predicted.	Dec-15			Determine if further changes are needed to the Water Typing System.	Water Type Modification Process			
	2.d. Provide information that can inform the Board's basic administrative choices among "map-as-rule" vs. "guidance map with field adjustments".	Collate electrofishing work and model results to evaluate options to inform an approach for water typing.	Following the pilot LiDAR evaluation and electrofishing BMP work, a group of practitioners and scientists will need to make recommendations to TFW Policy for review of options for the Board.	May-16							

WASHINGTON STATE DEPARTMENT OF
Natural Resources

PETER GOLDMARK
Washington State Commissioner of Public Lands

MEMORANDUM

July 30, 2015

TO: Forest Practices Board

FROM: Hans Berge, Adaptive Management Program Administrator

SUBJECT: Wetland reports to guide CMER research and monitoring projects

CMER (Cooperative Monitoring, Evaluation, and Research) completed two important reports that together form the basis of the best available science to guide an assessment of forest practices in and around wetlands. Both of these reports were authored by Dr. Paul Adamus and are titled:

1. ***Effects of forest roads and tree removal in or near wetlands of the Pacific Northwest: a literature synthesis***

2. ***Wetland research and monitoring strategy: forest practices and wetlands***

These two products are complimentary in directing a wetland research strategy for CMER that is based on the best available science from an extensive literature review with direction provided by the strategy. Although these two reports focus on directing future research, each have important findings in their own right.

Literature Synthesis

The literature synthesis includes the review of over 600 publications with relevance to forest practices and wetlands. One key finding of the literature synthesis is highlighting the lack of research related to wetlands and forest practices. Because of the paucity of wetland specific research in forested areas of the Pacific Northwest, much of the material in the report heavily relied on research related to stream and riparian zones. Dr. Adamus used his experience and best professional judgment to make connections between forest practices and processes and functions in riparian zones that influence wetlands. The literature review covered many important topics including hydrology, water quality, nutrients, chemicals, soils, and habitat for fish and wildlife.

Research and Monitoring Strategy

The intent of the wetland research and monitoring report was to provide guidance to CMER in defining how resource objectives for wetlands and wetland functions are being affected by the application of the forest practice rules. Specifically, the research strategy prioritizes projects to evaluate interactions of forest practices and water temperature, hydrologic connectivity, and wetland management zone effectiveness.

The four studies recommended in the report for immediate consideration in order of priority are as follows:

A1. Effects of Timber Harvest That Occurs Within Forested Wetlands*:*
Effects on forested wetland water regime, water quality, vegetation, fish and wildlife, and connectivity to downgradient and upgradient waters.
A2. Effects of Timber Harvest That Occurs Outside of Wetlands*:*
Effects on wetland water regime, water quality, vegetation, fish and wildlife, and connectivity to downgradient and upgradient waters.

B. Effects of Forest Roads Near Wetlands:
Effects of roads located upgradient and downgradient of wetlands on wetland water regime, water quality, vegetation, fish and wildlife, and connectivity to downgradient and upgradient waters.
An additional and separate project considered of lower immediate priority is:

C. Effects of Applying Silvicultural Chemicals In or Near Wetlands

<u>Summary</u>
In conclusion, both of these reports help frame the research priorities for CMER in moving forward to evaluate the effectiveness of forest practices in protection public resources. Both of these documents are already being integrated into the work of the Wetland Technical Writing and Implementation Group (TWIG) as well as the Wetland Scientific Advisory Group (WetSAG).

HB/

Effects of Forest Roads and Tree Removal In or Near Wetlands of the Pacific Northwest: A Literature Synthesis

By:
Paul Adamus, Ph.D.

WASHINGTON STATE DEPARTMENT OF
Natural Resources
PETER GOLDMARK - Commissioner of Public Lands

December 2014

CMER #12-1202

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Washington State Forest Practices Adaptive Management Program

The Washington State Forest Practices Board (FPB) has established an Adaptive Management Program (AMP) by rule in accordance with the Forests & Fish Report (FFR) and subsequent legislation. The purpose of this program is to:

> *Provide science-based recommendations and technical information to assist the FPB in determining if and when it is necessary or advisable to adjust rules and guidance for aquatic resources to achieve resource goals and objectives. The board may also use this program to adjust other rules and guidance.* (Forest Practices Rules, WAC 222-12-045(1)).

To provide the science needed to support adaptive management, the FPB established the Cooperative Monitoring, Evaluation and Research (CMER) committee as a participant in the program. The FPB empowered CMER to conduct research, effectiveness monitoring, and validation monitoring in accordance with WAC 222-12-045 and Board Manual Section 22.

Report Type and Disclaimer

This technical report contains scientific information from research or monitoring studies that are designed to evaluate the effectiveness of the forest practices rules in achieving one or more of the Forest and Fish performance goals, resource objectives, and/or performance targets. The document was prepared for the Cooperative Monitoring, Evaluation and Research Committee (CMER) and was intended to inform and support the Forest Practices Adaptive Management program. The project is part of the Eastside Type F Riparian Effectiveness Program, and was conducted under the oversight of the Riparian Scientific Advisory Group (RSAG).

This document was reviewed by CMER and was assessed through the Adaptive Management Program's independent scientific peer review process. CMER has approved this document for distribution as an official CMER document. As a CMER document, CMER is in consensus on the scientific merit of the document. However, any conclusions, interpretations, or recommendations contained within this document are those of the authors and may not reflect the views of all CMER members.

The Forest Practices Board, CMER, and all the participants in the Forest Practices Adaptive Management Program hereby expressly disclaim all warranties of accuracy or fitness for any use of this report other than for the Adaptive Management Program. Reliance on the contents of this report by any persons or entities outside of the Adaptive Management Program established by WAC 222-12-045 is solely at the risk of the user.

Proprietary Statement

Full Reference

Adamus, Paul Ph.D. 2014. Effects of Forest Roads and Tree Removal
In or Near Wetlands of the Pacific Northwest: A Literature Synthesis. Cooperative Monitoring Evaluation and Research Report CMER 12-1202. Washington State Forest Practices Adaptive Management Program. Washington Department of Natural Resources, Olympia, WA.

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Effects of Forest Roads and Tree Removal In or Near Wetlands of the Pacific Northwest: A Literature Synthesis

December 2014

Prepared for:

The State of Washington
Forest Practices
Adaptive Management Program
Department of Natural Resources
Personal Service Contract #11-350

Prepared by:

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Effects of Forest Roads and Tree Removal In or Near Wetlands of the Pacific Northwest: A Literature Synthesis

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December 2014

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Appendices [in separate document]

A. Suggested Hypotheses and Strategy Options for Selecting Research Sites

B. Suggested Metrics and Parameters for Quantifying Forest Practice Effects on Wetland Functions

C. Equipment or Procedures Potentially Useful for Quantifying Forest Practice Effects on Wetland Functions

1.0 Introduction

In the Pacific Northwest, hundreds of studies over the past three decades have focused on the effects of timber harvests and logging roads on the functions and species in *streams*. However, few studies have examined the effects on *wetlands*. Selected studies covering this topic in the Pacific Northwest were described by Cooke Scientific Services (2005) under contract to the Cooperative Monitoring Evaluation and Research Committee/Wetland Scientific Advisory Group (CMER/WETSAG). Elsewhere in North America, literature on the effects of forest practices on wetlands in the southern United States was reviewed in part by Shepard (1994), Aust (1994), Conner (1994), Sun et al. (2001), and others, whereas much of the literature on forestry impacts to wetlands in Canada was reviewed by Smith et al. (2007). The very limited literature on forestry impacts to lakes of the Pacific Northwest (mainly British Columbia) was compiled by Miller (1997).

Because studies of forestry effects on wetlands have been so infrequent in the Pacific Northwest, each section in this report drew heavily from studies of forestry impacts to streams and riparian zones. After assembly and synthesis, that information was extrapolated, mostly in the form of hypotheses (Appendix A), to the very different conditions known to be present in the region's wetlands. Inferences were based largely on the author's knowledge of wetland functions and decades of experience as a wetland scientist in this region. In a similar manner, information from pertinent studies of the region's wetlands was used to hypothesize the possible effects of forest practices on wetlands even when a particular study did not specifically address the separate effects of timber harvests, logging roads, or silvicultural chemicals. As such, this study provides an initial framework for considering how to examine the reality and perhaps the extent of those effects.

1.1 Scope of the Synthesis

In the context of wetlands, this report addresses the physical, chemical, and biological effects of diverse forest practices. These effects may be the direct or indirect result of tree removal (i.e., logging, timber harvest), roads and other infrastructure created in support of logging operations, or use of silvicultural chemicals. Where possible, the separate effects of these are distinguished, and with regard to both their magnitude and duration. Within the category of "tree removal," effects resulting from clear-cutting of trees are distinguished from effects of partial (selective) harvests, as available information allows. This report addresses not only the effects of cutting trees within forested wetlands (i.e., the effects of on-site harvests), but also the effects on wetlands -- of any type -- where timber is harvested in nearby uplands (i.e., the effect of off-site harvests). In many cases, the effects of both on-site and off-site harvests depend on wetland type, so distinctions among effects based on wetland type are noted when supported by available science (see section 1.3 for brief description of wetland classifications used). Effects of off-site harvests on wetlands also depend on the width and other characteristics of wetland ***buffers*,** also called streamside, riparian, or wetland management zones (SMZ's, RMZ's, WMZ's), filter strips, setbacks, or streamside/ riparian reserves. These are areas in which existing vegetation generally remains unharvested as one means of potentially reducing the potentially adverse effects of harvesting trees or other land uses on nearby water bodies. This report reviews the literature on the effectiveness of buffers as it may pertain to wetlands in forested areas of this region. Geographically, this report defines the Pacific Northwest (PNW) region as Oregon, Washington, British Columbia, and Southeast Alaska. To a lesser extent, studies from other western states and provinces along the U.S.-Canada border were considered, as well as (to a lesser degree) studies from more easterly states and provinces along the border. Those studies were accorded lower priority for review because of limited time and resources for this review, and because their flora and fauna differ significantly from that in the Pacific Northwest.

1.2 Role of the Synthesis

In this region, most natural resource agencies have adopted rules or recommendations regarding whether and under what circumstances (season, wetland sizes and types, geomorphic settings, types of buffers, equipment, harvest methods, etc.) timber harvests and road-building may occur in or near streams and/or wetlands. This report is intended to capture the best available science on its topic in this region. It is not intended to be a review of the technical adequacy of any specific regulation or rule in the State of Washington (WAC 222-16-035, -036, and others) or elsewhere. Information on some of the forest practices regulations in this region and compliance monitoring associated with those has been compiled and compared by Broadmeadow and Nisbet 2004, Michael 2004, Adams 2007, Council of Western State Govenors 2007, Tschaplinski and Pike 2010, and others.

1.3 Wetland Classes and Categories

As noted above, effects of forest practices on wetlands -- and consequently selected regulations that govern those practices -- depend partly on wetland type. That is because (1) wetlands differ with regard to their functions and the factors that determine those, and (2) wetlands appear to differ with regard to their sensitivity (resilience and resistance) to various components of forestry operations, although data from this region are limited. Many schemes have been devised for scientifically classifying or administratively categorizing wetlands in this region (see review: Adamus 2004). The three referred to in this report are those used most often by agencies in Washington or the Pacific Northwest:

1. State of Washington Forest Practices Code

The Code categorizes wetlands administratively as Forested Wetland, Bog, Type A, or Type B. Depending on category, they must be ¼ or ½ acre in extent in order to be subject to forest practices rules. *In brief*, **Forested** wetlands are any wetland or portion thereof that has (or would have, if the trees were mature) tree cover with a crown closure of 30% or more. **Bogs** are wetlands with organic soils and ground cover usually dominated by mosses, but sometimes by other woody or herbaceous plants named specifically in the Code. **Type A** wetlands are herbaceous wetlands on the fringes of ponds, lakes, or rivers that contain surface water for at least 7 consecutive days between April 1 and October 1. **Type B** wetlands are all other herbaceous wetlands.

2. Cowardin et al. (1979) Classification

This is a scientific classification used in the maps of the National Wetlands Inventory. It has many hierarchical levels that describe a wetland's major system (estuarine, lacustrine, riverine, palustrine), vegetation forms (e.g., emergent, scrub-shrub, forested), and water regime (e.g., permanently flooded, saturated, seasonally flooded). Under this classification, most wetlands categorized as Forested under the Washington Code (above) would be classified as Palustrine Forested or Palustrine Scrub-shrub. Most wetlands categorized as Bogs under the Washington Code would be classified as Palustrine with a Saturated water regime modifier under this classification, but not necessarily vice versa. Wetlands belonging to Type A or Type B belong to the Cowardin Emergent class, but cannot be assigned to a Cowardin system (e.g., riverine, Palustrine, Lacustrine, or Estuarine) without further information. All wetlands that the Cowardin classification describes as Lacustrine would be categorized as Type A wetlands by the Washington Code, but many other wetlands would be as well.

3. Hydrogeomorphic (HGM) Classification

This scientific classification (Brinson 1993, Table 1) emphasizes the predominant source of water to a wetland (groundwater, runoff, or direct precipitation), its direction (unidirectional or bidirectional), presence and direction of flow, and geomorphic setting (connected or isolated from other surface waters). Major classes are estuarine, riverine, lacustrine, depressional, slope, and flat. The first three of these do not correspond perfectly with their same-named classes in the Cowardin classification. Wetlands categorized as Forested under the Washington Code occur in all of these HGM classes (but are rare in the HGM estuarine class). Most wetlands categorized as Bogs under the Washington Code would be classified as flats or slope wetlands, or perhaps depressional. Nearly all wetlands that the HGM classification describes as lacustrine or riverine would be categorized as Type A wetlands by the Washington Code, but many other wetlands would be as well.

Because they are based on hydrology, vegetation, and water chemistry, none of these three classifications correlate directly with wetland use by fish and wildlife. Thus, if these classifications alone are used as the basis for regulations, they may be suboptimal for protecting the diversity of native fish and wildlife species. In such instances, the complementary use of additional classifications (e.g., stream typing, as defined in Washington State by WAC222-16, or hydrologic landscape classification – Wigington et al. 2013) may be helpful. Similarly, a random selection of research sites stratified only by HGM class and subregion will likely fail to optimally address the variability in wetland use among different wildlife and fish species.

Table 1. Definitions of hydrogeomorphic (HGM) classes of wetlands, as interpreted from Brinson (1993), Smith et al. (1995), and Adamus (2001)

Hydrogeomorphic Class	**Water Sources***	**Flow Direction**	**Examples**
Riverine	runoff> groundwater> precipitation	Unidirectional (channels) & bidirectional (floodplain)	Wetlands along streams, rivers, ditches with flowing water.
Depressional	runoff> groundwater> precipitation	Vertical (seepage)	Wetlands in ponds, potholes. Often in headwaters.
Mineral Soil Flats	precipitation > groundwater> runoff	Vertical (seepage)	Vernal pools. Usually lack natural outlets.
Organic Soil Flats	precipitation > groundwater> runoff	Vertical (seepage)	Bogs, some fens.
Slope	groundwater> runoff	Unidirectional, horizontal	Swales, stream headwaters.
Lacustrine Fringe	runoff> precipitation > groundwater	Bidirectional (seasonal overflow), horizontal	Wetlands along lakes (>20 acres)
Estuarine Fringe	ocean> runoff> groundwater	Bidirectional (from tide), horizontal	Salt marshes, tidal swamps.

* "runoff" is surface flow from catchment, "groundwater" is lateral or vertical subsurface flow. These rankings are not quantitative and in any given wetland, they may change seasonally and interannually.

1.4 Endpoints: Wetland Functions and Wetland Condition

The focus of this review is primarily on impacts to wetland ***functions*** because functions are the endpoints most commonly identified for protection in Washington wetland regulations. Functions are what wetlands potentially do, such as store water and other natural processes, regardless of how much those processes directly affect humans. However, because wetlands have hundreds of potential functions, judgment was exercised in selecting *which* functions (and their level of aggregation) were to be the focus of this review. An explicit decision was made to focus on the hydrologic (water regime), water quality (sediment, phosphorus, nitrate, carbon), microclimate-sustaining, and habitat-supporting (for wetland plants, invertebrates, amphibians, turtles, wetland birds and mammals, fish) functions. This was done largely because these are the functions, and the level of function aggregation, recognized by the Washington Department of Ecology and many other agencies when addressing wetland issues.

Another endpoint is wetland ***condition***. That describes a particular state, usually one defined by features that are specified by the investigator. Wetland condition is often used interchangeably with terms such as wetland health, integrity, quality, or intactness, all relative terms that carry considerable definitional ambiguity.

Despite popular perceptions, high-functioning wetlands are not always considered to be in good condition and wetlands believed to be in good condition are not always high-functioning. This is true for at least three reasons (De Leo and Levin 1997, Hruby 1999, McLaughlin and Cohen 2013) : (1) There exists no widely-accepted scientific definition of what wetland conditions should be, (2) There exists no widely-accepted scientific protocol for measuring wetland condition comprehensively (all taxa and processes, or using fewer taxa or processes known to correlate with all others), and (2) No single wetland, regardless of how intact or pristine it may be, can provide all functions at their highest potential level because many wetland functions operate naturally in opposing directions.

With regard to reasons #1 and #2, no scientific consensus exists as to which individual or combined processes (primary productivity? sedimentation rates?), biological group or groups (birds? plants? microbes? algae?), or metrics (species richness? stem density? tolerance indices?) most accurately represent a wetland's ecological condition Although some processes, taxonomic groups, and/or metrics often respond in a similar direction to pollution, habitat alteration, and other stressors (e.g., Rooney & Bayley

2012), in other cases the responses show little concordance. That may depend on which contaminant or type of habitat alteration (or their combination) is locally dominant, its intensity, compensatory factors such as natural resilience and resistance of some types of landscapes, the scale of measurement, and other factors difficult to predict beforehand. Thus, although some groups (notably plants) and metrics (percent cover of exotic species) are used to represent what the authors who study them believe is wetland ecological condition (typically assuming the absence of human influence is synonymous with the best ecological condition), no research has shown that PNW wetlands that support (for example) a rich variety of native plants also support a rich variety of fish, aquatic invertebrates, microbial communities and processes, waterbirds, etc. Amphibians, microbes or other taxa may respond to pollution and habitat alteration quite differently than plants, in some unknown proportion of the wetlands. It also is likely that their separate response to pollution and habitat alteration is indistinguishable, without using prohibitively large sample sizes, from their response to natural variation. An impoverished fish community, for example, might be the result of limited wetland connectivity with other waters rather than pollution, and reduced functional diversity of microbes could be the result of naturally cloudy or acidic waters. Many instances of "disturbance" to wetlands (if that can be defined objectively) exist that result in sustainable increases, not decreases, in levels of some native wetland species and functions.

With regard to the second point made at the beginning of this section – that no single wetland, regardless of how pristine it may be, can support *all* functions at a high level because many wetland functions operate naturally in opposing directions – this is supported by several analyses of field data (e.g., Hansson et al. 2005, Adamus et al. 2009, Acreman et al. 2011). For example, wetlands most effective for storing water (such as those with naturally large water level fluctuations) are not necessarily the most effective for functions such as supporting pollinating insects or habitat for wetland plants. Similarly, wetlands most effective for supporting fish are not necessarily the most effective for supporting amphibians and aquatic invertebrates (which are preyed upon by fish in diverse circumstances). Thus, it is misleading to describe a wetland as having "high function" or being "highly functional" without specifying the function or combination of functions to which one is referring.

In summary, although *generally* high levels of many wetland functions can be expected to correlate positively with *generally* high levels of ecological condition (intactness, integrity, health, etc.), a *causal* connection has never been proven and should not be automatically assumed. Any correlation will depend on how functions and indicators of condition are measured, the types of stressors to which particular wetlands are being exposed, spatial variation of natural factors within the landscape, and other influences.

1.5 Wetlands in Forests of the Pacific Northwest

Forested wetlands are likely the type of wetlands most often subject to on-site or off-site tree harvest. In 2004, a survey of the bankfull zone of headwater streams in 30 watersheds in the Washington Coast Range (Janisch et al. 2011) revealed an average of 2.3 wetlands per first-order channel. All were smaller than 0.1 ha and occurred mainly where (a) their contributing areas were north-facing, (b) surface water was perennial, and/or (c) channels contained large wood originating from adjacent riparian forest. About 40% of the channels surveyed were sourced by a channel-head wetland. Several wetlands were associated with streamside topographic depressions left by root balls of toppled trees. As they rapidly fill with water and fine sediments, those depressions may facilitate wetland formation. The authors commented:

> "Were our sample representative, every 1000 such catchments would support, on average, ~19 ha of wetlands not typically surveyed. Given that river miles of headwaters greatly exceed that of mainstem rivers, headwater wetland area could, in rugged topography, rival or exceed that of lowlands. Whether wetland area or stream area dominates headwater catchments is thus a key question."

Yet, nearly all studies of the hydrology of headwater catchments have focused only on channels, not on wetlands. Ecologically, the influence of these tiny wetlands could be significant. For example, headwater wetlands one-third of an acre or less (< 1,335 m^2) can increase the duration and magnitude of stream discharge as well as affect stream chemistry and fish access, particularly during periods of base flow (Morley et al. 2011).

Several publications have described in detail the plant community composition of wetlands in parts of the Pacific Northwest, in some instances organizing the information as a vegetation-based classification. Examples are Murray 2000, MacKenzie and Banner 2001, MacKenzie and Shaw 1999, MacKenzie and Moran 2004, Christy 2004, Crowe et al. 2004, Kovalchik and Clausnitzer 2004, Wells 2006, and Rocchio et al. 2012. What follows is a very general listing of some of the major plants found in forested wetlands in all or part of the PNW region. These descriptions set the stage for discussions of forestry impacts to wetlands later in the report.

Conifer **trees** occurring as dominants in the region's forested wetlands are, perhaps most frequently:
western hemlock (*Tsuga heterophylla*), western red-cedar (*Thuja plicata*), Sitka spruce (*Picea sitchensis*), Engelmann's spruce (*Picea engelmannii*), and (primarily in bogs) lodgepole pine (*Pinus contorta*). Often, the deciduous species occurring as dominants in the region's forested wetlands are willow (*Salix* spp.), alder (*Alnus* spp.), black

cottonwood (*Populus trichocarpa*), Oregon ash (*Fraxinus latifolia*), quaking aspen (*Populus tremuloides*), and paper birch (*Betula papyrifera*). Douglas-fir (*Pseudotsuga menziesii*), which dominates forests and timber harvesting in much of the western part of the region, is not a typical dominant in the region's wetlands. In the PNW, most forests next to streams and wetlands include more deciduous trees, fewer conifers (though sometimes with equal or higher basal area), a more open canopy, more berry-producing shrubs, and fewer evergreen shrubs than adjacent upland forest (Pabst and Spies 1999, Pearson and Manuwal 2001). Wetlands at lower elevations tend to be dominated by deciduous trees and shrubs to a greater degree than wetlands at higher elevations.

In western parts of the region, native **shrubs** that are dominant in forested wetlands are, perhaps most often: salmonberry (*Rubus spectabilis*), snowberry (*Symphoricarpos albus*), elderberry (*Sambucus racemosa*), red osier dogwood (*Cornus sericea*), hardhack (*Spirea douglasii*), black hawthorn (*Crataegus douglasii*), western crabapple (*Malus fusca*), willow (*Salix* spp.), and alder (*Alnus* spp.). In forested wetlands of Southeast Alaska, blueberries (*Vaccinium* spp.), several native berries (*Rubus* spp.), and devil's club (*Oplopanax horridum*) are frequent dominants.

Native herbaceous plants that often dominate the understory of forested wetlands in the western part of the Pacific Northwest commonly include: slough sedge (*Carex obnupta*), skunk cabbage (*Lysichitum americanum*), stinging nettle (*Urtica dioica*), touch-me-not (*Impatiens* spp.), and Pacific golden saxifrage (*Chrysosplenium glechomifolium*). In coastal British Columbia and Southeast Alaska, bluejoint reedgrass (*Calamagrostis canadensis*) and several moss and sedge species dominate many wetlands.

Several plants not originally native to the Pacific Northwest have invaded many of the region's forested wetlands. Non-native **shrubs and vines** that are perhaps the most widespread invaders of the region's forested wetlands include Himalayan blackberry (*Rubus armeniacus*), cut-leaf blackberry (*Rubus laciniatus*), climbing nightshade (*Solanum dulcamara*), and English ivy (*Hedera helix*). However, these species do not tolerate inundation or saturated soils for long and thus seldom become dominant throughout any forested wetland. In western Oregon and Washington, non-native **herbaceous** species that are perhaps the most widespread and dominating invaders of wetlands in forested landscapes include reed canary-grass (*Phalaris arundinacea*), Canada thistle (*Cirsium arvense*), creeping bentgrass (*Agrostis stolonifera*), creeping buttercup (*Ranunculus repens*), bird vetch (*Vicia cracca*), garden vetch (*Vicia sativa*), scented bedstraw (*Galium odoratum*), and giant knotweed (*Polygonum sachalinense*).

2.0 Literature Synthesis Methods

2.1 Identifying and Prioritizing Sources

A systematic literature synthesis was conducted, generally following the steps described by Pullin and Stewart (2006):

1. Formulate questions
2. Define and implement a literature search strategy
3. Index and prioritize the identified literature
4. Read and extract key information
5. Synthesize the information, partly by identifying connections among subtopics
6. Peer review

The first step – formulating the main questions – was completed by the WETSAG prior to project start-up. Those questions are shown in Table 2.

Table 2. Main questions to be addressed by this literature synthesis (from WETSAG)

Water Regime Questions 1. What are the potential effects from clear-cutting wetlands, and the magnitude and duration of those effects on the water regime of wetlands? • What factors (For example: wetland soils, HGM type, timing of clear-cut, location of wetland in the watershed) affect the magnitude and duration of the hydrologic response? • How do these hydrologic changes affect the opportunity and potential[2] of wetlands to maintain fish and amphibian habitat and productivity in a watershed? 2. What are the potential effects from partial harvesting of wetlands, and the magnitude and duration of those effects on the water regime of wetlands? • What factors (For example: wetland soils, HGM type, timing of partial harvest, location of wetland in the watershed) affect the magnitude and duration of the hydrologic response?

[2] Hruby, T. 2004. Washington State wetland rating system for western Washington – revised. Washington State Department of Ecology Publication # 04-06-025, pg. 32-35. The DOE rating system defines "Potential" as using structural wetland characteristics as indicators of the capability or "potential" of a wetland for performing a function. "Opportunity" is defined as the second part in characterizing the wetland function by characterizing to what degree a wetland's position in the landscape will allow it to perform a specific function. Opportunity and potential are both integral parts of the DOE rating system for rating wetland functions.

- How do these hydrologic changes affect the opportunity and potential of wetlands to maintain fish and amphibian habitat and productivity in a watershed?

3. What are the potential effects of road construction and maintenance activities in/or adjacent to wetlands, and the magnitude and duration of those effects on the water regime of wetlands?

What factors (For example: wetland soils, HGM type, timing of road construction, location of wetland in the watershed, location of road relative to wetland and other aquatic resources) affect the magnitude and duration of the hydrologic response?

- How do these hydrologic changes affect the opportunity and potential of wetlands to maintain fish and amphibian habitat and productivity in a watershed?

Water Quality Questions

4. What are the potential effects of clear-cutting wetlands, and the magnitude and duration of those effects on the water quality (temperature, suspended sediment, nutrient loads, pH, dissolved oxygen, toxicity) of wetlands?

- What factors (For example: wetland soils, HGM type, timing of clear-cut, location of wetland in the watershed) affect the magnitude and duration of the water quality response?
- How do these changes in water quality affect the opportunity and potential of wetlands to maintain fish and amphibian habitat and productivity in a watershed?

5. What are the potential effects of partial cutting, and the magnitude and duration of those effects on the water quality (temperature, suspended sediment, nutrient loads, pH, dissolved oxygen, toxicity) of wetlands?

- What factors (For example: wetland soils, HGM type, timing of partial harvest, location of wetland in the watershed) affect the magnitude and duration of the water quality response?
- How do these water quality changes affect the opportunity and potential of wetlands to maintain fish and amphibian habitat and productivity in a watershed?

6. What are the potential effects from road construction and maintenance activities in/or adjacent to wetlands, and the magnitude and duration of those effects on the water quality (temperature, suspended sediment, nutrient loads, pH, dissolved oxygen, toxicity) of wetlands?

- What factors (For example: wetland soils, HGM type, timing of road construction, location of wetland in the watershed, location of road relative to wetland and other aquatic resources) affect the magnitude and duration of the water quality response?
- How do these water quality changes affect the opportunity and potential of wetlands to maintain fish and amphibian habitat and productivity in a watershed?

Wetland Management Zone Question

7. What are the effects of leaving buffers around wetlands on maintaining wetland functions that sustain fish, amphibians and water quality?

Cumulative Effects Questions

8. What are the potential cumulative effects (spatial and temporal) of clear-cutting wetlands on watershed processes that support fish, amphibians and water quality?
9. What are the potential cumulative effects (spatial and temporal) of partial harvesting wetlands on watershed processes that support fish, amphibians and water quality?
10. What are the potential cumulative effects (spatial and temporal) of constructing and maintaining roads in/or adjacent to wetlands on watershed processes that support fish, amphibians and water quality?

Parameters and Metrics
11. What parameters and metrics can be used to assess, evaluate and quantify the effects of forest practices on the water regime and water quality of wetlands, and fish and amphibian productivity and use of wetlands?

Although those questions were essential to guiding the synthesis and all are addressed in this document, they were slightly re-organized in the presentation of this document. Specifically, clear-cutting and partial cuts were combined into "Tree Removal Effects" subsections because of the unfortunate paucity of studies that have distinguished their effects. Nonetheless, when information that distinguished the effects of these was available, it was highlighted in the narratives. Questions above that are related to "how changes affect the opportunity and potential of wetlands to maintain function ___" as well as the questions about cumulative effects are discussed (when information allows) mostly in subsections titled "Biological Effects of [type of forest practice]." The question on Wetland Buffer Management Zone effectiveness is treated separately within each major chapter (Water Regime, Water Quality, and Microclimate-Vegetation-Animals).

At the project outset, a database was created in Excel® for references that might be included in this synthesis. The database was selectively populated with citations of publications from the literature cited sections of several prior syntheses on related topics. The synthesis reports were searched manually for citations that appeared useful based on their titles, and included (for example): Adamus et al. (2001), Cooke Scientific Services (2005), and Pike et al. (2010).

Next, sets of keywords were identified in three categories: Wetlands, Forest Practices, and Geography. Over a dozen synonyms or closely related terms were included in the Wetlands category, including (for example) swamp, marsh, bog, fen, riparian, pond, off-channel, seep, amphibian, and waterfowl. Terms in the Forest Practices category included (for example): logging, forest road, clearcut, timber harvest, partial harvest, buffer, herbicide, and fragmentation. Geographic terms were applied that define the states, provinces, and major features (e.g., Cascades) of the Pacific Northwest, and secondarily other states and provinces near the U.S.-Canada border. Research on the effects of forest practices on wetlands in the southern United States was not reviewed because of the need to prioritize the literature reviewed, due to time and resource limitations, as well asdifferences in climate, topography, species, and wetland types of the PNW increase the level of uncertainty when extrapolating between these regions.. Likewise, research on forested wetlands in the more northerly boreal regions of Canada and Alaska, where artificial drainage of peat soils is often a prerequisite for timber harvest, was mostly excluded.

Initially, the automated keyword search tool that was used was the online bibliographic database, *Web of Science*®. It allows complex Boolean querying of its millions of listings that go back several decades, and provides abstracts from most of the journals it references. Several queries of *Web of Science*® using the chosen keywords resulted in a list of over 5000 papers and reports. By manually reviewing the title of each of these (and where necessary, reading the abstract), the principal investigator narrowed the list to about 800 citations. These were added to the Excel® database of citations selected previously from the prior syntheses (as described above) and duplicates were eliminated.

2.2 Indexing and Prioritizing the Literature

At this point, cell formulas were written in the Excel® database to search the title and abstract of each database citation for particular keyworded topics, one per database column, e.g., evaporation, macroinvertebrate, soil compaction, depressional, saturated. The cell formula places a "1" in any cell where the term specified in the column is found in the title or abstract of a citation (row). In this manner the database was indexed automatically. Using Excel's "sort" tool, the citations can be grouped by any topic or combination of topics, and re-sorted as desired. Additional manual review and indexing of the citations allows them now to be sorted by wetland type, publication year, and geography.

Next, each of the 800+ citations was categorized as A, B, or C to reflect the priority for obtaining and reading it. Higher priority was assigned to publications that described original PNW research involving both wetlands and forest practices, or which, from their titles or abstracts, appeared to be most relevant to the objectives of this project. Lower priority was assigned to literature reviews and "white papers" (not original research), to publications not in peer-reviewed journals, and to publications about wetlands or forest practices but not both. A mostly successful effort was then made to obtain an electronic or hard copy of the full publication referenced by each A-priority citation and most of the B-priority citations. When a publication could not be obtained, an attempt was made to at least obtain its abstract, and all obtained abstracts were read. Finally, nearly all the A-priority publications, most of the B-priority citations, and some of the C-priority citations were read. Relevant information from each was incorporated directly while writing this report, rather than creating an intermediate step wherein the relevant information was first extracted to a separate file before being written up.

In all, 669 publications (171 priority A, 471 priority B, 27 priority C) were read in whole or part and included in the database. Information from a few additional publications recommended by reviewers was incorporated into the final version of this report and its Literature Cited section, but was not catalogued in the database. Of the 669 publications catalogued, 493 (74%) are primary literature (based on original field data or analyses) and the rest are literature syntheses and opinion documents. Nearly half were published since 2002 and 14% were published since 2009. Of primary literature sources, 284 (57%) mention wetlands, 287 (58%) mention forest practices, 240 (49%) pertain to studies in the Pacific Northwest, and 85 (17%) have all three elements, i.e., are from the PNW and mention both wetlands and forest practices. It is important to understand that: (a) simple mention of wetlands and forest practices in the same publication does not mean that effects of the practices on wetlands were studied, and (b) many studies of stream riparian areas were assumed to be studies of river-fringe wetlands, when in fact they may not have included wetlands at all, because not all (or even most) riparian areas are jurisdictional wetlands. Thus, the actual number of studies of forest practices in twetlands (as defined in this review) in the PNW is far less than the 85 indicated. Without better description of the study site conditions, the true number is impossible to determine. Tables 3-6 contain tabulations of the numbers of primary literature publications from the PNW that were reviewed, by topic.

Table 3. Number of reviewed PNW field studies of sites known or assumed to be wetlands, by HGM class.

Depressional	1
Lake Fringe	1
River Fringe	83
Slope	4
Tidal	1
Undeterminable HGM class	44

Table 4. Number of reviewed PNW field studies of sites known or assumed to be wetlands, by Washington Forest Practices Code type.

Bog	2
Forested	42
Type A or B (indeterminable)	90

Table 5. Number of reviewed PNW field studies of sites known or assumed to be wetlands, by topic

Nearly all were studies of stream riparian sites, not necessarily jurisdictional wetlands.

	#	%
Timber Harvest	78	58%
Forest Roads	24	18%
Forest Chemical Applications	6	4%
buffers	27	20%
hydrology	28	21%
ground water	11	8%
biogeochemistry	50	37%
temperature	23	17%
microclimate	10	7%
fragmentation	25	19%
algae	7	5%
invertebrates	17	13%
fish	24	18%
amphibs	24	18%
birds	13	10%
mammals	10	7%

Table 6. Number of reviewed publications by publication year and type

Publication Year	Field Studies	Review Papers	Total
1967	1	0	1
1968	1	0	1
1970	1	1	2
1971	0	1	1
1972	3	0	3
1973	3	0	3
1975	4	0	4
1977	2	1	3
1978	2	0	2
1979	1	3	4
1980	2	4	6
1981	5	1	6
1982	2	2	4
1983	2	0	2
1984	3	0	3
1985	5	0	5
1986	6	0	6
1987	6	1	7

Publication Year	Field Studies	Review Papers	Total
1988	8	5	13
1989	5	5	10
1990	6	2	8
1991	9	0	9
1992	4	3	7
1993	11	4	15
1994	9	7	16
1995	9	9	18
1996	16	0	16
1997	26	3	29
1998	17	4	21
1999	11	6	17
2000	30	6	36
2001	24	7	31
2002	22	5	27
2003	30	8	38
2004	17	11	28
2005	28	13	41
2006	39	7	46
2007	35	10	45
2008	26	13	39
2009	29	17	46
2010	19	15	34
2011	12	1	13
2012	2	1	3

2.3 Understanding the Limitations of the Best Available Science

Uncertainties in understanding the effects of logging operations on wetlands have arisen not only from a lack of such studies in the PNW, but also from past difficulties in designing and conducting studies of streams and watersheds that would have resulted in more definitive conclusions that could be applied to wetlands. Past investigations have used a wide variety of sampling and analytical methods which, when combined with apparent natural variation across time and space in hydrologic interactions, presents a challenge to making reliable, unified inferences about the relative influences of logging and natural processes on responses of wetlands and their functions. Ideally, most research should feature manipulative forest management experiments with pre- and post-treatment data, random assignment of replicates to treatments, and analyses over multiple spatial and temporal scales. In contrast, nearly all research which has attempted to relate effects of forest management to hydrologic, water quality, and biological impacts to streams and wetlands in the PNW has been of short duration, with some studies only evaluating post-harvest conditions. Even when pre- and post-harvest conditions are compared, between-year differences in the amount and timing of precipitation and temperatures between years can confound inferences one might make from the data, most notably if unharvested reference (control) sites were not part of the study. Likewise, even when harvested vs. non-harvested landscapes are compared, differences in soils, topography, vegetation, specific harvest practices and their configuration, and other factors can limit inferences that might otherwise be made. Moreover, many studies have occurred in landscapes that were harvested previously, and for which the precise histories of harvest may be ambiguous or unknown, which limits effective comparisons between current and historical distributions of plants, amphibians, and other organisms. Too often, biological studies have considered only the presence or absence of a species, rather than analyzing its degree of dependence on wetlands and upland buffers. Few studies have measured the reproductive success and long-term sustainability of populations of species, rather than abundance or density. Even the studies with pre- and post-treatment data can be affected by time lags. Effects on groundwater quantity and quality may occur distantly in space and time. Similarly, the longevity of selected wetland species may result in treatment effects not being manifest for several years. Few attempts have been made to measure the adaptability and resilience of individual members of a species to potentially harmful impacts of logging. Also, forest practices in the PNW have changed dramatically over the last two decades, and information about responses to current management rules is very limited.

When reviewing the literature for this report, the above limitations were taken into consideration generally but not specifically. That is, it was impractical to record and then judge the experimental design and field methods behind every one of the 600+ publications that were reviewed for this report, or the extent to which their findings can accurately be extrapolated to all wetlands and landscapes in the region. Nonetheless, it is believed that this report's inferences that were categorized as being the most certain (see Summary, section 4.0) are adequately supported by the aggregate of published scientific literature.

3.0 Forest Practices Effects on Wetlands

3.1 Effects on Water Regimes of Wetlands

3.1.1 Tree Removal Effects on Water Regimes of Wetlands

The existence of wetlands, which as a group are intermediate between uplands and deeper water, is often hydrologically precarious. Small changes in the amount and timing of groundwater, surface water, and precipitation that reach a wetland can determine whether (and how rapidly) the wetland transitions to a different ecosystem type or remains a wetland, and if the latter, whether these hydrological changes significantly alter its flora, fauna, and functions in ways that are judged as negative or positive. By a host of mechanisms, natural disturbances (fire, insect defoliation, landslides, windthrow) can just as easily trigger hydrologic changes on the land surface, and conversely, can be caused or amplified hydrologic changes (e.g., increased slope failure from changes in water level, snowfall accumulation, and rainfall interception that follow tree loss). Such changes from natural disturbances – like those associated with logging -- can create or eliminate wetlands or alter the functions of existing ones (Geertsema and Pojar 2007). However, when tree harvest is added to the suite of natural phenomena already disturbing wetlands, especially when both coincide in space and time, then natural disturbances are sometimes amplified. Effects compiled across all harvested watersheds in a region can be additive or they may be cumulative, meaning their sum over time and space may be greater than additive, in either a beneficial or detrimental manner (Preston and Bedford 1988). The degree to which effects may be cumulative is often determined by the degree to which individual impacts are staggered in time or are distributed sequentially in space, e.g., harvest which advances progressively uphill over time in a watershed, as opposed to occurring at nearly-random locations throughout (Ziemer et al. 1991, Beschta et al. 1995, Elliot et al. 2010).

A key factor that determines wetland type and function is *water regime*. Water regime pertains to the depth, duration (hydroperiod), frequency, diurnal fluctuation, and seasonal timing of groundwater and surface water. Water regime can be described by probability of an event occurring (e.g., 10-year flood probability or recurrence interval) and by standard statistics (e.g., mean, minimum, maximum flow) for specified time periods (e.g., daily, spawning season, annual). A large suite of variables – not just water yield, peak flow, and base flow -- have been used as "indicators" to describe hydrologic change in watersheds, streams, and rivers (Konrad et al. 2005, Poff et al. 2006, 2010, Poff 2009, Poff and Zimmerman 2010, Gao et al. 2009, Merritt et al. 2010). A similarly large number could be used to characterize changes in wetlands. Determining which variables significantly influence the biology, chemistry, and physical environment in wetlands remains a challenge. In general terms, some indicator variables that apply to estimating the hydrologic effects of forest practices on wetlands include:

- volume of water inputting to wetland (i.e., water yield of contributing area) and its timing
- peak water level or flow within the wetland: magnitude (depth or rate) and timing
- minimum water level or flow: magnitude (depth or rate) and timing

- percentage of days annually with surface water or measurable flow (both continuous and total)
- fluctuation (variance) in water level or flow: daily or annual
- percent of wetland water budget derived from groundwater vs. surface runoff vs. direct precipitation (and snow vs. rain)

Wetlands are dynamic, but the natural, actual, or desired range of these variables among the region's wetlands is unknown. Small isolated headwater wetlands are perhaps most at risk from hydrologic changes occurring in their contributing areas (catchments) because their hydrologic inputs are usually the least. In glaciated landscapes, some wetlands that comprise only one-third of their catchment area can produce 50-70% of the annual streamflow, because wetlands often occur where groundwater intercepts the land surface (Verry and Kolka 2003).

Many but not all studies have shown that removal of trees near a stream or in a wetland causes a mean annual rise in the local water table (see compilations and reviews of the vast literature on this, most notably by Stednick 1996 and 2008, Miller et al. 1997, Scherer and Pike 2003, Moore and Wondzell 2005, Guillemette et al. 2005, Brown et al. 2005, National Research Council 2008, Grant et al. 2008, Mallik and Teichert 2009, Smerdon et al. 2009, Troendle et al. 2010, and Winkler et al. 2010). As regeneration occurs in cutover areas, the previous rates and amounts of water transfer between uplands and wetlands return. This usually begins within 3-7 years post-harvest (Beschta 2002) -- less if the area has not been clearcut (Thomas and Megahan 1998). Hydrologic recovery to pre-harvest conditions takes 10 to 20 years in some coastal watersheds but may take many decades longer in mountainous, snow-dominated catchments (Whitaker et al. 2002, Moore and Wondzell 2005). Recovery is measurably delayed if the logged area is repeatedly treated with herbicide to control weeds that compete with replanted trees (Hornbeck et al. 1993).

The probability of a harvest operation having an effect on a wetland's water regime is greatest if trees are removed directly from a wetland or, if removed from outside the wetland, the removal occurs close to and upslope from the wetland. Impacts are also greater if the size of the harvested patch is large relative to the size of that wetland's catchment. Several other factors influence the degree to which tree removal causes water tables to rise. Especially on windy south-facing forest edges during the summer, tree roots can transfer large amounts of soil moisture to foliage and then to the atmosphere via transpiration and evaporation (Keim and Skaugset 2003). This effectively removes some of the water before it can reach wetlands and streams. Trees also intercept significant volumes of rain and especially snow, allowing some of that retained water to evaporate before it can reach wetlands and streams located farther downslope (Troendle and King 1987, Winkler et al. 2005). Thus, when trees are removed from within or above a wetland, that potential source of liquid water becomes available, the water table often rises, and the wetland may receive more water. This has been suggested by the data from many studies of streams and watersheds in the Pacific Northwest, such as those by Hetherington (1982, 1987), Jones and Grant (1996), Troendle and Reuss (1997), Thomas and Megahan (1998), Beschta et al. (2000), Hudson (2001), McFarlane (2001), and MacDonald et al. (2003). If resulting increases in peak flows are great, the morphology of channels can be affected (Grant et al. 2008). This can create, expand, or shrink riverine wetlands. Depending on the soils and topography, the slashburning and soil compaction components of some harvest operations provide additional surface runoff to wetlands, at least during a few years post-harvest (Lamontagne et al. 2000). In addition, in snow-affected areas, clearcuts have sometimes been shown to cause greater runoff during rain-on-snow events (Berris and Harr 1987) and earlier peaking of streamflow (or wetland water levels). This could cause shifts in aquatic species composition.

On the other hand, harvest might measurably *reduce* runoff to streams and wetlands in some parts of the Pacific Northwest during low runoff periods, partly by temporarily eliminating trees that otherwise contribute water by intercepting fog (Harr 1982, 1983). During the autumn, streams in clearcut watersheds in the PNW tend to have lower flows than in uncut watersheds (Harr et al. 1975). Also, cutting or windthrow of trees in or near wetlands can increase open-water evaporation sufficiently to reduce water persistence in late summer (Petrone et al. 2007), especially in larger wetlands and/or in drier parts of the PNW. In wetlands, this can have potentially detrimental effects on dissolved oxygen and fish access, as well as affect the maturation rate of larval amphibians. In at least one instance, a reduction in summertime stream flows was alleged to be due not only to changes in the amount of riparian vegetation, but from a harvest-caused shift from conifers to deciduous species (Hicks et al. 1991). However, in some situations deciduous trees may trap more snow (Helvey 1971) and after autumn leaf-fall, they would not continue to lose water via transpiration as evergreen trees would . In any case, where tree removal exceeds approximately 14% of a catchment, this has been shown to temporarily increase daily and/or seasonal *fluctuations* in the water levels of small water bodies located downslope in at least one instance (Taylor 1993).

Compared to an equivalently sized area that is clearcut, do patch cuts and thinning generate less new runoff? Unfortunately, the number of studies of partial cuts or thinnings is far fewer than the number of studies of clearcuts (Troendle et al. 2010). However, a wetland study in northern Minnesota (Kolka et al. 2011) may provide clues. Treatments included an uncut control (i.e., the upland and buffer were uncut) and three treatments in which the upland was clearcut but the buffer was either uncut, partially harvested, or clearcut. Water levels in the wetland rose following all treatments, with the largest increase in the wetland with no buffer and a clearcut located upslope. Differences among treatments were greatest during the first year post-harvest. By the fifth year after harvest the water levels in the treatment wetlands were not significantly different from the control. A study in Quebec (Pothier et al. 2003) similarly found that when 0, 40, 50, 60, and 100% of the tree basal area surrounding a conifer-forested wetland was removed, the degree of water table rise during the first post-harvest year was proportional to the amount of tree area removed. The water table returned to its previous level within 5 years post-harvest. In contrast to these two investigations, a study of two boreal lakes -- one with extensive logging in the watershed and along the shoreline and the other with moderate logging and a shoreline buffer -- found no measurable difference in water reaching the lakes after their watersheds were logged (Steedman 2000). The larger volume of the lake might have rendered immeasurable any water table changes that occurred.

In general, about 20% of the tree basal area above a stream must be removed before a statistically significant change in mean annual flow can be detected (Hibbert 1967, Bosch and Hewlett 1982, Stednick 1996). From a review of 50 studies globally, Guillemette et al. (2005) recommended that "logging should not cover more than 50% of a watershed, to minimize the occurrence of peak flow increases above 50%, which are deemed to affect stream morphology significantly." Peak flow data were from within 5 years post-harvest. The studies were analyzed if they met these criteria: (a) results were from paired watershed studies with a calibration period, (b) one result per watershed per treatment was used, with two exceptions, (c) peak flow changes at bankfull discharge (recurrence interval 1–2 years) could be evaluated and (d) the statistical significance of changes had been reported. The extent of wetlands, if any, in the study watersheds was not reported. Based on a detailed statistical analysis of many decades of data from western and eastern North America, Jones and Post (2004) determined that in the 5 post-harvest years, water yield increases 6-8 mm at conifer forest sites and 2-3 mm at deciduous forest sites. In conifer forest watersheds the increased water yields can persist for up to 35 years.

All before-and-after comparisons of harvesting operations face the challenge of statistically separating harvest and/or road-building effects from annual variation in the amount, form, and pattern of temperature and precipitation (Alila et al. 2009). Likewise all paired-watershed and multi-watershed comparisons face the challenge of statistically separating harvest and/or road-building effects from effects of different soil types (texture and depth to bedrock), topography, aspect, elevation, and other factors -- some unquantifiable -- that are potentially important in creating functionally meaningful differences among the studied watersheds. At a fine scale, the spatial and temporal variability of soil water storage capacity -- as influenced by evaporation, precipitation, and groundwater flow direction and amount -- complicates interpretation of forest harvesting studies (Devito et al. 2005). Despite these difficulties, results from most independent studies point in the same direction; this leads credence to the patterns the results suggest as a whole.

3.1.2 Logging Road Effects on Water Regimes of Wetlands

Construction of new roads accompanies many timber harvests. Maintaining existing forest roads in good condition is also important both for economic (timber management, fire control, recreation) and water quality protective reasons. Depending on how roads are designed, constructed, and maintained, the effects of roads on wetlands and watershed hydrology can be undetectable or significant, and they can be short-term or long-term (Schuldiner et al. 1979). Roads can change the volume and/or rate of runoff, its timing, and the proportion of precipitation that infiltrates and becomes groundwater rather than runoff. These effects can rival or exceed those of the harvests themselves. Road-diverted flow paths often directly or indirectly lead runoff into wetlands, streams, or onto downhill slopes. Roads in lowlands, especially older roads that were built in narrow valley bottoms, sometimes directly impinge on channels and wetlands. Road fills can increase the channel gradient, scour new areas, and reduce opportunity for overbank flow, thus reducing wetland area or the flooding frequencies needed to maintain some wetland functions. Road crossings of streams can induce channel changes immediately downstream of the crossing due to the effects of focusing water through a narrow culvert or other constriction narrower than in an unaltered stream.

Old roads can sometimes be relocated to reduce their impacts. Hydraulic excavators, which can excavate and place materials more precisely, have widely replaced bulldozers that formerly were used for road construction on mountain slopes. Roads are now designed to minimize cut and fill volume by constructing no wider than necessary and by fitting as closely as possible to natural topography (NCASI Forest Watershed Task Group 2003).

Runoff from roads generally follows one of four pathways: infiltration back into the hillslope below the road with no delivery to streams; direct delivery at channel crossings; direct delivery through gullies formed below relief drains; or indirect delivery via overland flow below the road. Direct delivery at channel crossings is the most common and most rapid form of delivery, and occurs where roadside ditches and/or road tread runoff are directed to the stream crossing structure, whether it is a culvert, bridge, or ford. Delivery at stream crossings is controlled partly by the spacing of relief drains; i.e., if relief drains are located only a short distance from the actual crossing, less road surface area will deliver water directly to the crossing.

Components of forest roads include cutslope, tread, fillslope, and any additional widening for ditches, berms, or other artificial surfaces that are part of the road right-of-way (NCASI Forest Watershed Task Group 2003). Most roads constructed for timber harvests in the Pacific Northwest are unpaved, often with a gravel surface. Many are closed during at least part of the year, usually during the wettest time. There are also many inactive forest roads that were closed to traffic immediately after completion of log hauling and/or silvicultural activities such as slash disposal, thinning, and tree planting. In many of these, measures have been taken to re-establish vegetation on the road surfaces and to minimize chronic erosion and future washouts.

Results from dozens of studies on the effects of forest roads on runoff and stream flow in the Pacific Northwest have been analyzed and critiqued many times, including reviews by Reiter and Beschta 1995, Wemple et al. 1996, Austin 1999, Gucinski et al. 2001, Scherer and Pike 2003, NCASI Forest Watershed Task Group 2003, Coe 2004, and Winkler et al. 2010. None are specific to wetlands because too few wetland studies exist to review. Relatively few of the dozens of studies of harvest and watershed hydrology have attempted to separate the effects of timber harvests from effects of logging roads and skidder trails associated with the logging.

The hydrologic effects of new roads are attributable to the following processes:

- slowing and occasional impounding of runoff and channel flow,
- connecting, by means of excavated roadside ditches, of existing natural drainageways that run perpendicular to the road,
- excavating into slopes and subsurface water flow paths, which causes more water to flow on the land surface, and
- removing vegetation, just as logging does, with consequent changes in water table height.

Essentially, roads can increase peak stream flows by replacing subsurface flow paths with surface flow paths, doing so through capture of subsurface water in road cuts and by reducing the rate of infiltration into compacted surfaces. In Quebec, Guillemette et al. (2005) attributed heightened post-harvest peak flows to the fact that a logging operation had connected skid trails and road ditches with branches of the stream in that watershed. They reported that maximum peak flow increased by 63% when harvesting and associated roads reached 61% of the watershed area. During the five-year period after the watershed had been 85% harvested, the maximum increase in bankfull flow was 57%. Previously, patch cutting 31% of a 394 hectare basin using chain saws (no skidder trails or roads) did not significantly modify rainfall generated peak flows and storm flows (Plamondon et al. 1998, Plamondon and Ouellet 1980). Small, wet, steep, headwater areas may be the most hydrologically-sensitive areas with regard to both timber harvests and road building (Moore and Wondzell 2005, Smerdon et al. 2009).

However, as is true of timber harvest effects, considerable variability exists in responses of water tables and stream flow to new forest roads (Wemple et al. 1996, Smerdon et al. 2009). One study (Bowling and Lettenmaier 1997) found that peak flows increased at a larger watershed scale only if the road construction occurred in headwaters of the larger watershed. Road construction near or below the centroid of a large basin can desynchronize the runoff hydrograph at the downstream location, potentially leading to *decreased* peak flows. Such de-synchronization effects may be responsible for the erratic results from field studies of the effects of road construction on peak flows in experimental watersheds, some of which show peak flows increasing, some decreasing, and others showing no statistical change (NCASI Forest Watershed Task Group 2003). Similarly, wetlands themselves have been shown to have varying effects on flood volume and stream low flows, and simple classifications (such as headwater vs. mainstem wetlands) have failed to predict these hydrologic conditions (Bullock and Acreman 2003).

Describing the variable effects of roads at a local scale, the NCASI Forest Watershed Task Group (2003) noted:

> Road cut interception of subsurface flow can be very erratic; it is highly dependent on specific site conditions, and can also be affected by harvest on hillslopes above the road. For example, a road in the Pine Creek watershed in the Idaho Batholith intercepted 8.4 inches of subsurface flow from watershed area above the road, which represented about seven times the amount of direct runoff from the road surface (Megahan 1972). In the Lochsa River drainage in north central Idaho, a road located several hundred yards downslope of the drainage divide intercepted on the order of 7 to 8 acre-feet of subsurface flow per day per mile of road and on the order of 5 to 6 acre-feet of overland flow per day per mile of road during the peak snowmelt season in early June (Burroughs et al. 1972). Conversely, a road in the Olympic Mountains of Washington intercepted no subsurface flow; there was no cutbank seepage and no base flow in road ditches (Reid and Dunne 1984). In central Idaho, Megahan (1972) found that one section of road intercepted more than three times as much water per unit length of road as another road section.

The same authors observed the following at a watershed scale:

> It has been hypothesized that increases in peak flows from roads may be due to increases in "drainage density" stemming from connectivity between the road system and the stream network at channel crossings and through gullies below relief drains (Montgomery 1994; Wemple et al. 1996; Jones et al. 2000). Although various studies have suggested increases in "drainage density" of 23 to 60% due to roads (Bowling and Lettenmaier 1997; Montgomery1994; Wemple et al. 1996), road mileage that drains to streams is not the same as an increase in the

length of streams within the watershed (Jones et al. 2000). Surface water instream develops as subsurface flow through the soil and geologic mantle, accumulating to the point of saturation and causing channelized surface flow. Roads also intercept subsurface flow, but interception may be partial, and there is a compensating effect in that runoff from intercepted subsurface flow is not supplied to the slope below the road, so storm runoff from the portion of the watershed below the road is reduced (Bowling and Lettenmaier 1997). Furthermore, if drainage density did actually increase because of road connectivity, relationships developed for natural drainages linking flood peaks and low flows to drainage density should be suitable for predicting the flow changes that occur from increased "drainage density" from road construction. However, studies of road construction effects on experimental watersheds show no such effects (Harr et al. 1975; Rothacher 1973). Jones et al. (2000) suggested that indices based on the number of road-stream crossings, particularly at mid-slope locations, may be more reflective of potential road effects on watershed processes than road density alone.

Arguments are made that runoff from intercepted subsurface flow occurs rapidly as concentrated overland flow, and therefore tends to increase peak flows (Jones and Grant 1996). This effect may or may not occur, because subsurface flow often occurs in macropores, where flow velocities can exceed that of overland flow. In such situations, intercepting overland flow will reduce peak flows (Bowling and Lettenmaier 1997). In fact, Cheng et al. (1975) reported that compaction associated with logging in a coastal British Columbia watershed *reduced* peak flow magnitude and time to peak because large subsurface channels which normally transported stormwater were crushed (although no surface flow resulted), forcing storm flow through the soil matrix at reduced velocity.

In some of the earliest work on road effects on peak flows, Rothacher (1970, 1973) did not detect any significant increases in mean peak flows or annual water yields due to roads that occupied 8% of a 250 acre western Oregon watershed. In the Oregon Coast Range, Harr et al. (1975) reported that roads increased mean annual peak flow by 19% in a watershed with 12% of area inroads, but that watersheds with 3 to 5% of area in roads showed no significant increases in mean annual peak flows. Ziemer (1981) and Wright et al. (1990) found no significant increases in peak flows for a 1047 acre watershed in coastal northern California with 5% of the area in roads and 8% in tractor skid trails. In seven small forested headwater basins in northern Idaho (ranging in size from 69 to 365 acres) with 1.8 to 4.3% of area in roads, five watersheds experienced no significant increases in mean annual peak flows, peak flows decreased in one of the seven basins, and flow during spring snowmelt increased 30% in one watershed with amid-slope road occupying 3.9% of the watershed area (King and Tennyson 1984).

In western Oregon, Jones and Grant (1996) concluded that 6% of the area occupied by roads in a small (250 acre) watershed caused a (non-significant) 20% increase in mean annual peak flows. They also argued that roads and clearcutting in large watersheds (15,000 to 150,000 acre) have caused increases in peak flows in larger basins. They attributed much of the effect to altered flow paths caused by roads. However, using a different statistical methodology with the same data, Thomas and Megahan (1998) found significant increases in peak flows in the small watershed that was roaded and patch-cut, but only in the first 10-year period following harvest, which implied that the effect was due to harvest, with little effect from roads, as road effects should be more persistent. They found increases in peak flows of 15 to 40%, but percentage increases in peak flows decreased with increasing return interval, with no increases detectable for flows greater than the 2-year flow, which is generally considered the flow level where effects on stream

> channels begin to occur. In another re-analysis of the data set used by Jones and Grant (1996), Beschta et al. (2000) essentially agreed with the conclusions of Thomas and Megahan (1998), but concluded that "peak flow increases for 0.4- to 5-year return interval events have occurred on small watersheds as a result of clearcut silviculture and the accompanying effects of roads and broadcast burning as practiced in the mid-1960s." They concluded that peak flow increases in the small watershed were not detectable for flows of 5-year return interval or greater, and they further concluded that the analysis did not support Jones and Grant's conclusion that peak flows were increased in larger basins.

Another complicating factor is that much of the existing road system was designed and built before present standards were in place. Thus, an accurate assessment of effects at a watershed scale must consider the proportion of old roads to the newer roads that incorporate improved engineering design (Gucinski et al. 2000), but few published studies have done that.

3.1.3 Buffer Effectiveness for Maintaining Wetland Water Regimes

Moderation of stream flow, wetland water levels, or water table heights are not reasons usually given for requiring vegetated buffers along streams or around wetlands. With the possible exception of very confined headwater locations, buffers of only a few dozen meters width seem unlikely to affect the tendency of larger forestry operations to change the amount or timing of runoff. Nonetheless, forested buffers – like any forest with trees that transpire water – under some situations may partly offset runoff volume that has increased as a result of logging and logging roads farther upslope. Transpiration rates and volumes are commonly greater in buffers because of their riparian location and regularly replenished soil moisture, than in equally-sized vegetated areas beyond the riparian zone (Moore and Wondzell 2005). Transpiration rates decrease as buffer width increases, and may become negligible in woodlands larger than 100 ha (Herbst et al. 2007). At one site in Oregon, transpiration occurring primarily in riparian buffers (which covered only 0.1 to 0.3% of a catchment) was estimated to account for daily loss of 1-6% of summer streamflow (Bond et al. 2002).

However, it cannot be assumed automatically that more forest cover (i.e., wider vegetated buffer) means more water loss. Much depends on soil moisture levels. Those in turn are influenced by weather, soil type, proximity to water bodies and other forest edges, wind, aspect, shade, as well as tree species, age, rooting depth and mass, groundwater flow rates and direction, and other factors (Bladon et al. 2006, Moore and Heilman 2011).

Headwater wetlands themselves can sometimes be considered "buffers" in terms of their ability, at a watershed scale, to moderate flow extremes in downstream areas. This is especially likely to be the case where most of the wetlands are hydrologically isolated for most of the year and flood only seasonally (Todd et al. 2006). They perform this function by providing a confined vertical space for storing runoff, by evaporating water from unvegetated surfaces, transpiring water where vegetated, and together de-synchronizing runoff as it moves downslope through a watershed. However, the degree to which any given wetland may do this likely depends largely on local groundwater conditions which seldom can be predicted without significant expense.

3.1.4 Biological Effects of Altered Water Regimes

As Brown et al. (2005) note, some aquatic resources may benefit from increased water yield that temporarily results from tree removal, but others may not. Whether the effects are beneficial or harmful depends on seasonal timing of the increase (particularly its coincidence with periods of very hot or cold temperature) as well as its magnitude and duration.

For over a century foresters have noted the proliferation of new "wet areas" following harvest operations, and this sometimes has been such an economic concern (because it retards growth of commercially important timber) that strategies have been devised to speed the drying process by planting seedlings of tree species with the greatest evapotranspiration rates (e.g., Landhäusser et al. 2003). In Quebec, higher post-harvest water levels in wetlands are considered to be such an economic nuisance that ditches are dug in or around affected wetlands to partially offset the effect (Marcotte et al. 2010). If topography and soils are suitable, water table rises in flat non-wetland areas can create anaerobic soil conditions long enough to support plant assemblages that define wetlands, where none existed prior to tree removal. This appeared to be the case in a headwater wetland in the Washington Coast Range measured by Janisch et al. (2011) before and after timber was harvested by clearcutting its catchment. Four years after its catchment was clearcut, in one very small wetland they observed (1) an increase in the spatial extent from 3.6 m^2 to 9.5 m^2; (2) an increase in vegetation mass and a conversion from sparse skunk cabbage to nearly pure, dense bulrush; and (3) development of strong indicators of reducing conditions in the wetland soil. They noted that other post-logging changes they observed 2004–2009 suggested that small headwater wetlands are highly sensitive to hydrologic disturbance and may develop or fade at a time scale of several years. This may reflect short, emergent groundwater paths, meaning that hydrological effects from disturbances, such as result from timber harvesting of upslope areas in small catchments, occur rapidly.

Germination of woody plants may be reduced in previously "dry" wetlands (those chronically lacking surface water) due to higher post-harvest water levels, i.e., greater frequency and duration of sediment saturation or flooding (Croke and Hairsine 2006) as described further in section 3.2.2.4.

On most active forest roads, ditches are cleaned periodically to insure that water does not erode the ditch or the road surface. However, many road ditches comprise dispersal habitat or even oviposition habitat for amphibians. Cleaning could potentially resuspend sediment and remove vegetation where eggs are deposited. From their field observations of very small headwater wetlands in the Washington Coast Range, Janisch et al. (2011) postulated that small headwater wetlands, regardless of their origin,may be quite important to several amphibians -- a viewpoint also expressed by other herpetologists (Olson et al. 2007).

Culverts are another necessary feature of roads. For decades, most western states required that culverts be designed to pass only the 25-year flood – a design that is statistically predicted to have a 50% probability of overtopping within 17 years of installation. Currently, the minimum design requirement of most state forest practices rules is 50 to 100 years. While this improves passage for fish, it likely reduces the number of wetlands created incidentally by logging roads, and in some cases culvert replacements may incidentally shrink or entirely dry out some wetlands created long ago by logging operations on the uphill side of roads.

An increase in the magnitude, frequency, or duration of flooding in wetlands can have several effects, depending on initial conditions and various interacting factors (Adamus and Brandt 1990, Adamus et al. 2001):

- kills trees, leading to vegetation changes and/or an increased area of open water, as also happens when beaver dam a stream;
- drowns some herbaceous plants, particularly invasives and facultative indicators of wetland conditions, because many of those are associated with drier upland environments and wetland margins (Drinkard et al. 2011);
- either increases or decreases the exposure of plants to competitors and herbivores;
- increases the habitat space and habitat suitability for most waterbirds, aquatic invertebrates, fish, and some amphibians;
- usually increases the within-wetland richness of aquatic invertebrates and aquatic plants, thus increasing food web complexity (e.g., Wisinger et al. 1999, Duffy 1999, Ludwa and Richter 2000);
- connects wetlands, thus:
    - improving water circulation and growth rates of several plant species;
    - facilitating fish access to additional nursery habitat;
    - increasing the exposure of invertebrates and amphibian larvae to predators;
    - allowing mixing of gene pools of flora and fauna;

- facilitating the spread of invasive plants.
- decreases oxygen and (usually) pH in wetland sediment and water;
- increases the emission of methane, a potent greenhouse gas;
- increases the bioavailability of phosphorus previously bound in soil organic matter (by enhancing decomposition) or in sediments (by decreasing the oxygen in sediments); this benefits both desirable and undesirable (nuisance algae) species;
- increases (by enhancing decomposition) the availability of nitrate for plant growth, but decreases nitrate by enhancing microbial denitrification processes;
- increases the risk of iron and manganese toxicity to plants, depending on soil chemistry (Barrick and Noble 1993).

Topographic variation on the order of a few centimeters can shape the composition and richness of the plant community by influencing the duration (Dicke and Toliver 1990, Merendino and Smith 1991, David 1996, Vivian-Smith 1997, Silverton et al. 1999), timing (Merendino et al. 1990, Squires and van der Valk 1992, Scott et al. 1996, 1997, Gladwin and Roelle 1998), and frequency of saturation (van der Valk 1994, Smith 1996, Pollock et al. 1998) in the root zones of wetland plants. In floodplain wetlands, tree seedling survival may be lowest during years when flooding occurs at or shortly after the beginning of the growing season, or where surface water in wetlands persists for more than 40% of the growing season (Toner and Keddy 1997).

The amplitude and rate of water level **fluctuation** also influences plant species composition, biomass, and germination in wetlands (Hull *et al.* 1989, Hudon 1997, Shay *et al.* 1999). Water table fluctuations induced in wetlands by creation of impervious pavement, although far more profound and permanent than those possibly caused by logging, have been implicated in non-forest studies for facilitating the spread of invasive plants such as reed canary-grass (*Phalaris arundinacea*). Among 26 forested wetlands studied in the Seattle area, wetlands with mostly emergent or shrub vegetation whose water levels fluctuated more often and/or with greater amplitude had fewer plant species. In those wetlands, greater water level fluctuation decreased plant richness most noticeably during the early spring (Cooke and Azous 2000).

Plants themselves (especially particular configurations of woody and other deep-rooted plants, Loranty et al. 2008) can amplify runoff-related water level fluctuations in wetlands by transpiration processes, at a scale of hours, days, and seasons (Dubé et al. 1995, Jutras et al. 2006). In wetlands subject to periodic anoxia, increased water level fluctuations also can facilitate the denitrification process, resulting in loss of nitrate as nitrogen gas.

For streams, a few studies from the PNW have examined biological correlations with timber harvests. The most comprehensive analysis, conducted by Herlihy et al. (2005), analyzed invertebrate data from 167 randomly-selected headwater sites in Oregon with different degrees of timber harvest. At that scale, they found no statistically strong relationships between invertebrate index of biotic integrity (IBI) and logging activity (past or present), presence/absence of fish, catchment size, or ecoregion. All four severely impaired sites and five of the seven sites with moderate impairment were lower altitude, low gradient streams with evidence of agricultural activity in their catchment or riparian zone. See section 3.3.3 for additional information on biological effects of timber harvesting.

3.1.5 Summary and Data Gaps: Water Regime Effects

In this review, no studies were identified that measured directly the effects of various forest practices in the PNW on water regimes of wetlands. Specific data gaps are described by the hypotheses in part 2 of Appendix A.

Tentative inference may be made from the dozens of studies that have investigated logging effects on hydrology of streams in the region (summarized by Winkler et al. 2010) and studies not from this region yet focused on timber harvests in or near northern wetlands (Palik et al. 2001, Palik and Kastendick 2010, Hanson et al. 2009, 2010, Kolka et al. 2011). Collectively, these suggest that timber harvests in most PNW locations result in a rise in local water tables and greater water yield. The degree to which these effects extend off-site and influence wetland functions depends on local geomorphic conditions and remains unquantified. Construction of forest roads through wetlands displaces water that otherwise is often stored in wetlands. Forest roads also can hinder the downslope passage of surface water, especially during major storms. This potentially alters the timing and reduces the amount of water reaching wetlands immediately downslope, while potentially creating or expanding wetlands that adjoin the road on its uphill side.

3.2 Effects on Water Quality, Water Quality Function, and Soils

Wetlands have water quality **conditions**, and they have water quality **functions**. This is an important distinction. The concentration of nutrients is a condition, whereas the rate and capacity of a wetland to retain nutrients is a function. Forest practices can affect water quality condition with only minimal effect on water quality functions, and conceivably, can affect water quality functions with effects on water quality condition that are immeasurable over normal time scales. Both the condition and the function that are termed “water quality” are strongly influenced by soils. For example, when some soil types receive runoff, they release dissolved carbon into the surface water, affecting water quality *condition*. If that soil carbon is not replenished, or if soils are heavily compacted by machinery, the capacity of the soils to *remove nitrate (a function*) may decline over time. Forest practices can affect both the concentration of dissolved carbon in surface water, *and* the capacity of soils to influence that. A few studies have examined water quality *conditions* of harvested wetlands or wetlands with tree harvest nearby, but none have directly measured harvest-associated changes in the usual capacity of wetlands to remove nitrate, adsorb phosphorus, detoxify pesticides, or provide other water quality *functions*.

Popular media often describe wetlands as "kidneys on the landscape" for their capacity to remove pollutants. For example, one headwater forested wetland in British Columbia removed 27% of the organic nitrogen it received annually (Hill 1991). In Ontario, a 0.2-ha forested wetland that covered only 4% of its catchment removed 65-100% of surface water nitrate inputs (Spoelstra et al. 2010). However, like actual kidneys, wetlands have their limits. Excessive loading with some types of pollutants not only degrades water quality condition in a wetland, it can also diminish the future ability of the wetland to maintain or improve water quality. For example, many depressional wetlands are excellent for retaining whatever suspended sediment reaches them in runoff, but deposition of too much sediment will, over time, fill in a part of a depression, causing it to retain less runoff for shorter periods, and thus limit the wetland's future capacity to remove sediment (Whigham and Jordan 2003, Leibowitz 2003). Potential cumulative effects on a wetland's functional capacity to process pollutants were discussed by Hemond and Benoit (1988).

Vegetated buffers are widely used to maintain water quality of streams and wetlands. A common perception is that the main reason buffers are effective is because their vegetation takes up excessive nutrients in runoff from higher areas. However, plants in buffers usually retain for only a few months the nutrients they take up, returning most nutrients to the soil or exporting nutrients to the water column (and thence downstream if the wetland has an outlet) as the plants decay at the end of the growing season.

The most important reason buffers are effective is simply that they -- unlike clearcuts and other disturbances -- are usually not significant *sources* of additional sediment and nutrients. If they were a source, this would be the worst location to be a source, in terms of risk to other water bodies. That is because the low areas closest to streams and wetlands are the places where water tables tend to first intercept the ground surface during and after a storm (Walter et al. 2000, Buttle et al. 2004, Creed et al. 2008 a, b; Qiu 2009 a, b), thus connecting ephemeral drainageways and accelerating the downhill transport of sediment and nutrients that might originate from harvest. As one hydrologist (Walter et al. 2009) puts it:

> "A common conceptual assumption is that buffers "intercept" and treat upland runoff. As a shift in paradigm, it is proposed instead that riparian buffers should be recognized as the parts of the landscape that most frequently **generate** storm runoff. Thus, water quality can be protected from contaminated storm runoff by disassociating riparian buffers from potentially polluting activities."

Nonetheless, vegetation plays an important role in buffer effectiveness. Roots help maintain the capacity of soils to allow water to infiltrate, plants transpire sufficient soil moisture to keep soils unsaturated and receptive of runoff, carbon added by plants supports microbial communities essential for removing some pollutants, and shade cools runoff or a wetland's water directly.

Although discussions of buffer design typically focus primarily on the buffer's width (mainly because it is quickest to measure in a standard manner), several other buffer characteristics often have a greater effect on a buffer's effectiveness (Mayer et al. 2005, 2007). These include ground surface roughness, water source, flow pattern (concentrated vs. diffuse), slope, soil texture and organic content, location of the buffer relative to major paths by which water enters the wetland, contributing area size relative to buffer size, amount and dosing rate of the pollutant, vegetation type and density, and aspect (longer growing season on south-facing slopes promotes runoff retention and pollutant processing, provided soils are not dried out to less than 70% saturation by those warmer conditions; Kim et al. 2007, Hefting et al. 2006).

Of the factors named above, flow pattern is perhaps the most important. It is not unusual to find much of the runoff from harvest operations following gullies, ditches, and other semi-confined flow paths with sparse ground cover despite those gullies and ditches being located under a well-formed tree canopy constituting the required buffer. Under such conditions, the buffer is often an ineffective filter and detains the downhill movement of sediment only until the next storm (Dosskey et al. 2002, 2010). Thus, vegetated buffers are most effective in protecting the quality of wetlands when major inflows are diffuse (surface sheet flow or subsurface lateral flow) rather than concentrated in rills and gullies (Dillaha et al. 1989, Dosskey et al. 2001, Wigington et al. 2003). This depends on typical rainfall patterns (steady drizzle vs. concentrated in storm events, Lee et al. 2003) as well as soil type (coarser soils tend to promote infiltration and less gullying), extent of drainage alterations such as ditches that concentrate runoff, and slope (Abu-Zreig 2001, Mancilla et al. 2005). Within a buffer, spatial variation is often high in regard to the capacity of the soils and vegetation to remove nitrate (Hefting et al. 2006). In one study, only 9-18% of the vegetation in a buffer was actually in contact with runoff, due to the buffer's topography. Although under uniform flow the buffer could potentially remove 41-99% of sediment, the actual removal rate was 15-43% (Dosskey et al. 2001). Buffers in rural New York were found to be ineffective when crossed by small roadside ditches that were not buffered but were connected to pollution sources (Madden et al. 2007). If the sole purpose of a wetland buffer is to protect a wetland's water quality, then prescribed buffer widths might be reduced where the buffer slopes *away from* the wetland, or where uplands otherwise fall outside the path between the harvest area and the wetland. Such non-contributing areas do little or nothing to intercept polluted runoff that otherwise would reach the wetland.

Small buffers that are expected to bear responsibility for processing runoff from very large contributing areas tend to be ineffective, because storm runoff quickly overwhelms their processing capacity (Misra et al. 1996, Creed et al. 2008, Tomer et al. 2009). Not all buffer studies have found the ratio of buffer area to contributing area to be a good predictor of buffer effectiveness, but authors of those that have suggest the vegetated buffer acreage should be at least 15% of the acreage of its contributing area, especially the part of the contributing area that is capable of generating polluted runoff (Leeds et al. 1994).

For pollutant removal or maintaining water temperature, no data exist that indicate buffers dominated by non-native plant species are less or more effective than ones dominated by native plants. However, one relationship that does appear to be relatively well-documented is that wooded buffers dominated by nitrogen-fixing shrubs such as red alder (*Alnus rubra*) tend to be sources, not sinks, for nitrate (a potential pollutant) during at least some seasons of the year, and thus may be ineffective as buffers where the primary intent is to protect a particular wetland from overenrichment.

3.2.1 Forest Practices Effects on Wetland Temperature and Dissolved Oxygen

3.2.1.1 Tree Removal Effects

Most regional literature on impacts to stream temperature from timber harvest was summarized by Moore et al. (2005), Pike et al. (2010), and Tschaplinski and Pike (2010). In streams flowing through 40 small forested watersheds in the Olympic Peninsula, mean daily maximum temperatures averaged 58.1°F (14.5 °C) and 53.8°F (12.1°C) in logged and unlogged watersheds, respectively, even 40 years after harvest (Pollock et al. 2009, 2010). Diurnal fluctuations also were greater in the harvested watersheds, averaging 3.0 °F (1.7 °C) compared to 1.6 °F (0.9 °C) in the unharvested. Another study on the Olympic Peninsula (Murray et al. 2000) focused on just two watersheds with partial harvests (7-30%). Compared with an unharvested watershed, summertime maximum was elevated by 6.3° F (3.5° C) and became more variable. By 11-15 years after harvesting, stream temperatures were almost back to pre-harvest levels.

The proportional amount and pattern of shade in a watershed in some instances has an equal or greater cumulative influence on wetland and stream temperature than does shade from vegetation closest to the water (Brosofske et al. 1997, Sridhar et al. 2004, Stephenson and Morin 2008). For example, a study in Oregon (Beschta and Taylor 1988) found highly significant ($p < 0.01$) relationship between a cumulative index of forest harvesting and maximum stream temperatures. In a study on the Olympic Peninsula of Washington (Pollock et al. 2009, 2010), average daily maximum temperature depended on the amount of clearing in both the watershed as a whole and in just the parts of the watershed near the streams. The amount of recently clear-cut riparian forest (<20 year) within ~2000 ft upstream ranged from 0% to 100% and was not correlated to increased stream temperatures. The probability of a stream exceeding the temperature standard increased with increasing amount of the watershed harvested. All unharvested sites and five of six sites that had 25-50% harvest met the temperature standard. In contrast, only half the sites with 50-75% harvest and 2 of 9 sites with >75% harvest met the standard. Many streams with extensive canopy closure still had higher temperatures and greater diurnal fluctuations than the unharvested basins, indicating that that the impact of past forest harvest activities on stream temperatures cannot be entirely mitigated through the establishment of riparian buffers. Additional information on vegetated buffer effects on stream temperature is provided in section 3.2.1.3.

In British Columbia, a paired watershed study (Feller 1981) examined effects of clearcutting and slash burning on stream temperature and found maximum annual stream temperatures were 5.4 - 9.0 °F (3–5 °C) higher in the harvested watershed. The increase persisted 7 years in the unburned portion of the clearcut watershed and somewhat longer in the area where clearcutting was followed by slash burning. Clearcutting increased winter water temperatures, whereas slash burning caused a decrease in winter temperatures. Several other paired-watershed studies in British Columbia and Washington (Dong et al. 1998, MacDonald et al. 2003, Moore et al. 2005) have found that maximum daily water temperatures increase up to 10.8 °F (6°C) after clearcutting, and require at least 10 years to return to pre-harvest levels.

The severity of clearcutting's impact on water temperatures may depend partly on the amount, type, and configuration of shrub and ground cover that remains in the cutover area immediately after tree harvest (Gravelle and Link 2007). But more importantly, especially in most headwater areas and during low flow conditions, it will depend on the rates that groundwater and hyporheic flow are discharged into the stream or wetland (Story et al. 2003, Douglas 2006, Rayne et al. 2008). Ground water flowing into streams reduces stream heating by increasing the total discharge (measurably only in headwater areas) as well as cooling by conduction (Moore et al. 2005). Rough estimates of subsurface (hyporheic) flow, which often has a large groundwater component,can be made from observations of stream geomorphology in some settings (Kasahara and Wondzell 2003). In regions that experience winter ice cover, the simple presence of discharging groundwater is sometimes hinted at by the occurrence of unfrozen conditions later in the fall than is common among local waters of similar depth and circulation, and/or earlier thaw during late winter.

A study of two watersheds in the Oregon Cascades found that maximum stream temperatures increased 12.6 °F (7° C) and occurred earlier in the summer after clear-cutting and burning in one watershed, but occurred after debris flows and patch-cutting in another. Hourly temperature fluctuations also became more pronounced in both watersheds. Stream temperatures in both gradually returned to preharvest levels after 15 years. Another Oregon study found that thinning a forest to a density of 80 trees/acre neither affected soil temperature in streamside areas nor the water temperature of the stream (Olson and Chan 2005). A recent BACI experiment in Oregon which compared streams with cut and uncut riparian buffers before and after timber harvest reported average summertime stream temperature increases of only 1.3 °F (0.7° C) with an observed range of response from -1.6 to 4.5° F (-0.9 to 2.5° C) (Groom et al. 2011).

Although it is apparent from the above that spatial variation of temperature has been studied widely in streams, little is known about the effect most wetlands have on stream temperatures – not even which types of wetlands are more likely to increase it or decrease it. As streams flow downslope, water temperature typically increases, especially if the slopes are south- or west-facing (Zwieniecki and Newton 1999, Gomi et al. 2006). Generally, mean annual water temperature in low-order streams also becomes warmer with decreasing shade from vegetation and topography, as well as with decreasing groundwater input (groundwater typically being cooler than surface runoff during much of the year), decreasing water depth, and increasing detention time (Moore et al. 2005). Wind exposure (turbulent mixing), substrate color (light absorption), and industrial effluent also can influence temperature (Moore et al. 2005). The influence of particular factors in this list varies greatly among streams (and presumably wetlands), so it is seldom possible to predict their net effect in a specific wetland. However, in one study in British Columbia where tree harvest raised water temperatures a maximum of 14.4 °F (8 °C) in streams, the temperatures in streams that originated in headwater wetlands increased a maximum of only 1.8-3.6 °F (1-2 ° C) (Rayne et al. 2008). Similarly, another study in British Columbia found that well-vegetated wetlands and lakes near the top of a watershed helped offset warming caused by harvest above them, thus allowing more rapid return to pre-harvest temperatures as the stream flowed downhill (Mellina et al. 2002). This can be expected in many places where wetlands are areas of focused groundwater discharge, because groundwater in summer is typically cooler than air temperature. Even in streams, groundwater influx was shown in one British Columbia study to be responsible for about 40% of the 5.4 °F (3 °C) cooling that occurred up to 200 m downstream from a timber harvest (Story et al. 2003).

In one of the rare studies on the effects of near-shore harvest on lake temperatures, Steedman et al. (1998) detected almost no change in 4 Ontario lakes ranging in size from 8 to 46 hectares. The lake with the largest warming -- up to 2.2 ° F (1.2 °C) -- had a south-facing shore, and the main effect was increased fluctuation in diurnal temperatures.

3.2.1.2 Logging Road Effects

Few if any studies have attempted to separate the thermal impacts of logging roads from those of timber harvest operations. Streams (and presumably wetlands) whose catchments have a greater extent of roads (road density) tend to have higher temperatures. A study of 104 streams in British Columbia found there is a 6-in-10 chance that the summer maximum weekly average water temperature will increase by 2.3 °F (1.3 °C) if road density in the contributing area exceeds 27 feet of road per acre and by 5.8 °F (3.2 °C) if road density exceeds 53 feet of road per acre (Nelitz et al. 2007).

3.2.1.3 Buffer Effectiveness for Maintaining Wetland Temperature

In coastal British Columbia, buffers of 10 m and 30 m appeared to protect headwater streams from significant changes in daily minimum, mean, and maximum temperatures. In streams with no buffers, clearcutting resulted in increases of 3.6-14.4 °F) (2-8 °C) (Gomi et al. 2006). After half the forest was removed in three small watersheds (<50 ha) in Quebec, a 20 m buffer appeared to protect stream temperature, with pre- versus post-harvest changes in summer daily maximum and minimum stream temperature of less than 1.8 °F (1 °C) and changes in diurnal variation of less than 0.9 °F (0.5 °C) (Tremblay et al. 2009).

From a series of sensitivity analyses using simulation modeling, Sridhar et al. (2004) reported that increasing the buffer width beyond 30 meters did not significantly decrease stream temperatures. Leaf area index and average tree height more strongly affected maximum stream temperatures. Another study found that maximum air temperature within a 30-m wooded buffer was only slightly cooler than in a 5-m wide wooded buffer (Meleason and Quinn 2004). In a British Columbia study of buffers along 13 headwater stream reaches, forests were clearcut and stream temperature associated with three riparian buffer treatments (30-m buffer, 10-m buffer and clear-cut to the stream edge) where compared with streams with uncut catchments (Kiffney et al. 2003). During some seasons, streams whose catchments had intact forest were cooler than streams bordered by a 30-m buffer. From a study of 20 small streams in western Washington, Dong et al. (1998) found that forested buffers of 16 to 72 m width did little to protect a stream from a 7.2 °F (4 °C) increase in air temperature that occurred in associated clearcuts during the middle of summer. However, they asserted that buffer width was not a significant variable in predicting air temperature above the streams, and that perhaps even the largest buffer was not sufficient to maintain air temperatures over a stream, because air temperatures over a stream with that buffer did not differ significantly from air temperatures over an otherwise analogous stream that lacked a buffer. In contrast, Groom et al. (2011) found that Oregon streams on private lands with minimal buffers experienced an average post-harvest increase in maximum temperature of only 1.3 °F (0.7 °C) with a range of -1.6° to 4.5 °F (-0.9 to 2.5 °C). Maximum, mean, minimum, and diel fluctuations in summer stream temperature increased with a reduction in shade, longer treatment reaches, and lower gradient. Despite the thinning of tree stands in 10- and 30-m buffers that adjoined timber harvests, stream temperatures were maintained for up to 200 m downstream in two stream reaches in British Columbia (Story et al. 2003).

The following (in italics) is quoting from a review by Liquori et al. (2008):

In California, Lewis et al. (2000) observed that cool tributary inflow (2.2° to 7.7° C below receiving stream) decreased the receiving water temperature for distances ranging from 3,000 to 35,000 ft (900 m to 10,700 m) downstream of the tributary junction. In Washington, Caldwell et al. (1991) found that headwater streams had minimal influence on the downstream water temperature because of the large size difference between headwater tributaries and receiving (typically fish-bearing) waters. Using a stream flow mixing equation and the relationship between distance from divide and discharge, they determined that a headwater stream could not affect the temperature in a typical fish-bearing stream by more than 0.49° C if the confluence of the receiving stream is more than 7 km (4.5 miles) distance from the watershed divide. Caldwell et al. (1991) reported that small streams are very responsive to localized conditions and that the longitudinal effect of any one headwater stream on downstream temperatures is limited to 150 meters or less. This study also evaluated the potential cumulative effects of multiple headwater streams feeding warm water into a fish stream. Based on a map analysis of tributary junctions, *they found that spacing between tributaries often exceeded 150 m and concluded that no cumulative effect was likely to occur.*

In summary, due to the varying and unpredictable effects of groundwater influx and other factors, no single, fixed-width buffer or canopy closure prescription will be adequate to maintain stream or wetland temperatures in all harvest operations (Richardson et al. 2012). Computer models (e.g., Oregon's Shade-o-lator, Boyd & Kasper 2003) are available for predicting water temperatures site-specifically, based on estimates of some or all of the key influencing variables, but are not routinely used.

3.2.1.4 Biological Effects of Altered Wetland Temperature and Dissolved Oxygen

Temperature is a fundamental regulator of biogeochemical cycles and biological productivity in wetlands. For example, as temperatures rise, less oxygen is capable of remaining dissolved in water. This critically affects the development, respiration, and metabolism of aquatic organisms, as well as a whole array of biogeochemical processes. Through this and other mechanisms, temperature (extremes, seasonal timing, and magnitude of daily fluctuations) can influence which species become established and persist at a particular location. Temperature can affect production of insects and algae; incubation of the eggs of invertebrates, fish, and amphibians; timing of fish rearing and migration; fish and amphibian susceptibility to disease; and many other factors (MacDonald et al. 2003).

The importance of water temperature is recognized by legal standardsadopted for streams. Cool waters (less than 68°F (°C), ideally less than 60°F (°C)) are particularly important to salmonid fish because at higher temperatures, less of the dissolved oxygen necessary for their survival (a minimum of 5 ppm is needed by most local fish) is able to remain in the water. In many PNW streams where vegetation cover has been reduced, water temperatures that are non-lethal but harmful to salmonid fish are common (Sullivan et al. 2000). Within a stream reach, the spatial extent and persistence (over weeks and months) of sublethal water temperatures may be more likely to influence salmon behavior and growth than the maximum temperature reached (Liquori et al. 2008).

Wetlands connected to rivers or in floodplains are used extensively by important temperature-sensitive fish such as coho salmon. Being highly mobile, fish can of course avoid channel segments with excessive temperatures unless trapped in pools by rapidly dropping water levels. However, when fish avoid areas due to such conditions, this reduces the extent of useable habitat and thus the number of fish that can exist in a stream overall. In Southeast Alaska, Thedinga et al. (1989) found that coho salmon in streams flowing through old-growth forest actually had fewer fry (age 0) than in clearcut and buffered streams, and the fry were smaller and emerged later. The fry remained longer in buffered streams than in clearcut or old-growth streams, but the size of coho parr (age 5 and older) did not differ among buffered, clearcut, or old-growth streams.

3.2.2 Forest Practices Effects on Sediment and Soils in Wetlands

Sediment inputs to wetlands from soil erosion are likely to increase as a result of ground disturbance associated with harvest (especially on steep slopes with erodible soils). Sediment inputs also increase as a result of increased windthrow of remaining trees, construction of logging roads and related facilities, and dust and runoff from those roads (Grayson et al. 1993, Kreutzweiser and Capell 2001). Processes that influence the transport of eroded sediment from all these sources are key to determining accumulation rates in wetlands (Western et al. 2001, Stieglitz et al. 2003). Hydrologic connectivity between topographically low areas such as wetlands is likely to increase during storms if logging-associated loss of tree transpiration and interception causes the water table to surface more often or for longer as described in section 3.1 (Wigington et al. 2005, Bracken and Croke 2007, Jones et al. 2009, McGuire and McDonnell 2010). Several models may have a capacity to predict the duration and extent of connectivity between wetlands and other surface waters (see review by Golden et al. 2014).

Being low points in the landscape, wetlands also tend to accumulate sediment. If a wetland neither has an outlet nor is on a floodplain, that sediment accumulates over time. In large enough amounts it can fill a wetland, ultimately converting it to upland. In other situations, excessive sediment can reduce the rate of exchange between ground and surface water (Moore and Wondzell 2005), reduce the water detention time, and harm some wetland plants and animals as described in section 3.2.2.4. On the other hand, when sediment is deposited along margins of deep open water areas (e.g., 1-2 m), it eventually provides a substrate for rooting of emergent plants, creating new wetlands or allowing existing fringe wetlands to expand outwardly. This pattern is prominent along lakeshores and sheltered estuaries.

3.2.2.1 Tree Removal Effects on Sediment in Wetlands

Studies of sediment and/or nutrient export from timber harvest operations were compiled and reviewed by Feller 2005, Gomi et al. 2005, NCASI Forest Watershed Task Group 2003, Gomi et al. 2005, Croke and Hairsine 2006, Liquori et al. 2008, Kreutweiser et al. 2008, Malik and Teichert 2009, Neary et al. 2009, and Pike et al. 2010. In western

Washington, watersheds containing less than about 15% forest, as a result of soil disturbance associated with logging or urbanization, have significantly more exceedences of water quality standards for suspended solids (Ludwa 1994). However, in many situations the loads of sediment generated specifically by timber harvests (not the associated roads which are discussed in section 3.2.2.2) appear to be relatively modest.

Erosion is typically greatest just after harvesting and road construction, and decreases soon thereafter (Megahan and Kidd 1972). For example, monitoring by MacDonald et al. (2003) determined that sediment levels in runoff returned to pre-harvest levels within two years of decommissioning of a logging road. Recovery may take longer where there are steep slopes (e.g., greater than about 30%) and catastrophic landslides, or where suspended sediment is composed mainly of very fine particles (e.g., clay, Duncan and Ward 1985), or where it is transported during storms in gullies, ditches, skid trails, and drainageways rather than as overland sheet flow. The propensity of some logged areas, during the post-harvest period of rising water table, to generate landslides that can either fill or create wetlands permanently has been well-documented (see review by Jordan et al. 2010). Landslide risk depends on slope, soil type, position in watershed, precipitation, residual cover, groundwater flow patterns, and other factors (Wemple et al. 2001, Jakob et al. 2006).

A survey of nearly 200 harvest units in Oregon and California, where logging had occurred 2-18 years previously, found only 19 occurrences of sediment-transporting gullies, rills, or sediment plumes. Only 6 of those occurrences (nearly all associated with skid trails) were connected to streams (Litschert and MacDonald 2009). Another survey of 300 harvest sites in California found only 37 incidences where erosion was evident in riparian areas that adjoined the harvests (Cafferata and Munn 2002).

A sediment dosing experiment involving two small streams determined that the streams stored a large proportion of the sediment washed from a road surface (Duncan et al. 1987). In no instance did either stream transport more than 45% of the added material to their mouths, distances of 95 and 125 m. Added sediment <0.063 mm in size was transported efficiently through the systems at all but the lowest flows tested. Material in the size ranges of 0.5 and 0.063 mm and 2.0- 0.5 mm in size was retained at progressively higher rates, and no more than 10% of the sediment in the coarser size category transited the entire stream length. In-stream woody material temporarily retained much of the sediment. A study of 6 ephemeral streams in Oregon found 60-80% of suspended sediment (size range= 1.6-53 μm) was removed from the water column over a 75 m stretch at moderate input levels (Dieterich and Anderson 1998). Even greater proportional retention would be expected in wetlands because of their usually flat topography. Also in Oregon, 9 years of monitoring the sediment output from an 8000-ha block of intensely managed forest indicated that no long-term changes existed in sediment yields, despite 180 km of roads being constructed and 3400 ha of old-growth forests being harvested from slopes averaging over 60% (Sullivan 1985). In one Washington watershed where turbidity in streams was high following logging and road construction in the 1970s and 1980s, turbidity had returned to pre-harvest levels by 2000 even with continued active forest management. The improvement was not attributable to interannual changes in flow (Reiter et al. 2009). It is possible that harvests might have elevated the stream turbidity and suspended sediment loads at more localized areas within the watershed and/or for short but ecologically significant periods in the first few post-harvest years.

Three types of soil disturbance can occur in association with timber harvests (Miller et al. 2001):

- Compaction: the process by which the soil grains are rearranged to decrease void space (particularly large pores) and bring them into closer contact with one another, thereby increasing the soil's bulk density;
- Puddling (also called liquidification): the destruction of soil structure usually by churning or kneading action of wheeled or tracked equipment;
- Displacement: the act of moving soil laterally from narrow ruts or wider areas.

The destruction of soil structure in puddled soils inevitably results in compaction. However, a soil can be compacted with only minor structural change. Even if soils are puddled without compaction, they will self-compact as they dry (Chancellor 1977). Soil compaction from harvesting equipment creates small depressions (rutting) and reduces the capacity of precipitation to infiltrate downward in soils. This sometimes creates small wetlands, but it also redirects runoff and accelerates the passage of water through the landscape, potentially increasing erosion, allowing less time for retention of suspended sediment, and resulting in sedimentation of downslope waters. Most wetland soils are sensitive to even minor compaction and other disturbance of their surface layer. Organic and clay soils are particularly susceptible to compaction, puddling, and rutting. In western Alberta, Corns (1988) estimated that compacted soils would require 10 to 21 years to return to pre-disturbance conditions, with surface layers requiring the longest.

Soil is least disturbed when low volumes of timber per unit area are removed per unit area. In Ontario, selective cutting of up to 50% of the timber in various harvest units appeared to result in no observable increase in sediment delivery to adjoining riparian areas (Kreutweiser and Capell 2001). Also, as noted in the review by Miller et al. (2004), soil is least disturbed when low when yarding systems are used that primarily lift rather than drag logs (e.g., skyline, balloon, or helicopter). Balloon or helicopter logging compacts or disturbs soil deeply in only 2-5% of the logged area (Dyrness 1972; Bockheim et al. 1975, Megahan 1988). In contrast, where cable systems do not provide full suspension or lift, the area of disturbed soil can range up to 45% of the logged area. Because full-suspension yarding methods are more costly, skidding logs with tractors, especially rubber-tired tractors, is more common where slopes are less than about 30% and skidding distances less than about 200 m (Miller et al. 2004). The amount and types of disturbance also vary depending on size and amount of logging residue, irregularity of terrain, moisture content at time of traffic, and inherent resistance of each soil to disturbance. Charts for assessing the susceptibility of a particular site to soil compaction were published by the B.C. Ministry of Forests (1999). Under some conditions when prescribed fire or slashburns are used, those practices decrease the capacity of soils to allow infiltration of precipitation, i.e., makes them more water-repellant (Certini 2005).

Soil compaction usually reduces plant cover and growth of surviving plants (Greacen and Sands 1980, Miller et al. 1996). Tree growth sometimes does not recover for several decades (Wert and Thomas 1981, McNabb et al. 2001). However, especially in coarse-textured soils, compaction sometimes increases growth of the surviving tree seedlings by improving near-surface moisture retention and reducing vegetative competition. Arthropods, fungi, nematodes, and/or microbial populations are generally lower in compacted than in reference soils (Smeltzer et al. 1986, Dick et al. 1988, Dexter 1978, Whalley et al. 1995), and overall biological activity is reduced (Dulohery et al. 1996). Resulting decreases in nutrient mineralization and availability may also contribute to reduced root growth (Phillipson and Coutts 1977). In addition, compaction-related changes in soil oxygen availability and root physiology can increase the incidence of soil pathogens (Jacobs and MacDonald 1990).

From a study of forest soils in the Rocky Mountains of Alberta under 3, 7, and 12 cycles (individual loaded trips) of skidding with mostly wide-tired skidders, McNabb et al. (2001) found that soil compaction occurred only when the soils were at or wetter than field capacity. A significant increase in bulk density due to skidder activity did not affect field capacity, permanent wilting point, and available water holding capacity. That was because the changes in soil porosity were essentially confined to the macro (larger) pore space while the micropore space remained unaffected (Startsev and McNabb 2001).

3.2.2.2 Logging Road Effects on Sediment in Wetlands

Forest roads, landings, and skid trails have been repeatedly implicated as the primary source of soil erosion and sediment runoff from silvicultural operations, e.g., Megahan and Kidd 1972, Schuldiner et al. 1979, Toews and Henderson 2001, Rivenbark and Jackson 2004, Jordan 2001, 2006.

Surveys of logging roads in western Washington and Oregon found that 42-66% of road drainage points discharged to hillslopes with no delivery to streams, 28-35% delivered directly to streams, and 17-28% delivered to streams via gullies (Bilby et al. 1989; Bowling and Lettenmaier 1997; La Marche and Lettenmaier 1998; Wemple et al. 1996). More importantly, however, these same or similar studies found that only 17-35% of the total road mileage contributes sediment to the stream system (Bowling and Lettenmaier 1997). In at least one logging operation where best management practices for sediment were aggressively implemented, the rates of sediment delivery from roads to streams were very low (0.05 to 0.2 tons/km^2/year) despite high road density. Thus, reducing the road mileage that discharges to streams and wetlands – not merely reducing total road mileage or density – can reduce the quantity of sediment that reaches streams and wetlands (Miller et al. 2001).

Road-related soil losses can be reduced with the use of several best management practices (Hynson et al. 1983, Welsch et al. 1995, Ice 2009, Ice and Schilling 2012). These include immediately vegetating cut and fill slopes (Swift 1988, Burroughs and King 1989), improving road surfaces (Reid and Dunne 1984), dispersing water onto hillslopes via broad based dips, turnouts and relief culverts (Luce and Black 1999), scheduling traffic during dry periods (Bilby et al. 1989), and providing vegetated buffers (Swift 1986).

3.2.2.3 Buffer Effectiveness for Protecting Wetlands from Excessive Sediment

Many studies have shown that sediment retention is greatest in the first 5-20 ft of a well-vegetated buffer, that is, the most uphill portion which is closest to eroding soil (Polyakov et al. 2005, White et al. 2007). A study in Georgia (White et al. 2008) found that under ideal conditions, even the finest sediment particles were removed within about 15 m (49 ft) as long as sheet flow, rather than gully transport, was the primary mechanism that transported the sediment. A review of 80 studies of buffers (Liu et al. 2008) concluded that for retaining sediment, vegetated buffers of about 10 m (33 ft) are usually optimal where sheet flow conditions predominate because additional widths retain only slightly more sediment. Similarly, a study of 22 logging sites in the Pacific Northwest reported that 10 m wide buffers were effective in eliminating chronic delivery of sediment to stream channels within 2 years after the harvest operation, except where buffers were crossed by cable yarding routes or skid trails (Rashin et al.

2006). A study in Ontario (Kreutzweiser and Capell 2001) reported that riparian buffers made very little difference in the amount of sediment reaching streams downslope from a timber harvest, perhaps because their effectiveness was partially compromised by roads and trails that intersected them. Even where experimental studies indicate that nearly all sediment is retained by buffer vegetation, retention is not necessarily long-term, as storms at decadal or longer intervals can remobilize sediments and move them into wetlands and streams (Gomi et al. 2005). Also, if buffers are too narrow, buffer trees are more susceptible to soil-disturbing windthrow (Pollock and Kennard 1998, Lewis et al. 2001). This can increase sediment delivery to streams and wetlands, especially as water tables rise in response to temporary elimination of transpiration losses from those trees.

3.2.2.4 Biological Effects of Sediment in Wetlands

Although no federal or state agencies have established numeric standards addressing sediment and nutrients in wetlands specifically, numerous studies have documented both their beneficial and adverse effects on species and functions in lakes and streams. In wetlands, some organisms might be expected to tolerate or even require higher concentrations of sediment and nutrients than is the case with stream organisms, but no studies have addressed that. What is known is this: wetlands in the Pacific Northwest whose watersheds have been partially cleared of vegetation do tend to experience both increased loads of sediments (suspended solids, turbidity) and nutrients (mainly phosphorus and nitrate), and these wetlands simultaneously experience shifts in their aquatic biological communities (see sections 3.2.2.4, 3.2.4.5, and 3.3). Those shifts can be judged beneficial or harmful depending on the species or processes affected and one's perspectives. And whether the increased sediment and nutrients are the primary cause of biological changes, as opposed to associated changes in runoff amount and timing or other factors, remains undetermined. A series of dosing experiments with wetland plants in Pennsylvania found that sedimentation generally lowered community biomass, diversity, and richness, while enrichment increased community biomass (Mahaney et al. 2004, 2005). As expected, depressional wetlands accumulated more sediment than riverine and slope wetlands (Wardrop and Brooks 1998). Plant species typical of floodplain wetlands were less sensitive to sediment additions than plant species typical of depressional wetlands (Mahaney et al. 2004). In another dosing experiment, sediment deposition caused an immediate drop in alder photosynthesis (Ewing 1999). Wetlands that are sufficiently deep and permanent to support submerged aquatic plants are perhaps most sensitive to inputs of suspended sediment, because most of those plants (e.g., sago pondweed in ponds, eelgrass in estuarine wetlands) require very clear water (Davis and Brinson 1980).

3.2.3 Forest Practices Effects on Nutrients, Carbon, and Silvicultural Chemicals in Wetlands

3.2.3.1 Tree Removal Effects on Nutrients and Carbon in Wetlands

In the short term, when trees in a wetland are cut and the wood is moved to distant locations, the wetland loses carbon that had been introduced by photosynthesis, as well as nutrients that had been taken up from the soil and incorporated into wood. In addition, logging waste (e.g., foliage and woody debris) releases nutrients and carbon as it decays. With the higher water tables resulting from logging (see section 3.1), there is increased risk of nutrients and carbon, as well as chemicals applied for silviculture, being transported off-site in runoff. In some cases, logging roads can expedite the export process.

Timber harvests also affect biogeochemical cycles by altering nutrient sinks and sources, increasing in soil temperature and sometimes humidity, altering soil structure, and flushing of nutrients and dissolved organic carbon from organic surface soils into wetlands and other surface waters (Carignan and Steedman 2000). As is the case with stream temperature, the amount of nutrients and carbon exported from timber harvest sites to wetlands depends partly on the amount, type, proximity, and configuration of vegetative cover that remains in the cutover area immediately after tree harvest, its proximity to wetlands, type of equipment used (degree of ground disturbance and compaction from skid trails, landings, etc.), time of year when logging occurs, soil erodibility, slope, restoration actions, and width of vegetated buffers. These and other factors are reviewed in the context of forest practices by Brown 1980, Binkley and Brown 1993, Brown and Binkley 1994, Neary and Hornbeck 1994, Dissmeyer 2000, Neary 2002, Feller 2005, Gomi et al. 2005, Gundersen et al. 2006, Stednick 2008, Kreutzweiser et al. 2008, VanMiegroet and Johnson 2009, Neary et al. 2009, and Pike et al. 2010.

Concerns have sometimes been raised about whether forests can retain their fertility after several harvest rotations. If the forest landscape surrounding wetlands loses nutrients over time, so may the wetlands that receive runoff and groundwater from it, with resulting reduction in their biological productivity. Much of the nutrient content of forest soils is contained in organic matter in the duff layer (including leaves, down wood) and other parts of the upper soil profile. Thus, loss of organic matter after harvesting or site preparation can have profound effects on soil physical, chemical, and biological properties and reduce soil productivity (Perry et al. 1989, Powers et al. 1990, Everett et al. 1994, Harvey et al. 1994, Jurgensen et al. 1997, Bulmer 1998, Page-Dumroese et al. 2001). This is especially concerning in drier parts of the region, because ectomycorrhizal root activity at such sites strongly influences site productivity and is closely tied to soil organic matter (Jurgensen et al. 1990). Some species, such as western hemlock, produce more seedlings and their survival rate is significantly higher when the highly organic duff layer of the soil is intact, particularly in drier areas. Studies of post-harvest changes in forest soil nutrients were compiled and reviewed by Kreutweiser et al. (2008) and Pike et al. (2010). Harvest effects on biogeochemical cycling specifically in northern wetlands were reviewed by Lockaby et al. (1999).

Phosphorus

Phosphorus can be lost from post-harvest soils by downward leaching of soluble phosphorus from decaying organic matter, as well as by increased transport off-site in connection with higher post-harvest water tables and erosion of phosphorus-bearing soil particles and decaying organic matter. In southern Alberta, release of phosphorus (P) from soil organic matter was found to be very fast during the first post-harvest year and declined thereafter (Prescott et al. 1993). However, of the relatively few studies that have compared soil phosphorus fluxes before and after logging, most have shown no statistically significant change in soil phosphorus (Kreutweiser et al. 2008, Malik and Teichert 2009).

Phosphorus export from upland harvested sites to wetlands increases in association with timber harvests partly because phosphorus readily adsorbs to fine sediment particles. Those particles are easily carried into low spots (streams and wetlands). Thus, like sediment, phosphorus export from harvested areas to wetlands is affected by landscape position, soil properties, and post-disturbance precipitation patterns (Putz et al. 2003, Chanasyk et al. 2003). Phosphorus and nitrate are common components of fertilizers applied to some managed forests (see section 3.2.3.3), and phosphorus is a major component of chemical retardants applied to wildfires. If some types of forest soils are not intentionally fertilized, it can take decades or centuries after trees are harvested to return soil phosphorus -- a key component of forest fertility -- to pre-harvest levels (Trettin et al. 1997). Soil phosphorus is restored very slowly because its main source is erosion of phosphorus-bearing rock.

In the Blue Mountains of eastern Oregon, dissolved phosphate in runoff increased after a forest was clearcut (Tiedemann et al. 1988). However, post-harvest phosphate concentrations in a coastal Vancouver Island lake were less than before logging occurred (Nordin et al. 2007). Following timber harvest and road building in one northern Idaho watershed, there was no significant change in runoff phosphorus concentrations (Gravelle et al. 2009). In Quebec, lowland (large watershed) lakes with more clearcutting in their watersheds had higher concentrations of total phosphorus than lowland lakes that had little or no recent timber harvests (Carignan et al. 2000). Among 11 watersheds in central Alberta where harvests had removed 0-35% of the timber, there was a 40% increase in phosphorus concentrations in the lakes whose watershed area had more than 15% of the trees removed (Prepas et al. 2001). Increases were most pronounced in lakes that were shallow (mean depth = 3.1 m, range = 0.7–14.4 m) and had (a) weak thermal stratification, (b) large drainage basins, and (c) shorter water residence times. Cyanobacteria (blue-green algae) also increased in response to the nutrient additions, primarily in shallow lakes and wetlands. Buffer widths (20, 100, and 200 m) did not appear to influence lake response to harvest. When timber harvest is accompanied by wildland fires or perhaps by extensive slash burning, phosphorus as well as sulfate concentrations in receiving waters tend to increase (e.g., Carignan et al. 2000, McEachern et al. 2000).

Nitrate

Nitrate can also be lost from post-harvest soils by downward leaching of soluble nitrate. It can also be diminished by conversion to nitrogen gas if post-harvest water tables rise and thus improve (usually) the conditions suitable for denitrification. However, this might be partly offset where nitrogen-fixing plants like alders quickly become established, allowing the nitrogen component of soil fertility to recover at least partially (Murray et al. 2000, Rothe et al. 2002, Stednick 2008). Timber removal at one location in British Columbia resulted in higher levels of soil nitrate even 7 years after harvest (Hope et al. 2003). However, most studies (compiled by Kreutweiser et al. 2008) have found no statistically significant difference in soil nitrate before versus in the first few years after harvest. In one case nitrate losses apparently related to harvest did not occur until many years post-harvest (Hazlett et al. 2007). In an Alberta study, no effects of timber harvest on the amount of nitrate in soil and in surface and ground water were detected, whereas topographic differences were a strong predictor, with wetlands having greater nitrate concentrations (Macrae et al. 2006).

Unlike phosphorus, significant amounts of the otherwise-increased nitrate can be removed from shallow groundwater by microbially-mediated conversion of nitrate to nitrogen gas, i.e., denitrification. In fact, forested wetlands (Phillips et al. 1993) and hillslope seeps such as those commonly found in new clearcuts have been documented to be hot-spots for denitrification (Hill 1991, O'Driscoll and DeWalle 2010). However, if water tables rise further as a result of logging-associated loss of tree transpiration, causing more of the water to "surface" during storms, then the transport into downslope waters of nitrate – as well as phosphorus, sediment, and other substances -- is likely to increase (Vitousek and Melillo 1979, Reynolds and Edwards 1995, Creed et al. 1996, Devito et al. 2000, Gumiero et al. 2011).

With regard to nitrate, clearcutting in the Blue Mountains of eastern Oregon was associated with only minimal increases in nitrate concentration, which peaked at 0.52 mg/L (Tiedemann et al. 1988). In the Olympic Peninsula of Washington, partial harvesting in two watersheds (7 and 33% of watershed) was associated with higher nitrate in runoff, which the researchers attributed mainly to a post-harvest increase in nitrogen-fixing alders (Murray et al. 2000). In the western Cascades of Oregon, nitrate yields in a clearcut were highest in the third year following harvest (2.9 kg/ ha), whereas the peak concentration (0.005-0.010 mg/L) occurred in the fourth year after harvesting (Adams and Stack 1989). Differences among four watersheds with different treatments (uncut, shelterwood with 50% area removed, patch cut with 30% removed, and clear-cut) were negligible after 9 years. Another study in the Oregon Cascades found that nitrate concentrations increased six-fold in a clearcut treatment for 7 years after harvesting. Concentrations frequently exceeded 0.10 mg/L during a high-flow period (Harr and Fredriksen 1988). An earlier Oregon study of timber harvesting and broadcast burning (Martin and Harr 1989) found that clearcutting and shelterwood harvesting in combination with broadcast burning was associated with a 30-fold increase in stream water nitrate levels. Surprisingly, this was less than half the nitrogen input they estimated from precipitation. In an Oregon Coast Range watershed, nitrate increased from 0.70 to 2.10 mg/L on an area that was both clearcut and broadcast-burned, but concentrations returned to pre-logging levels after 6 years. On a patch-cut treatment, there were no associated changes in nitrate (Brown et al. 1973). However, following a 50% partial cut northern Idaho, Gravelle et al. (2009) found the concentration of nitrate increased significantly downstream. Nitrate downstream from the clearcut increased to 0.35 mg/L, also a statistically significant change. Statistically significant but smaller increases were also observed further downstream. Forest road construction did not increase nitrate runoff significantly.

In British Columbia, nitrate concentrations nearly doubled one year after logging began but persisted for only 2 years at low flows and for 7 years at high flows after harvesting activities ended (Scrivener 1988). Nitrate and ammonia/ammonium concentrations increased in a small coastal lake on Vancouver Island after logging near its shores. Highest concentrations occurred 2–3 years after logging, and returned to pre-harvest levels within 5–8 years (Nordin et al. 2007). Another study in British Columbia (Feller 1989) indicated that slashburning doubled the stream water nitrate output compared to clearcutting alone. Nitrate export rates from all western forest lands, excluding areas dominated by alder, have been estimated at 78-79 $kg/km^2/year$ (Wise and Johnson 2011).

The nutrient consequences of post-harvest domination of many clearcut sites by alders can be considerable, as red alder is perhaps the region's most prolific wetland nitrogenfixer. Where a semi-open canopy persists, red alders enrich the soil, resulting in a more productive and/or species-rich understory plant community with potential benefits to deer and perhaps other herbivores (Tappeiner et al. 1991, Hanley and Hoel 1996, Hanley et al. 2006). As compared with other riparian trees, alders may support more terrestrial insects that become prey for salmon (Allan et al. 2003). In Alaska, one study found that alders added 164 kg N per hectare per year to floodplain soils. Alders can account for up to 70% of the nitrogen that accumulates during vegetation establishment in river floodplains (Ruess et al. 2009). Some studies (e.g., Compton et al. 2003, Monohan 2004) have theorized or reported increased nitrate inputs to streams in watersheds with extensive nitrogen-fixing alders, with possible benefits to productivity of aquatic invertebrates (Hernandez et al. 2005, Medhurst et al. 2010) and perhaps salmon. However, Edmonds and Tuttle (2010) failed to find the expected higher nitrate concentrations in streams bordered by the most extensive alder cover.

Multi-year studies of logging effects are confounded by interannual variation in temperature and precipitation, which can be major drivers of local nutrient flux. Response of nutrients to timber harvesting can be very site-specific (Kreutweiser et al. 2009). Also, the effects of timber harvest are not always separated from the effects of new roads associated with the harvests, and different levels and configurations of tree harvesting are seldom compared. There appear to be no measurements of phosphate or nitrate loads or concentrations in or around this region's wetlands determined in the context of studies of forest practices.

Data from over 300 small forested streams throughout the United States suggest that organic forms of nitrogen prevail in hardwood (deciduous)-dominated watersheds whereas inorganic forms of nitrogen prevail in conifer-dominated watersheds (Binkley et al. 2004). A shift from a conifer to a deciduous forest often makes soils less acidic (Sabau et al. 2010) as does a shift from cedar to hemlock (Messier 1993, Prescott et al. 1996). Such changes could have strong implications for soil fertility and forest productivity over the long term (VanMiegroet and Johnson 2009). In 13 watersheds surrounding Puget Sound, deciduous riparian forests with moderate disturbance produced organic matter loads similar to those of conifer forests, but compared with conifer forests, they had a greater prevalence of leaf material and produced 54% higher nitrate loads and 40% higher phosphorus loads (Roberts and Bilby 2009). Conversion from coniferous to deciduous vegetation also produced subtle shifts in timing of inputs. Differences in forest architecture also can influence rates of nutrient subsidies (Cadenasso et al. 2004).

<u>Carbon/ Organic Matter</u>

Carbon is essential to nearly all life, and forest practices can influence its amount and cycling rate in wetlands. In wetlands, carbon-rich plant tissues (foliage, roots, woody debris) accumulate at a rate that depends on water residence time, turbulence, temperature, light, nutrients, acidity, the type of plant material, the abundance of decomposing organisms, and other factors. In coniferous forested wetlands or landscapes, the input and decomposition of organic matter is distributed more evenly throughout the year than in deciduous forested wetlands and watersheds, thus providing a more reliable source of carbon to food webs (Richardson et al. 2005b).

Carbon can be exported from wetlands in dissolved or particulate form (leached and infiltrated downward, or washed downstream if the wetland has an outlet) or as a gas – carbon dioxide and methane, both from respiring organisms. In addition, fire and floods can cause net losses of carbon from a wetland in the short term. Streams and lakes in watersheds with proportionately large areas of wetlands tend to have relatively high concentrations of dissolved organic matter (e.g., Creed et al. 2008). Some individual wetlands are net exporters of dissolved carbon (e.g., Dalva and Moore 1991, Walbridge and Lockaby 1994, Fitzgerald et al. 2003) whereas others are effective for sequestering carbon (e.g., Pelster et al. 2008). In wetlands of Southeast Alaska, levels of dissolved organic matter increase with shallower depth to water table and cooler soil temperature (D'Amore et al. 2010).

Apparently no published studies have measured changes in complete carbon budgets of wetlands in connection with timber harvesting in the Pacific Northwest. Those that have measured part of the budget -- i.e., dissolved carbon loads and concentrations in receiving waters before and after harvest -- have generally documented short-term two- to five-fold increases in dissolved carbon in downslope streams or lakes, especially when clearcuts further upslope were on peat soils. These include studies by Plamondon et al. 1982, Hinton et al. 1997; Startsev et al. 1998, Carignan et al. 2000, France et al. 2000, Lamontagne et al. 2000, Steedman 2000, Pinel-Alloul et al. 2002, O'Driscoll et al. 2006, and Bertolo and Magnan 2007. Multiple runs of a mass-balance model of carbon cycling suggested that stream organic matter might be temporarily reduced up to 80% as a result of removing riparian vegetation which provides the usual organic matter inputs to streams in southwestern British Columbia. In contrast, a stream temperature increase of 3 ^{o}C that resulted from shade removal might, through a tendency to increase decomposition of instream organic matter, reduce instream organic matter by only 20% (Karlsson et al. 2005).

From the moment trees are harvested, a potential exists for much of the residual non-marketable organic material (sawdust, limbs, foliage) to be washed or blown into wetlands. Especially in depressional wetlands, that material will add to a considerable amount of decomposing material already there which was produced by plants within the wetland. Many aquatic invertebrates in wetlands feed on plant detritus, and the specific characteristics of the carbon in that detritus -- which vary by its source (upland vs. wetland plant species) but not necessarily by forest age -- can influence its processing by those detritivores (Palik et al., 2001, 2006). If accumulation of carbon from both upland and wetland sources outpaces the capacity of organisms in the wetland to break it down, the wetland may eventually fill with organic matter and become more acidic (e.g., Shepard 1994, Brais et al. 1995, Trettin et al. 1997, Cui and Trettin 2005 a, b, Tremblay et al. 2009, McLaughlin et al. 2011). If hydrologic conditions are also suitable, native mosses (e.g., *Sphagnum* spp.) proliferate and amplify the acidifying effect, sometimes reducing plant species richness (Anderson et al. 2007). In bogs and many coniferous wetlands on peaty soils, the tendency of the post-harvest acidic conditions to restrict nutrient cycling limits the growth of most trees (e.g., Prescott et al. 1996, Gale et al. 1998). Well before that happens, the decaying material can severely deplete oxygen in water and sediments,. The oxygen depletion will stress some aquatic life, either directly or by supporting the emission of ammonia and methane from flooded decaying organic matter. Methane also is a potent contributor to global warming. Its emission rate from wetlands is difficult to predict, and increases or decreases depending on site characteristics and specific forest practices (Bubier et al. 1993, Roulet and Moore 1995, Dulohery et al. 1996, Lavoie et al. 2005, Li et al. 2004, Cui and Trettin 2005a, b). Dissolved carbon exports from logged watersheds also can be a vector for mercury, transporting this metal to downslope wetlands and lakes where high concentrations of methyl mercury can accumulate in animal tissues and become toxic to aquatic life (Garcia et al. 2007).

At the same time, increases in dissolved carbon inputs to wetlands, as a result of harvests further upslope, may have some ecological benefits. That is because some forms of carbon, besides supporting food chains and diverse biological communities, help protect aquatic life from harmful effects of ultraviolet radiation, and bind some toxic metals (Kerr et al. 2008). Soil organic matter also supports the conversion of soluble nitrate to harmless nitrogen gas by microbial communities, especially in groundwater seeps and wetlands within meandering stream networks (Pinay et al. 2003). In the Snohomish River Basin of western Washington, adult coho abundance and median adult coho densities were greater where peaty soils were more extensive, a finding that applied at both the watershed and stream reach scales (Pess et al. 2002). Peaty soils are typically associated with wetlands in this part of the PNW. Because of their high carbon content, such soils can be assumed to be particularly sensitive to even small alterations of soil structure. Those changes can result in significant carbon losses and reduced fertility (Li et al. 2004). Soil temperatures that speed decomposition of peat soils also can increase the export of carbon as carbon dioxide.

Literature reviews by Johnson (1992) and Johnson and Curtis (2001) found that most studies (of upland, not wetland soils) reported no statistically significant changes in soil carbon after timber harvest. Whatever losses were noted were usually small (seldom more than 15%). More recently, a survey of 19 sites representing a broad range of tree species, soil types, and climate identified no statistically significant losses of soil carbon from mineral soils after logging (Sanchez et al. 2006). However, a modeling analysis predicted a steady decline in soil carbon over a 300-year period for boreal forest tree species. The decline was exacerbated when shorter harvest rotation cycles were modeled (Seely et al. 2002). A study of Michigan forested wetlands on mostly organic soils found no difference between harvested and unharvested wetlands 11 years post-harvest in terms of carbon, nitrogen, calcium, magnesium, or potassium in three strata of above-ground vegetation, woody debris, roots, forest floor, and mineral soil (Trettin et al. 2011).

3.2.3.2 Logging Road Effects on Nutrients and Carbon in Wetlands

The effects of logging roads on nutrients and carbon have seldom been separated from the effects of tree removal. As noted earlier, roads potentially have the additional effect of accelerating the transport of nutrients, carbon, and silvicultural chemicals from a harvest site to wetlands.

3.2.3.3 Silvicultural Chemicals and Wetlands

<u>Fertilizers</u>

Timberlands are commonly fertilized to increase stand volume and reduce rotation length. In Oregon, approximately 95,000 acres have been treated annually (Chappell et al. 1992, Anderson 2001). Water quality concerns are mostly related to the potential for transfer into wetlands and other water bodies of phosphorus and nitrate, and the heavy metal contaminants sometimes associated with fertilizer. Studies on the nutrient effects on aquatic systems of the fertilizers used in forest management in the Pacific Northwest were reviewed by Bisson et al. 2008, Anderson 2002, Pike and Perrin 2005, and Pike et al. 2010. Overall, 1-27% of the nitrogen applied to forests runs off into streams (Anderson 2002). Based partly on results from simulation models, Wise and Johnson (2011) concluded that fertilizer applications under certain circumstances could temporarily be an influential source of nitrogen to streams in the Cascades and the Washington and Oregon Coast Ranges. Fertilization is not a reliable or long-term way to increase tree growth in all settings. This may be particularly true when attempting to reestablish trees in formerly forested wetlands where inundation and other factors can be more limiting. Even in uplands, controlling weeds that compete with tree seedlings can be a more effective long-term strategy for encourging growth of regenerating saplings (Rose and Ketchum 2002).

Pesticides

Insecticides are applied to forests for insect pest control and in wetlands are a particular concern to aquatic invertebrates and fish. **Herbicides** are generally of lesser direct concern to aquatic animals. They are applied, sometimes in conjunction with prescribed burns, to kill vegetation that threatens newly planted seedlings, i.e., "site preparation." Herbicides not only kill plants, but in doing so they directly or indirectly increase the concentration of nutrients in runoff (Likens et al. 1970, Sollins et al. 1981, Neary et al. 1986, Davis 1987, Feller 1989, Simpson et al. 1997). Nitrate increases can be minimized by increasing the intervals between herbicide applications sufficiently to allow revegetation to occur, assuming the new growth is not predominantly alder.

The transport of herbicides and their degradation products was reviewed by Norris et al. 1991, Dissmeyer 2000, Michael 2000, and Clark et al. 2009. Naturally, the potential for herbicide drift into wetlands is greater when they are applied aerially rather than manually. The most mobile herbicides are those that are water-soluble, do not degrade quickly, do not volatilize easily, and are not easily sorbed by soils. The fat-soluble–water-insoluble herbicides are generally more toxic than those that are water-soluble. Most herbicides tend to dissipate quickly or are detoxified quickly by microbial communities or photolytic processes, and thus do not bioaccumulate. However, pesticide formulations and tank mixes (including adjuvants and surfactants) are constantly being changed by manufacturers and information on some components is proprietary. This often makes it difficult to compare the toxicity of current brand name pesticides and their degradation products with ones of the same name formulated in past years, for which toxicological test results may be available. A review by Macneale et al. (2010) highlights the fact that relatively little is known about sublethal and indirect effects of forest pesticides on salmonids in the PNW. Also, relatively little is known about *indirect and cumulative* effects of pesticides, fertilizers, and shortened rotations on soil acidity, fertility, and availability of trace elements that influence the species composition of aquatic and terrestrial plant and animal communities. Limited evidence suggests such effects could be significant in at least some local instances (Flueck and Smith-Flueck 2006).

Fire Retardants and Dust-control Compounds

Fire *retardants* are part of a suite of tools and options for managing wildland fire. At any given location in the region, fire retardants are unlikely to be applied more than once in many decades, yet they are noted because of their potential toxicity to aquatic organisms, including those in wetlands. They typically are applied aerially, which increases the potential for wetlands being exposed because many wetlands are not visible from the air under conditions of poor visibility that accompany wildfire (smoke, night-time). Retardants are primarily phosphate- or sulfate- based compounds and often are contaminated with various levels of heavy metals. Toxic concentrations can occur, particularly when light levels are high and soils adjacent to wetlands or streams are coarse-textured and contain little organic matter (Little and Calfee 2002). Fire *suppressants* are foams comprised of proprietary mixtures of sodium and ammonium salts, alcohol, ether, and sulfates. *Dust suppressants and soil stabilizers* are applied seasonally to many unimproved forest roads, especially during construction near settled areas. Dust suppressants include various salts, asphalt emulsions, oils, synthetic polymers, mulches, and lignins. Many are by-products and their exact composition is unknown (Piechota et al. 2004).

3.2.3.4 Buffer Effectiveness for Protecting Wetlands from Excessive Nutrients and Silvicultural Chemicals

Phosphorus

Nutrients that are most often targeted by vegetated buffers are nitrate and phosphorus. Literature on phosphorus retention by vegetated buffers was reviewed by Hoffman et al. (2009). The ability of vegetated buffers to attenuate phosphorus before it reaches wetlands or streams depends largely on the degree to which runoff between the harvested area and receiving waters is concentrated in drainageways on the land surface, as well as the form of the phosphorus. Where phosphorus is mainly attached to sediment (as often it is), then buffer widths sufficient for sediment retention may be almost as effective as those specified for retaining phosphorus (White et al. 2007). For example, despite the limitations of the Zhang et al. (2010) meta-analysis of field studies, they calculated 97-100% retention of phosphorus by buffers of only 66 ft (20 m) width. However, where phosphorus is mostly in dissolved form (i.e., dissolved reactive phosphorus, soluble reactive phosphorus, orthophosphate), and where many surface drainageways intersect the vegetated buffer, then buffers may need to be very large or may not be effective at all (DeVito et al. 2000, Prepas et al. 2001).

The capacity of a wetland or its buffer to retain phosphorus has been shown to decline with continued exposure to nutrient runoff. As phosphorus accumulates in soils, its continued storage becomes more precarious. As it accumulates beyond some unknown equilibrium threshold, it is more easily desorbed and exported (Dillaha et al. 1988). This has led some investigators to propose harvesting of trees and other vegetation from wetlands and their buffers as a means of delaying the oversaturation of these sites with phosphorus (Lee et al. 2000). However, potential benefits from such harvests could easily be offset by increased transport of remaining phosphorus to wetlands as a result of higher post-harvest water tables.

Nitrate

In the most comprehensive literature review and meta-analysis to date, Mayer et al. (2007) synthesized results from over 60 peer-reviewed studies of **nitrate** removal by buffers adjoining a wide variety of land uses (agricultural, urban, silvicultural) with diverse nitrate loading rates in temperate climates. They found that widths of approximately 5 m, 50 m, and > 150 m are needed to achieve, respectively, 50%, 75%, and 90% removal efficiencies for nitrate. A similar meta-analysis of buffer widths was published by Zhang et al. (2010) but was based on only 8 studies of nitrate removal by buffers. Zhang et al. reported that 91-100% of nitrate loads can be removed by a buffer of only 20 m.

One study in Ontario found that where a confining layer was situated beneath very coarse soils, buffers with widths of up to 175 m were required to remove 90% of the incoming nitrate (Vidon and Hill 2006). With regard to runoff specifically from harvest, after a Nova Scotia forest was clear-cut, nitrate increased in only one of 6 streams where riparian buffers were 20 m (66 ft) wide or wider (Vaidya et al. 2008). Selective cutting within the buffers reduced their effectiveness for removing nitrate. Whether a buffer is forested or contains only intact herbaceous vegetation appears to have little influence on its capacity to remove nitrate (Sabater et al. 2003).

Buffer widths required to protect water bodies from nutrient-bearing logging runoff might be assumed to be narrower than those needed for protecting water bodies from agricultural or urban land uses, because under many or most conditions, even clearcuts would be expected to release smaller amounts of nutrients than from the other land uses. However, most studies of nitrate transport and removal have been conducted in lowland agricultural watersheds rather than headwater forested watersheds (Ranalli and Macalady 2010). In southwestern British Columbia, Feller (1989) found that the transport of nitrate to streams from clear-cutting generated about 10 kg N/ha, as compared with clear-cutting plus slash burning (~ 20 kg N/ha) and with herbicide application in young plantations (~ 40 kg N/ha). For comparison, on the average one horse on 5 acres generates about 20 kg N/ha of nitrate (in manure), while suburban lawns and croplands are commonly fertilized at much higher rates.

Pesticides

A sufficiently wide vegetated buffer, when maintained next to a pesticide application area, can help reduce transport of pesticides into wetlands and streams where their application is not generally allowed (Reichenberger et al. 2007). However, buffers are not a panacea. A review of studies published on herbicide retention by buffers concluded that the ratio of the acreage of the herbicide source area to that of the buffer did not generally influence buffer effectiveness in the area ratio range of 5:1 to 45:1 (Krutz et al. 2005). Under calm wind conditions, densely vegetated buffers with a width of 10 to 33 ft reduced most of the drift of aerially applied pesticides before surface waters were contaminated (Brown et al. 2004). At higher wind speeds, either a 20-m wide hedgerow or the same hedgerow plus a 10-m wide dense tree stand was found to be effective in one study. However, runoff can still carry these substances to nearby water bodies. A pesticide runoff study in Georgia demonstrated retention of some pesticides by a 125-ft buffer containing a mature hardwood riparian forest (Lowrance et al. 1997, Vellidis et al. 2002). Computer models developed by Rodgers and Dunn (1993) suggested that buffers of at least 330 ft (100 m) width would be needed to retain and detoxify one common herbicide (atrazine) during times of peak runoff. This finding was confirmed in wetland studies by Moore et al. (2001), although Gay et al. (2006) found 92-100% of atrazine could be retained within 105 ft if vegetation was dense and calm wind conditions prevailed at the time of application. Even larger buffers would be needed to retain chlorpyrifos or metolachlor, insecticides which are directly toxic to aquatic life (Moore et al. 2001, 2002). Zhang et al. (2010) calculated that 93% of pesticide loads (all compounds lumped together) are retained by buffers of 30 m. Their analysis suggested that buffers wider than that would not appreciably improve the removal efficiency. The applicability to the Pacific Northwest of their conclusions may be limited due to this region having steeper slopes and greater annual precipitation than most of the studies included in their meta-analysis. Moreover, even near-trace amounts of some pesticides can have harmful biological effects (Vandenberg et al. 2012).

3.2.3.5 Biological Effects of Excessive Nutrients and Silvicultural Chemicals

Nutrients

No state or province has adopted numeric water quality standards specifically for wetlands. Moreover, neither the federal governments nor the states/ provinces have established nutrient standards for any water body type. This is the case despite the widespread recognition that if nutrient loads are excessive, wetlands – like any water body – can experience large blooms of algae that temporarily diminish dissolved oxygen, shade out aquatic plants, and stifle aquatic productivity. Even when massive algal blooms are absent, slight shifts in the dominant algal species as a result of canopy removal (e.g., from diatoms to filamentous green taxa; Shortreed and Stockner 1983, Danehy et al. 2007) and shifts in the nutrient content and types of leaf litter (deciduous or coniferous; Cummins 2002) have the potential to influence invertebrate and fish populations (Anderson 2002). Timber harvests have been reported to have had such impacts on lakes (e.g., Planas et al. 2000) so it is perhaps even more likely that wetlands, with generally smaller ratios of catchment area to wetland surface area, could experience such impacts. However, no strong evidence exists that shows which changes in leaf litter type or forms of algae should be judged to be "good" or "bad" for favored consumers at various seasons and at different points in post-harvest time.

Also, many of this region’s rare and threatened native plants are ones that inhabit only the most nutrient-poor wetlands (e.g., bogs, fens, alpine meadows). In general, organisms in nutrient-poor aquatic habitats are most likely to show large responses (positive or negative) to nutrient additions (Marczak et al. 2007). No studies exist to evaluate their vulnerability to runoff from fertilizer applications. For nitrate, forest fertilizer applications must be considered as additional inputs on top of apparently increasing inputs of wet and dry deposition of atmospheric nitrate. Also, some studies have suggested that elevated levels of nutrients might contribute to increased vulnerability of wetlands to invasive species, which reduce plant richness and can ultimately homogenize a region’s flora (Lougheed et al. 2008). A study of 16 Michigan depressional wetlands surrounded by various extents of development within 1 km indicated that wetlands with greater nutrient concentrations had greater cover of duckweed and less cover of other floating-leaved and submerged aquatic plants (Lougheed et al. 2008). However, nutrient increases typically accompany other impacts and in many cases evidence of their separate impact is unclear. Compared to wetlands with submerged aquatic plants, duckweed-covered wetlands have less dissolved oxygen in their water, greater phosphorus mobility, and greater capacity to remove nitrate (Veraart et al. 2011).

Another perspective on nutrients holds that certain favored animals (such as salmon) grow slowly in forested wetlands and water bodies which have little nutrient input. This is a concern to some consumers. In fact, some lakes, reservoirs, and streams in British Columbia are fertilized in an attempt to improve local fisheries (Pike and Perrin 2005). Historically, many streams and connected wetlands were fertilized naturally by spawned-out fish that brought in nutrients from the ocean. With the decline of many salmon runs, recently some agencies have attempted to intentionally add nutrients to streams, mainly in the form of salmon carcasses. In nearly all instances, concentrations in streamwater have been elevated for fewer than 100 meters downstream, and lasting biological benefits are uncertain. A single PNW study evaluated the possible effects of applied fertilizer on stream invertebrates (Meehan et al. 1975) but results were somewhat uninformative for a variety of reasons (Anderson 2002).

Many wetlands naturally convert phosphorus and carbon from inorganic to organic forms. The degree to which forest practices might influence or interfere with this function in wetlands is unknown, as is the ultimate effect of altering these processes, in terms of wetland food chains, productivity, and biodiversity. Decomposition of organic matter (plant detritus) is usually faster in cutover areas due to warmer temperatures and in some cases, greater soil moisture immediately post-harvest (Trettin et al. 1996).

Pesticides

Literature on the ecological effects of applying pesticides (especially herbicides) in forestry operations was compiled and reviewed by Ponder 2002, Solomon and Thompson 2003, Krutz et al. 2005, Thompson et al. 2006, and Clark et al. 2009. Reviews by Solomon et al. (2008) and Hayes (2011) debated the dangers posed by atrazine, and a review by Govindarajulu (2008) focused on glyphosate, the most widely-used pesticide in the region and one for which sublethal effects on amphibians have been detected (Relyea et al. 2005, Cauble and Wagner 2005, Thompson et al. 2006, Relyea and Jones 2009). The observed toxicity appears tied to adjuvants used at that time rather than the parent compound (Govindarajulu 2008). Herbicide concentrations in surface waters have sometimes exceeded permissible levels, but little is known of the levels of specific herbicides, associated surfactants, and their by-products that result in no harm to all life stages of non-target plants and animals. Even when applications of some pesticides result in concentrations that meet federal water quality guidelines, they have been shown to harm amphibians native to the PNW (e.g., Westman et al. 2010, endosulfan, azinphosmethyl, and diazinon impacts to Pacific treefrog). Amphibians and rare native plants may be especially vulnerable because vegetated buffers are not routinely required for protecting the ephemeral drainageways and temporarily saturated wetlands that are habitat for many species in these groups. Pesticide concentrations that appear to be non-toxic when applied at one time of year may be toxic at others, and impacts of repeated dosing and interactions with other environmental stressors are seldom evaluated (Thompson 2004, Jones et al. 2010). Exposure levels and probabilities also are seldom measured *in situ*, and depend on species life history relative to usual times of pesticide application, subsequent precipitation, natural concentrating factors such as water thermal stratification (Jones et al. 2010), and extent of dilution by runoff or groundwater from untreated areas.

Most studies have not found herbicides to be directly toxic to larger vertebrates at the dosages typically applied. However, indirect effects can occur, especially if herbicides are applied annually at the same location (Anthony and Morrison 1985, McComb et al. 2008). Indirect pesticide-induced changes can include alterations of food chains, cover, and the normal chemical environment in waters of forested wetlands (Chen et al. 2004). Herbicides such as glyphosate have been shown to mobilize potentially toxic metals such as copper from forest and wetland soils that already have naturally high concentrations as a result of local geology (Barrett and McBride 2006). This can harm salmonids and other aquatic life. In Alberta, herbicide treatments reduced winter ungulate and summer elk forage but enhanced summer forage for moose about 14% (Strong and Gates 2006).

<u>Fire Retardants and Other Silvicultural Chemicals</u>

The very limited information on ecological effects of fire retardants and dust suppressants was reviewed by Adams and Simmons (1999) and Giménez et al. (2004). An instance of a chemical dust suppressant damaging stream invertebrates and fish was reported by Ettinger (1987) but few other studies on these compounds have been published. More recently, a study that included some temporary wetlands (Angeler et al. 2006 a, b) found that one retardant (Fire Trol 934) reduced invertebrate diversity and was possibly responsible for decline of submerged aquatics due to reduced light penetration following the retardant's application.

3.2.4 Summary and Data Gaps: Water Quality Effects

It should be apparent from the aforegoing review that few if any peer-reviewed studies have measured directly the effects of various forest practices in the PNW on water temperature, sediment, nutrients, or silvicultural chemicals in **wetlands**. Specific data gaps are described by the hypotheses in part 3 of Appendix A.

Tentative inferences can be made from the dozens of studies that have investigated harvest effects on the water quality of streams (as reviewed, for example, by Moore et al. 2005). However, it must be recognized that wetlands generally tend to be more acidic, warm, and anoxic than streams (althoughmany exceptions exist). Removal of a forest canopy increases the temperature of surface water over variable distances downslope, including water temperature in wetlands. Increased water yield associated with tree removal, especially when accompanied by ground disturbance, increases the downslope transport of soil and its associated elements and compounds over variable distances (as reviewed, for example, by Liquori et al. 2008, Kreutweiser et al. 2008, Pike et al. 2010). Forest roads are potentially a source of suspended sediment to downslope wetlands, and this depends on their design and location. Under some situations, retention of vegetated buffers around wetlands can reduce the transport of sediment and chemicals into wetlands located downslope of forestry operations. As noted earlier, in one study from Michigan, no statistically significant differences were found in nutrients between harvested and unharvested wetlands 11 years post-harvest (Trettin et al. 2011).

3.3 Effects of Forest Practices on Microclimate, Vegetation, and Animals in Wetlands

3.3.1 Effects on Microclimate

Microclimate refers to conditions of temperature, moisture, wind, and sunlight measured at scales ranging from a few centimeters up to perhaps a kilometer. Microclimate is usually described for aboveground environments, but the concept can also be applied to water and soils. At the scales at which microclimate is measured, its components are influenced chiefly by:

- vegetation (including plant litter and down wood)
- topographic relief
- snow cover extent and duration
- groundwater exchange
- heat absorption/retention capacity of the substrate
- proximity to large water bodies or extensively bare areas

Microclimate contrasts with *climate* which is influenced mainly by elevation, latitude, marine proximity, and other factors measured mainly at continental or regional scales. Even in wetlands and forests unaltered by humans, microclimate varies spatially to a large degree as a result of natural disturbances such as windthrow (blowdowns), fire, and plant succession. Timber harvesting and replanting, logging roads, and herbicide applications can all affect wetland microclimate directly or indirectly, positively or adversely. These effects are described in this section with the exception of effects on water temperature, which are described in section 3.2.1. Studies of "edge effects" on microclimate within forests or above streams have been compiled and reviewed by Trombulak et al. 2000, O'Connell et al. 2000, Gucinski et al. 2001, Coffin 2007, Fahrig and Rytwinski 2009, and Daigle 2010.

Although microclimate is a major determinant of the species composition and local distribution of wetland plants and animals, relatively little is known about the microclimate requirements or preferences of individual wetland species. It appears that no single set of microclimate conditions is preferred by all wetland species (Keller et al. 1993).

Different forest practices as well as different natural disturbances can affect wetland microclimate to varying degrees, benefitting some species and harming others. Microclimate can also be altered by clearings created for buildings or roads, by natural phenomena (windthrow, landslides, streams), and by overgrazing of shrub and understory vegetation by deer and domestic animals. Microclimate conditions (humidity, temperature, etc.) and their natural variation have not been quantified among a wide range of wetlands within the PNW region.

Lakes, streams, and marine waters have been shown to influence the microclimate of adjoining upland areas at varied distances and consequently influence the upland flora and fauna (Olson et al. 2007). This effect has been estimated to extend only about 10 (Danehy and Kirpes 2000) to 20 m (Rykken et al. 2007) from the edges of headwater streams (channels less than ~1 m wide)and perhaps as much as 100 m from mid-sized streams (channels ~ 2 to 15 m wide) (Chan-MacLeod 1996). Effects on upland flora of increased air moisture resulting from overwater evaporation in a stream or wetland may be difficult to balance against drying effects of increased sunlight from a stream- or wetland-caused break in the forest canopy.

The capacity of wetlands to influence upland microclimate has not been documented in the Pacific Northwest. It likely depends on wetland size and configuration, vegetation extent and structure, water depth, groundwater influence, surrounding topography, season, and other factors. All of these factors can be influenced by forest practices.

When the area of a forest is reduced by harvests that remove all or most of the tree canopy, the forest's remaining vegetation is exposed to more sunlight and wind. This increases the evaporative water losses, reduces soil moisture, and potentially shortens the duration of inundation in some wetlands. However, as explained in section 3.1, in most cases the losses are offset by increased water availability resulting from timber harvest and associated reduction in water losses from transpiration.

Many estimates have been made of the distances over which timber harvests affect microclimate. Some have found that the influence of cleared areas on the microclimate of an adjoining forest extends about 50 m (~160 ft) into the forest but in extreme cases can extend as far as 500 ft (Dignan and Bren 2003, Ries et al. 2004, Moore et al. 2005, Hennenberg et al. 2008). Studies in western Washington found the light regime on the forest floor was affected ~100-200 ft from the edge, while humidity and air circulation were affected as far as ~800 ft into the forest (Chen et al. 1990, 1995).

A second study of riparian areas in western Washington suggested a wooded buffer of 31-62 m on both sides of a stream, comprised of about 75% canopy cover, might be necessary to approximate the natural microclimate gradients around the stream, and for some microclimate parameters, widths of up to 300 m might be necessary to maintain conditions (Brosofske et al. 1997). Edge effects (effects on microclimate of adjoining clearing) are most pronounced along south- and west-facing edges, perhaps suggesting the need for wider vegetated buffers there (Gehlhausen et al. 2000).

A third study from the region reported that most changes in light and temperature occurred within 20 m of an edge, and soil temperature reached normal levels 30 m from edges (Heithecker and Halpern 2007). The distance from edge within which the microclimate of a forested buffer was altered depended on forest structure and aspect, especially those conditions within 20 m of the edge of dense stands on steep terrain. Edge effects extended much farther (56 m) into forests on south- or west-facing slopes than into forests on north- or east-facing slopes.

Based on the limited amount of research published prior to 1993, the Northwest Forest Plan (FEMAT 1993) suggested that a forested riparian buffer having a width of about 0.6 times the potential height of tree species growing along a given stream might be adequate to maintain enough shade in that stream, at least for many small streams. Assuming a potential tree height of 200 ft, this translates to a shade buffer of 121 feet on each side of a stream. If maintaining shade at naturally-occurring levels in wetlands is considered important, the FEMAT guideline may be considered applicable to many wetlands.

A modeling simulation suggested that air temperature in a forest might sometimes be affected up to 230 ft from an edge; a warming of only 7 ^{o}F could change relative humidity exponentially from 94% to about 77% (Dong et al. 1998) with consequent effects on mosses, lichens, amphibians, and other organisms, many of which require sufficient humidity during certain phases of their development. Lichens and mosses have been affected by edge-induced microclimate changes extending at least 15 m into forested areas (Hylander et al. 2002, Stewart and Mallik 2006, Boudreault et al. 2008) and as far as 50 m (~170 ft) from the forest edge (Baldwin and Bradfield 2005, 2007). On Vancouver Island, even small (< 1 ha) 120-year-old conifer stands, surrounded by old-growth and containing much structure in the form of remnant large trees, did not contain the same abundance or composition of epiphytic lichens as did old-growth stands (Price and Hochachka 2001), although the difference cannot be attributed solely to difference in microclimate. The orientation of the edge that is created by forest roads or clearcuts can influence the impact on lichens and other plants (Johansson 2008) or not

(Heithecker and Halpern 2007). Effects on some lichens of removing the forest canopy can be reduced by making the forest edge a spatially "soft" transition that shifts gradually from dense forest to shrubs to short open vegetation (Stevenson and Coxson 2008).

Gradual loss of buffers as a result of windthrow not only alters the microclimate within wetlands, but also can alter their nutrient regimes and habitat suitability. Following the loss of lakeside buffers in Ontario, both as a result of harvest and windthrow, the average overwater wind speeds tripled and the thermoclines of those lakes deepened, although other factors influencing those could not be ruled out (France 1997). This potentially diminished the habitat available to coldwater fish and might have resulted in reduced phosphorus mobility in these lakes, and thus lower productivity.

A less direct way of considering microclimate is to examine the minimum size and configuration of a forested tract, patch, or leave-tree cluster (residual forest aggregate, green tree patch) required to adequately maintain microclimate of its interior (“core”). Heithecker and Halpern (2007) found that forest aggregates (groups of trees left standing after surrounding trees were cut) of only 1-ha, with normal tree densities and suitable configurations, were sufficiently large to contain areas which provided conditions of light, temperature, and soil moisture comparable to those in undisturbed forest, at least at a point in time that was 6-7 years post-harvest. That study also noted that the effects on microclimate of aspect (north- or south-facing etc.) were at least as strong as the effects of forest structure (e.g., percent retention).

Although most studies have examined *clearcut-associated* changes to the microclimate of adjoining forests, a few have investigated the effects of forest *thinning*, and have determined that thinning does alter localized air temperature as compared with unthinned stands, at least in the southern parts of the PNW region. In one case, thinning resulted in mean air temperature maxima above adjoining streams that were 1.8 to 7.2 ^{o}F (1 to 4 ^{o}C) warmer than where adjoined by unthinned stands (Anderson et al. 2007). However, where unthinned forested buffers of at least 15 m width were present, the daily maximum air temperature above an adjoining stream was virtually unchanged, and daily minimum relative humidity was less than 5% lower than for unthinned stands. Another study (Olson and Chan 2005) found that wooded areas averaging as narrow as 15 ft could offset changes in microclimate that otherwise would occur as a result of thinning upland forests. As a result of a variable retention harvest in one forest, wind speeds increased threefold and consequently the loss of moisture from evapotranspiration also increased threefold (Bladon et al. 2003).

Other studies have looked more specifically at the *degree* of thinning or partial cutting that triggers changes in microclimate in leave-tree clusters and other small forest patches. A study of 1-hectare forest patches in western Washington (Heithecker and Halpern 2006, 2007, Aubrey et al. 2009) found that when only 15% of a forest canopy within a patch was retained, it did little to protect the remaining forest from microclimatic changes induced by adjoining clearcut areas. When canopy retention within the patch reached 40%, the light conditions were indistinguishable from those in an unthinned forest. Mean air temperature in those patches was significantly cooler than in clearcuts, but maximum air temperature did not differ. Mean and maximum soil temperatures did not differ among patches with intermediate levels of canopy retention, but soil temperatures varied temporally to a greater degree as thinning within the forest patches increased. Different levels of canopy retention had no detectable effect on *minimum* air and soil temperatures, or on late-summer soil moisture. For most biological responses, the total amount of canopy was more important than how it was distributed horizontally (clumped or dispersed). In another study, thinning to a density of 80 trees/acre within a stream buffer did not affect soil temperature in streamside areas or the water temperature in a stream (Olson and Chan 2005).

3.3.2 Effects on Wetland Plants

The species composition of trees and other vegetation that survives or colonizes a forested wetland following the harvesting of timber in or near the wetland depends on many factors. These include the species of trees that were harvested, the initial structure of the forest stands, other vegetation that was present pre-harvest, the intensity and pattern of harvest, elevation of harvest relative to post-harvest water table level, logging techniques and equipment used, woody debris management practices, replanting and weed control efforts, soils, climate, topography, and other factors. The post-harvest species composition is of obvious interest because it affects a site's future biodiversity, wildlife habitat suitability, microclimate, disease and fire susceptibility, soil development, nutrient cycling, water balance, and many other aspects of structure and function. This section (3.3.2) primarily describes the following effects on vegetation that are associated with timber harvesting:

- shifts in vegetation species richness and invasive species
- shifts in vegetation structure (horizontal and vertical) including the amount of dying, dead, and down wood

The effects of timber harvesting on microclimate were covered in the preceding section.

<u>Shifts in Plant Species Richness</u>

The species richness of **native** understory plants is usually an excellent indicator of the effects of forest practices, but is sensitive to survey methods and data processing procedures (Loya and Jules 2008). Within a few years following most types of harvest, richness of native herbaceous plants normally increases in the cut-over areas. This may be particularly true where alder colonizes harvested areas because alder tends to enhance soil fertility (Hanley 2005). However, after most harvests, herbaceous plant richness usually declines within the remaining forests, at least within 10 m from forest edges (Halpern and McKenzie 2001, Halpern et al. 2005). In Manitoba, total native plant diversity was approximately 30% higher on clearcuts than in woodlands, whereas moss and lichen diversity and cover were greater in wooded control sites (Locky and Bayley 2007).

Some native wetland plant species decline in response to more frequent and prolonged anaerobic and acidified conditions associated with the higher post-harvest water table, while others that are more adapted to aquatic conditions may increase as a result of increased duration of adequate soil moisture in wetlands that are (or were) inundated only temporarily or seasonally (Tiner 1991). Whether higher post-harvest water tables depress or enhance on-site plant species richness depends partly on the pre-harvest conditions and seasonal timing of post-harvest water surpluses. Wetland plant richness may increase most dramatically as soon as a decline begins in the logging-related higher water table levels, as has been observed in former beaver flowages.

Gradually, as trees (especially conifers) regenerate in cut-over areas and shade out shade-intolerant graminoids and forbs, understory plant diversity declines in harvested areas. But eventually, as trees approach late-successional stages and gaps form in the forest canopy, the diversity of native understory plants increases (Halpern and Spies 1995). Although probably no plant species in the PNW is associated with a single successional stage, a majority of forest plants are most abundant in old growth (Halpern and Spies 1995). As opposed to clearcutting, thinning sometimes accelerates this second burst of plant diversity, and may pose less risk of facilitating the spread of invasive plants. Green tree retention ("lifeboating") also appears to accelerate the post-harvest recovery in clearcuts of ectomycorrhizal fungi, epiphytic lichens, and small ground-dwelling animals, while perhaps being less effective for restoring the diversity of mosses and vascular plants (Rosenvald and Lohmus 2008).

As the area of a patch of natural habitat increases within a landscape, so does the diversity of native plant species. Blocks of forest smaller than about 9 acres may be less capable of supporting the expected array of mosses in British Columbia (Baldwin and Bradfield 2007). Forested wetlands and stream banks next to waterfalls contain greater abundance and taxonomic richness of lichens and mosses than do drier forests, at least on the windward slopes of inland rain forests of British Columbia (Radies et al. 2009). Contributing factors include the higher moisture levels, greater resistance to fire, and relatively mild temperatures. These conditions make these habitats refugia for rare lichens. A leveling off of the plant species-area accumulation curve in Alberta forests appeared at a forest patch size of about 27 acres (Gignac and Dale 2007). A study in Washington found that forest patches as small as 2.5 acres, if not narrow, may be large enough to have a microclimate supportive of most native plants and animals (Heithecker and Halpern 2007). In Wisconsin forests that were studied over a 55-year period, patches which were larger and contained more surrounding forest cover retained more plant species and were more likely to be colonized by new native species than smaller forests in more fragmented landscapes. Plant community composition was better explained by the amount of surrounding forest than by environmental factors within the studied forests (Rogers et al. 2009). The richness of native plant species specifically in wetlands has been found to correlate negatively with the extent of landscape alteration measured as far as 250-300 m from the wetlands (Houlahan et al. 2006). However, many factors such as differences in land use history are not well-accounted for by such correlational studies.

<u>Shifts in Vegetation Composition and Structure</u>

The most obvious harvest-related change in vegetation structure is a temporary loss of large trees in the harvested area and -- due to increased windthrow -- along logging roads and in adjoining forested wetlands. This results in a loss in the vertical complexity of habitat and also reduces the epiphytes (particular mosses and lichens) characteristically associated with larger trees, especially in wetlands. The other major structural effect is the accompanying increase in herbaceous plants and shrubs (e.g., MacCracken 2005), which has been shown to occur within forested wetlands even if the wetlands themselves remain uncut and separated from upland timber operations by a narrow buffer (Palik and Kastendick 2010).

After forested wetlands are logged, the time required to return the wetlands to approximately the same forested condition (with regard to canopy cover, species composition) usually is much greater than in recovering upland forests. This is particularly true if large parts of the wetland remain flooded for weeks or months at a time during the growing season, and/or if soils are relatively infertile, compacted, or peaty (Prescott et al. 1996). In such situations, restoration of forest cover depends partly on the extent of mounded microtopography, but the large root wads and residual logs that create such mounds are sometimes removed by logging equipment even during winter operations (MacKenzie and Moran 2004). Elevated mounds allow flood-sensitive tree seedlings to become established because they keep the seedlings out of the zone where prolonged inundation and soil anoxia can stymie growth. Site treatments intended to simulate natural mounds have generally not increased seedling survival in wetlands with well-humified, highly erodible organic materials (MacKenzie and Moran 2004). At least in conifer-dominated wetlands in western Canada, mounding can promote establishment of acidifying mosses between mounds which may reduce forest productivity in the longer term (Asada et al. 2004).

Within logged wetlands, poor tree regeneration means a delay in return to prior forested conditions. This in turn means that the consequently increased water table in the logged wetlands, with deeper and more seasonally persistent surface water, may continue for years longer than it takes for stream flows to return to pre-harvest conditions following the same operation. Depending on site characteristics, prolonged elevation of the water table can either increase or decrease the richness of herbaceous plants, but it nearly always hinders the growth and diversity of trees, especially on peat soils (Emil et al. 2006). In wetlands near Puget Sound, the height of 50-year-old trees (western red cedar, Sitka spruce, western hemlock) is only about 90 feet and this is approaching the maximum they are likely to reach in many wetlands in that area (Painter 2007, 2009). The same study found that those tree species in Puget Sound forested wetlands averaged 15-18 inches in diameter when mature, and 27 inches in a few old-growth forested wetlands.

Compared with conifers, mature hardwoods tend to produce higher densities of snags required by cavity-nesting wildlife, may export more nutrients to adjoining waters (Roberts and Bilby 2009), may be of greater overall importance to bird species known to be declining in the PNW (Betts et al. 2010), and are more suitable than conifers for wetland mammals such as beaver and moose. Beaver subsequently create wetlands along streams. Although beaver dams can temporarily restrict fish movements, the waters impounded by beaver dams are often more productive in terms of both the number and size of fish (Leidholt-Bruner et al. 1992, Schlosser 1995) and the variety of other plants and animals (See reviews by Naiman et al. 1988, Pollock et al. 1994, Stoffyn-Egli and Willison 2011).

Among shrubs, wetland-associated hardwoods (e.g., alder, ash, paper birch, aspen, cottonwood, willow, dogwood) tend to colonize many harvested sites more readily than conifers (e.g., western red-cedar, western hemlock, Sitka spruce, larch)(Villarin et al. 2009). Alder increases in response to increased soil moisture (caused by reduction of tree-associated transpiration) and increased light availability, as well as increased phosphorus availability (Uliassi et al. 2000, Brown and Courtin 2003, 2007). Red alder becomes dominant mainly on mineral soils, and tends to thrive better than most of the region’s trees where conditions on these soils are more open and wet. Its positive response to logging is generally similar to its response to landslides and severe floods, and is particularly pronounced where two or three of these events have occurred at the same location within a few decades (Gomi et al. 2006). Red alder saplings fare poorly in closed-canopy forests, in clearcuts on upland sites (Haeussler et al. 1995), on sites heavily grazed by cattle or wild ungulates (Case and Kauffman 1997), or where soils remain water-covered for as little as one week during the growing season (Ewing 1999). Once mature tree height is reached, most red alder can survive low-intensity fire (Fonda 2001).

Because red alder quickly forms dense canopies on many sites, over a span of several decades it can inhibit the regeneration of many shade-intolerant woody and herbaceous species, thus reducing vertical habitat complexity in some instances (Hibbs and Giordano 1996). In British Columbia, the stem volume of western red-cedar was significantly less where red alder density exceeded 500 stems per hectare, whereas paper birch was not detrimental to western red-cedar growth until its densities exceeded 1000 stems per hectare (Cortini and Comeau 2008). Where red alder in southeast Alaska riparian forests comprised more than 53% of the total live basal area, the density of other tree species, their basal area, and mean diameter were significantly related to the percent of alder, measured as a proportion of total stand live basal area (Orlikowska et al. 2004). Conifer regeneration under dense alder canopies is influenced by distance from conifer seed sources, and perhaps slightly by understory cover (Beach and Halpern 2001).

For several years after wetlands are logged, vegetation structure may also shift as a result of a shift from mainly facultative wetland species to a higher proportion of obligate wetland species, caused by the logging-related increase in soil saturation noted previously. The specific types of structural and species composition shifts that will occur (as predicted by state-and-transition models or succession models, for example) have not been documented in forested wetlands of the PNW, but will likely depend on the plant species originally present; seed bank composition; magnitude and timing of post-logging water table changes; changes in light, sediment deposition, and nutrients; and proximity and connectivity to other wetlands. At least in Quebec, most wetland plant species are less limited by dispersal than are upland species, so fragmentation of wetlands by forestry operations might pose less threat of reducing wetland plant diversity than is the case for upland plants subjected to fragmentation of upland forests (Flinn et al. 2010).

Rotation length (the time between harvests of the same forested site) and fire suppression policies also influence vegetation structure and consequently habitat over long time periods. Short rotations (harvests that occur before trees reach much of their potential height) often deplete coarse woody debris and limit the extent of old-growth structure important to some wildlife species (Bunnell et al. 1997). Forest age and width of nonharvested buffers may be more important than the rotation age of plantation forests in supplying wood to streams and wetlands over the long term (Meleason et al. 2003). The effects on forested wetlands of rotation lengths in upland forests that adjoin wetlands have not been studied, nor has the structure of a series of "virgin" (or long-rotation) forested wetlands been quantified and compared with that of forested wetlands in similar geomorphic settings but harvested at shorter intervals and intensities.

Fire, although infrequent in most forested wetlands of the PNW, potentially affects soil organic matter (especially in bogs and other peat wetlands), biogeochemical cycling, hydrologic processes, vegetation composition and structure, amount of snags and down wood, and overall habitat quality. This has not been quantified, and policies that require suppression of all fires are likely to affect some wetlands in a variety of ways.

Invasive Exotic Plants

Another vegetation change that sometimes occurs in association with tree removal and construction of logging roads is an increase in non-native plant species. Non-native plants are a concern partly because they typically reduce the diversity of native plant species present at a site (Perkins and Willson 2005, Magee et al. 2008). Invasive plants tend to be more prevalent in narrower buffers and in smaller unshaded, recently-formed wetlands that experience large water level fluctuations. Some studies have inferred a reduction in productivity or diversity of wildlife populations where non-native plants have invaded, but no studies in the Pacific Northwest have yet demonstrated this. The assumption is well-founded, being based on the fact that the most common invasive plants typically simplify the physical structure and reduce the diversity of the plant community by outcompeting more diverse assemblages of native plant species. To varying degrees, native fish and wildlife species have come to depend on native plants (specifically their berries, seeds, foliage, associated insects, and leaf litter) being available for food and/or cover at specific times of year. Thus, any significant simplification of vegetation structure, or shifts in the seasonal timing of food availability (due to different maturation, flowering, or fruiting times of non-native plants, or different times of leaf-fall, leaf decay, and nutrient release) is likely to adversely impact many fish and wildlife species (Burghardt et al. 2009, Rodewald et al. 2010). However, the likely effects of non-native plants on wildlife are probably very species-specific and region-specific, with some invasive plants benefiting particular native species of wildlife and others being detrimental or neutral (e.g., Kennedy et al. 2009, Kapust et al. 2012). Invasive plants can also alter biogeochemical cycling rates and chronology (e.g., Urgenson et al. 2009) and can hypothetically change the water balance and duration of saturation in small isolated wetlands.

Even when invading non-native species do not substantially diminish a wetland's native biodiversity or appear to alter its functions, they often indicate the occurrence of physical or chemical conditions that are outside the normal range of variation, thus potentially constraining some important ecosystem functions (Parendes and Jones 2000). Non-natives invade forested wetlands most often following soil disturbance, such as from fire; the introduction of cattle; population increases of native herbivores following timber harvest; and/or increased disturbance from natural (e.g., landslides, floods, windthrow) or human-associated factors (e.g., logging, agriculture, construction of roads, trails, gravel pits) (Harrod and Reichard 2000). Because non-native plants tend to have broad environmental tolerances, many are good indicators of inconspicuous changes to underlying ecosystem processes and functions. Moreover, the areas they come to dominate often become more resistant to further change (Werner et al. 2002, Wigand 2003, Stohlgren et al. 2002), which has both benefits and costs in terms of habitat for other species.

Logging roads in particular are often the first point of entry for exotic species into a landscape, and roads can serve as corridors along which disturbance-associated plants move farther into the landscape, carried by logging equipment, humans, and animals that travel along road corridors (Lonsdale and Lane 1994, Greenberg et al. 1997). Many invasive plants occur in or near disturbed areas such as gravel pits, and seeds of these plants can be dispersed rapidly throughout a forest and into its wetlands when gravel is spread on roads.

Because most invasive species prefer upland to wetland environments, forest practices that lower wetland water tables increase the risks to forested wetlands from invasive plants. On the Olympic Peninsula, early-successional forested wetlands (e.g., alder flats) in floodplains were found to be more susceptible than uplands to invasion by non-native plants, and hosted even more invasive species than recent clearcuts (DeFerrari and Naiman 1994). Nonetheless these areas were not a major source of non-native plants to other habitats. The same study found that the presence of invasives was not predicted by patch size of the associated forest, slope, aspect, elevation, or to distance to human population centers, major highway, or river mouth. Ditches that accompany forest roads can serve as a vector for movement of invasive plants into wetlands (Watterson and Jones 2006). The indirect hydrologic, chemical, and biological effects on wetlands of non-native plants that often dominate clearcuts in the PNW but seldom invade wetlands (e.g., Scotch broom, Himalayan blackberry) have not been studied.

Most invasive plants in the PNW prefer unshaded conditions (Washington Department of Agriculture 2013). Nelson and Halpern (2005) found that non-native plants invaded forests and reduced native plant richness mostly within 10 m of the forest edge. A study of Alberta forests found that non-native plants were most abundant between 15 and 50 ft from the forest edge, and some species were found up to 130 ft from the edge. In hardwood forests of Wisconsin, forest roads increased the abundance of invasive plants and reduced native species richness within 5-15 m of the edges they created (Watkins et al. 2003). Although larger patches of forest generally support more non-native plant species than smaller fragments, the smallest fragments sometimes have the greatest number of non-native species per square meter (Gignac and Dale 2007). Dense vegetation tends to restrict wind-driven dispersal of seeds of many non-native plants into forests (Cadenasso and Pickett 2001). However, a study in North Carolina reported that riparian forests were not better protected from invasion by non-native plants by wide than by narrow buffers (Vidra and Shear 2008), perhaps emphasizing the importance of considering individual species traits and geography rather than relying on general paradigms.

3.3.3 Effects on Fish and Aquatic Invertebrates

Literature on the effects of forest practices on anadromous salmonid fish was reviewed by Liquori et al. (2008). Coho salmon and cutthroat trout in particular use both forested and herbaceous riverine wetlands extensively for rearing or overwintering (Heifetz et al. 1986, Brown and Hartman 1988, Swales and Levings 1989, Beechie et al. 1994, Henning et al. 2006). Some of these wetlands (usually termed off-channel areas, backwaters, oxbows, or floodplain wetlands) are connected to larger rivers only intermittently during annual high water, yet are heavily used, especially where they contain or adjoin deep pools. In one instance, stream reaches with wetlands accounted for less than 1% of the total available coho habitat in a watershed, yet supported over a third of all juvenile coho salmon (Murphy et al. 1989). Coho emigrating from streams with many wetlands are larger than those from higher velocity streams (Bennett 2006). Where stream temperatures are not near thresholds for coldwater fish, the streams which flow through meadows have sometimes been found to be more productive than either densely forested streams or logged streams with an open canopy (Dolloff 1987). Larger smolt size leads to increased overwinter and marine survival of juvenile anadromous salmon (Ebersole et al. 2006). Based on a full range of coho life history needs, the optimal size for an off-channel, salmon-accessible wetland or pond was estimated by one study to be 5,000–10,000 m^2 (Rosenfeld et al. 2008). In streams -- and perhaps also in some lakes (Roth et al. 2007) and wetlands -- large submerged wood provides fish with important cover, although even in streams, other factors are often more predictive of fish abundance (e.g., (Bjornn et al. 1991, Bugert et al. 1991). Shorter forest harvesting rotations could mean a gradually decreasing supply of large logs falling into streams and wetlands (Anderson and Meleason 2009). Where fish are present, these provide essential cover for fish over the long term.

If they contain fish at all, permanently inundated wetlands and ponds that never connect to rivers or lakes are occupied mainly by non-game species (e.g., sculpins, dace) and various introduced species (e.g., bass, brown trout). Other factors (such as elevation) being equal, temperatures in such wetlands tend to be warmer than in wetlands connected to channels, and suspended sediment from logging or other sources tends to be deposited and accumulate. Even where fish access to headwaters is limited, the carbon from headwater wetlands (and particularly from their herbaceous plants) has been shown to have a significant effect on downstream food chains important to anadromous fish at some locations (Dekar et al. 2012). Aquatic invertebrates that drift or are washed out of inaccessible headwater wetlands also benefit downstream fish populations.

Forest roads can impact fish use of wetlands by blocking access if not culverted, or if culverts are inadequately sized or placed. In one Washington watershed, 13% of the historical coho habitat was lost as a result of barriers created by improper culvert placement or design (Beechie et al. 1994). Timber harvest operations also can reduce water depth and persistence in wetlands as a result of increased sedimentation (see section 3.2.2). At least in theory, this can diminish the suitability of pools and off-channel wetlands as fish habitat (Bjornn et al. 1977, Reiser and Bjornn 1979, Jackson and Beschta 1984, Alexander and Hansen 1986). Timber harvest also can adversely affect anadromous fish by increasing water temperature (section 3.2.1). However, the temporarily increased water levels resulting from tree removal in or near wetlands (section 3.1) can, in theory, also increase access and habitat space for fish and aquatic invertebrates. The resulting increased connectivity of headwater wetlands to mainstream areas can temporarily facilitate not only fish movements, but also the export of carbon and aquatic insects from headwater wetlands to downstream food chains.

Many studies in the PNW have found that partial removal of a canopy that otherwise completely shades small streams can increase the growth and biomass of algae, aquatic invertebrates, and/or fish (Hawkins et al. 1983, Hetrick et al. 1998a, 1998b, Keith et al. 1998, Fuchs et al. 2003), at least until the riparian forest grows back. When this happens, invertebrate abundance temporarily increases but the number of taxa within the water body sometimes declines temporarily, especially if a substantial influx of fine sediments occurs (Richardson 2008). In British Columbia, the invertebrate biomass in recently harvested streams was nearly twice that in non-harvested or older harvested sites (Fuchs et al. 2003). No differences were detected among the 3 stream categories in regard to substrate composition, large organic debris density, or dimensions of pools and riffles. Also, temporary post-harvest shifts from conifer trees to hardwood shrubs (particularly alder) often occur, and could increase the amount of nutrients available to aquatic invertebrates and fish. In Southeast Alaska, streams adjoined by extensive alder have a greater abundance of invertebrates than those adjoined by young conifers (Wipfli 1997, Wipfli and Musslewhite 2004). This difference can be so great that, if downstream habitat is not limiting, the invertebrates could support a biomass of fish that is four times that of the conifer sites (Piccolo and Wipfli 2002).

In the Pacific Northwest, wetlands have apparently not been the focus of studies of the effects of timber harvest operations on invertebrates and fish. In aspen-dominated landscapes of Minnesota, invertebrate *richness* in seasonally ponded wetlands was found to be greater next to young than old (>35 year old) aspen stands, perhaps due to more light reaching wetlands next to open-canopied young stands, which triggered extensive growth of submerged macrophytes that support larger numbers and diversity of invertebrates. When old-growth aspen stands surrounding 16 wetlands were clearcut, the wetlands subsequently experienced longer duration of standing water, increased primary productivity, and both increases and decreases (depending on the functional group) in *abundance* of their invertebrates (Palik and Kastendick 2010, Hanson et al. 2009, 2010). Algae exhibited no significant response to harvest treatments or to the measured environmental variables. Another Minnesota study of timber harvesting effects on wetlands (Palik et al. 2001) found many physical characteristics of small seasonal ponds were unaffected by harvest of the adjacent upland forest. Canopy openness was one characteristic that was affected. Small wetlands with more open canopies had greater total macroinvertebrate abundance and a larger number of sensitive species. Whether these relationships would hold true for conifer-dominated landscapes and species in the PNW is unknown.

As noted in section 3.1, timber harvests located upslope from wetlands typically do have measurable effects on water levels downslope. Literature on ecological effects of streamflow conditions, which was reviewed by Poff and Zimmerman (2010) and Poff et al. (2010), may have some relevance for predicting ecological responses to changing water levels in wetlands, but effects are unlikely to be identical to those noted in streams because wetlands host different species and have different geochemical conditions.

In the Pacific Northwest, the contrast between the streamside and upslope forest is not as pronounced as that found in drier regions (Richardson et al. 2005a), and the same is likely true of the region’s forested wetlands. In interior British Columbia, aquatic invertebrate communities were found to differ more between streams than between harvest treatments (Melody and Richardson 2007). In particular, some aquatic processes and species assemblages in streams are distinctly different in headwater areas compared with lowland portions of streams (Richardson and Danehy 2007). Some studies have found very different water quality in headwater (slope) wetlands and as compared with riverine wetlands at lower topographic positions (Cole et al. 1997a), whereas other studies have found either no differences or only minor differences (Azzolina et al. 2007).

In the Snohomish River Basin of western Washington, adult coho abundance and median adult coho densities were correlated at a landscape scale with wetland occurrence, as well as with local geology, stream gradient, and land use (Pess et al. 2002). This finding applied at both the watershed and stream reach scales. Forest–dominated areas had 1.5 to 3.5 times the densities of coho than densities found in rural, urban, and agricultural areas. Similarly, in Puget Sound lowland streams, the condition of invertebrate communities correlated positively with both the total amount of riparian vegetation and with the contiguity of riparian with upland vegetation (Shandas and Alberti 2009). However, in an area of British Columbia where 21% of a watershed was clearcut, no adverse effects on summer or winter condition or abundance of coastal cutthroat trout were detected (DeGroot et al. 2007). Also, no increases in stream temperatures were detected, but weather in the post-logging years was generally cooler, confounding the detection of logging effects.

Effects of timber harvesting on aquatic food chains were reviewed by Hanson et al. 2010 and in meta-analyses of prior literature by Marczak et al. (2007, 2010). In Oregon, results from one study suggested that the proportion of a watershed that is harvested and its proximity to a water body may wield greater influence on aquatic invertebrate diversity in that water body than the density of forest roads in the watershed (Fore and Karr 1996).

Using data from a probability sample of 167 headwater streams in forested watersheds of western Oregon, Herlihey et al. (2005) found no statistically significant relationship between history of timber harvests and the prevalence of disturbance-tolerant stream invertebrate communities (represented by an Index of Biotic Integrity, IBI). Another regional study of headwater streams where forest management (harvested-roaded vs. unharvested-unroaded) varied found significantly higher aquatic invertebrate density at harvested sites, while taxonomic richness and diversity did not differ (Medhurst et al. 2010). Based on review of many studies in the PNW, Richardson (2008) concluded that for the first 10-20 years post-harvest, harvesting near streams increases the production and abundance of aquatic invertebrates but in some cases temporarily reduces their diversity. However, in some cases, the effects of harvesting on aquatic invertebrate assemblage can be detected for at least 40 years post-harvest due to associated changes in the type of forest cover (Zhang et al. 2010). The effects are not necessarily adverse.

Increased soil saturation following tree removal could temporarily increase surface water in wetlands, and thus habitat space. At the same time, increased sediment from logging could temporarily reduce habitat space and populations of some invertebrate species in shallow wetlands. Sedimentation could also possibly expand wetland area where sediments are deposited at the transition between shallow and deepwater areas. Increased seasonal persistence of water in post-harvest landscapes could increase the proportion of wetland species such as dragonflies that require more time to develop from larvae to adults. Increased light and warmer water temperatures from tree removal could temporarily favor species that feed largely on algae, provided that post-logging turbidity levels in the water do not remain high. This might occur at the expense of species feeding mainly on leafy detritus.

3.3.4 Effects on Amphibians and Reptiles

Many amphibians (frogs and salamanders) and selected reptiles (mainly garter snakes and turtles) are obligate wetland species in the PNW. This section focuses on those that require calm waters (ponds and some wetlands) at any point during their life. Most studies of the effects of harvesting operations on amphibians in the PNW have focused on stream-breeding amphibians that use wetlands only sporadically, such as Coastal tailed frog and Coastal giant salamander (e.g., Richardson and Neill 1998, Wilkins and Peterson 2000, Stoddard and Hayes 2005, Pollett et al. 2010) or forest amphibians that apparently have little or no affinity for wetlands (e.g., western red-backed salamander). A fewer number of studies of forest practices have included amphibians that inhabit small rocky seeps during part of their life, such as torrent, Dunn's, and Van Dyke's salamanders (Corn and Bury 1989, McIntyre et al. 2006). An unknown portion of those habitats would be classified as jurisdictional wetlands. As will become evident from the discussions in sections below, an even fewer number of studies have addressed the effects of forest practices on wetland- and pond-breeding amphibians such as northern red-legged frog, Cascades frog, Pacific treefrog, western (boreal) toad, northwestern salamander, rough-skinned newt, and long-toed salamander. There also have been no studies in this region of timber harvest effects on the wetland-dependent western painted turtle.

Most of this region's wetland-requiring species also require upland areas with undeveloped (but not necessarily forested) cover, often at considerable distances from the wetlands (Semlitsch and Bodie 2003, Harper et al. 2008). Exceptions may be the

Oregon spotted frog, and turtles that lay their eggs on land but whose hatchlings and adults spend extensive time in water.The amphibians in this assemblage lay eggs in water (attached to wetland vegetation) and the mature hatchlings and adults spend extensive time on land. During most of their time on land, these species generally exhibit only limited movements (e.g., <10 m) in moist ravines, underneath logs, in burrows, or in other generally moist cover. However, long periods of relative immobility are sporadically interrupted by significant movements over sometimes large distances (> 1 mile), which occur mostly during rain and at night.

In general, frogs and toads tend to prefer more open-canopied wetlands due to the dependence of their tadpoles on algae and biofilms, which thrive best under conditions of high light and warm temperatures. Their submerged eggs also may have specific light needs in order to deter losses due to fungal growth. In contrast, adult pond-breeding salamanders are mostly predatory and can flourish in somewhat more shaded waters (Earl et al. 2011). Thus, other factors being equal, frogs in the PNW -- with the exception of the Coastal tailed frog -- would be expected to be impacted less adversely than salamanders by reductions in shade from trees, and might even be affected positively. This is suggested by data from harvesting studies outside the PNW (DeMaynadier and Hunter 1995, Clawson et al. 1997, Palik et al. 2001, Skelly et al. 2005, Todd et al. 2009).

In mostly developed landscapes of western Washington, richness of pond-breeding amphibians was strongly associated with proportional coverage of forest within 1 km of wetland edges (Richter and Azous 2000, Hayes et al. 2008). Data on species not found in the PNW further suggest that many amphibians avoid clearcuts and, to a lesser degree, partial timber removals (e.g., Rothermel and Semlitsch 2002, Semlitsch et al. 2009, Strojny and Hunter 2012). Maintaining buffers and corridors of unlogged habitat between wetlands or streams (Perault and Lomolino 2000, Lomolino and Perault 2000, Olson et al. 2007) as well as retaining large woody debris (Aubry and Hall 1991, Patrick et al. 2006) might partly mitigate reductions in populations that could otherwise occur for some amphibian and small mammal species, but this remains untested. Also, maintaining a hydrologically-diverse array of wetlands within the usual 0.1-10 km range of wetland-breeding amphibian populations might reduce risks of there being insufficient breeding habitat during any year due to cyclic drought or flood conditions. This has not been tested, and one review of published studies indicated that if amphibians can be considered to have “metapopulations” (a group of spatially separated populations of the same species which interact at some level), that is likely true for only some species at some locations (Smith and Green 2005).

Small pools that are excavated in clearcuts and along logging roads, either to provide gravel for road surfacing or to help mitigate loss of wetlands, have been shown in other regions to benefit several amphibian species (Barry et al. 2008). However, to support amphibian reproduction, they must be situated in a manner relative to groundwater seeps that ensures they retain water through their usual breeding period (DeMaynadier and Hunter 1995, DiMauro and Hunter 2002). Such a strategy may be worth testing in the PNW, with an eye to ensuring that it does not also facilitate spread of the regionally exotic and predatory American bullfrogs and green frogs, both of which prefers open-canopied, warm, permanent pools.

If tree removal, as described in section 3.2.1, increases water yield during critical breeding seasons for amphibians and thus increases the extent, depth, and duration of surface water (to at least 4 months and preferably 8-9 months duration), then amphibian breeding habitat may benefit. Changes in amphibian populations could have measurable effects on nutrient balances. For example, one study of frogs and salamanders found they exported 6-12 times more nitrate from wetlands than is imported when they lay their eggs there (Seale 1980).

Although roads in general are known to be a barrier to pond-breeding amphibians, snakes and turtles (as reviewed by Fahrig and Rytwinski 2009), and amphibian abundance in wetlands was correlated negatively with road density in Ontario landscapes (Houlihan and Findlay 2003), it is unclear whether narrow unpaved roads with low traffic volumes, as is typical of forest roads in the PNW, are capable of restricting movements of these species. In North Carolina, even some narrow logging roads that had long been abandoned continued to impair movements and densities of salamanders (Semlitsch et al. 2007). That road effect appeared to extend about 115 ft into the adjoining woods on both sides of the road. However, another study (Marsh 2007) found that narrow forest roads closed to traffic did not hinder salamander movements, at least not as much as wider roads with vehicle access. In eastern Canada, fewer amphibian species were found in wetlands having a high proportion of roads, precommercial thinning, and hardwood forest in their surrounding landscape, especially within 180 - 200 m (Houlihan and Findley 2003, Jacobs and Houlihan 2011). Well-traveled roads near Ontario wetlands were associated with reduced amphibian abundance and this effect extended more than 250 m from roads (Eigenbrod et al. 2009).

Inadequate culverting of forest roads may hinder movements of some salamander species (Sagar 2004, Ward et al. 2008). However, in another study (Patrick et al 2010), culvert characteristics did not appear to influence culvert use by salamanders crossing roads. If new culverts allow fish to access previously fishless headwater wetlands, populations of some amphibian species (e.g., long-toed salamander) in those wetlands could be reduced.

It must be understood that finding an individual frog or pond-breeding salamander in terrestrial habitat at a particular distance from a wetland does not necessarily mean that particular individual is representative of the population, or that uniformly-wide wooded buffers extending to that point, and contiguous to the entire wetland perimeter, are needed to ensure survival of populations of the observed species. It remains unclear whether very wide (>100 m) buffers that completely surround wetlands, as suggested for wetlands in the southeastern United States by Semlitsch and Bodie (2003) and Semlitsch et al. (2009), are necessary to support populations of pond-breeding amphibians in the PNW. This uncertainty about buffer configuration may be greatest in less-settled areas where most of the surrounding land cover matrix is undeveloped regardless of whether or all the land immediately adjoining and surrounding a wetland is so. Uncertainty of extrapolating findings from distant regions is also due to differences in climate and species in the PNW. As noted by Cushman (2006), "The suggestion that forest cover in the landscape benefits amphibians may not apply to all species that are fully aquatic or that depend on nonforested upland habitat." Because extrapolating research results from one species and region to others risks misinterpretation, research is summarized here by individual wetland species, focusing on those in the PNW that appear to be the most dependent upon wetlands and ponds.

<u>Northern Red-legged Frog</u>

In Oregon, adult red-legged frogs were captured more frequently in riparian and wetland areas than in upslope habitats (Gomez and Anthony 1996). Streams wider than 3 m may be used much less than those narrower than 1.5 m (Chan-McLeod 2003). Contrary to expectations, a study in western Washington forests found that stream-dwelling red-legged frogs were negatively associated with coarse woody debris (Kelsey 2000). Buffers of 30 m width on both sides of streams that adjoined 2-year-old clearcuts appeared to adequately support movements of this species during the year they were surveyed. In the mostly unforested landscape of Oregon's Willamette Valley, consistent year-to-year occupancy of wetlands by red-legged frogs was more strongly predicted by the percentage of a wetland's perimeter containing trees within 5 m of "shore" than by percent forest cover within a 500 m buffer or by presence of predatory bullfrogs and non-native fish (Adams et al. 2011). Breeding sites vary in terms of water depth, degree of permanency, fish presence/absence, and associated species (Richter and Azous 1995, Adams 1999, Richter and Roughgarden 2005). Ponds with little or no emergent or submerged vegetation (i.e., >75% open water) are less likely to be used in consecutive years for breeding (Pearl et al. 2005, Adams et al. 2011). Wetlands preferred for breeding are sometimes very small. On Vancouver Island, 97% of wetlands identified by Beasley et al. (2000) as suitable for this species were <0.1 ha, and red-legged frogs were present in 26% of these wetlands. The same study found the species in a variety of wetland types -- shallow open water, marsh, swamp, fen, and bog wetlands -- but with the greatest frequency in bogs and fens. Hardwood (e.g., alder, willow) stands may be favored as nonbreeding habitat in some areas of Oregon (Gomez and Anthony 1996, Cole et al. 1997b) but data are inconclusive

Forests were identified as important to this species by Pearl et al. (2005) as well as by Hayes et al. (2008), who also noted its regular seasonal movements at distances ranging over 1000 m from wetlands. Studies in British Columbia (Chan-McCleod et al. 2000) demonstrated the ability of the species to travel >300 m. In Washington, the frogs were found 1.25 times more often in successional forests (30–76 yr) than in clearcuts (Bury and Corn 1988). In Oregon, Cole et al. (1997b) reported that logging did not significantly alter their capture rates compared to uncut controls, but Aubry (2000) reported they were found 5–10 times more often in pitfall traps in rotation age stands (50–70 years old) compared with younger age classes including clearcut sites. However, it is not apparent that either of these two studies accounted for possible differences in proximity of treatment sites to natal wetlands, and that is likely to have significantly confounded the study findings.

If clearcuts do pose a barrier to essential upland movements of this species, after 11 years of regeneration the barrier effect may be substantially reduced (Chan-McCleod 2003). In the Vancouver Island survey (Chan-McCleod et al. 2000), the species was present in 32% of 11 wetlands that were in logged and/or roaded areas and in 24% of 27 wetlands that were in unlogged old-growth. In another British Columbia study, 11 frogs were found in a 70-year-old second-growth stand before harvesting and only one frog one year post-harvesting (Maxcy 2000). However, the occurrence of this species among 85 wetlands in one part of western Oregon was not predicted by the amount of surrounding forest cover within 100 m or 1 km (Pearl et al. 2005). Breeding ponds favored in California were mostly unshaded by a forest canopy (Cary 2010).

Of particular note is a study that examined the effect on frog movements of residual (leave-tree) patches in clearcuts (Chan-McLeod and Moy 2007). That study found frogs moved towards large (>0.8 ha) patches and away from small (0.3 ha) patches 50 m away. If patches were spaced within 5-20 m of each other, frogs moved towards the forested patches rather than randomly. Frogs placed in small patches of trees were less likely to leave those patches if there was water nearby.

<u>Pacific Treefrog (Northern Pacific Chorus Frog)</u>

When not in larval stages, this species inhabits a wide variety of terrestrial habitats, including grassland, chaparral, woodland, forest, and farmland. Among wetlands, it also tolerates a wide range of hydroperiods (durations of standing water). In western Oregon, this abundant frog was found to occur most frequently in wetlands where there was the least amount of forest cover within 100 m and the least shade (Pearl et al. 2005). Studies in northern Idaho reached a similar conclusion (Goldberg and Waits 2009). Thus, this species might be expected to tolerate or benefit from tree removal associated with harvest. Individuals move up to several hundred meters between wetland breeding sites and nonbreeding upland habitats.

Western and Boreal Toads

In much of their geographic range, these closely-related species appear to prefer treeless areas or open-canopy forest. One study near Vancouver, BC (Deguise and Richardson 2009) determined that the movements of this species -- unlike those of the Northern red-legged frog -- do not appear to be restricted by clearcuts. In fact, toads appeared to move along forest roads more frequently than at random relative to the proportional area of those roads, and when placed in forests, they moved towards forest edges and clearcuts. They readily and rapidly colonize and reproduce successfully in created ponds and other ponds with mostly-unvegetated shallow water (Pearl and Bowerman 2006) and in the landscape devastated by the Mount St. Helens volcanic eruption (Karlstrom 1986, Dale et al. 2005). Non-breeding habitat of these species is seldom located next to their breeding ponds (Rittenhouse and Semlitsch 2007). In Idaho, toads spent almost 60% of their time in terrestrial areas farther than 10 m from the pond where they were born, which dried up late in the season. Individuals may travel up to 40 m daily, and seasonally they typically moved at least 0.36 (females) to 0.69 miles (males) from ponds, generally favoring shrublands and open forest (Muths 2003, Bartelt et al. 2004). However, in Alberta this species was more abundant in forest up to 100 m from lakes than in forest 400-1200 m away from the lake (MacDonald et al. 2006).

Northwestern Salamander

This species appears to favor deeper ponds and wetlands with shrubs and sedges that extensively overhang permanent water, or with extensive (>20%) submerged vegetation. They appear to especially favor ponds that lack predators such as fish and rough-skinned newts (Pearl et al. 2005, MacCracken 2007). Adults spend extensive time on land in concealed microhabitats, and tadpoles often overwinter within wetlands that contain water year-round. Most individuals appear to stay within a few hundred meters of their natal wetland. Effects of forestry practices have not been determined, but they have been found in both forested and clearcut areas (Grialou et al. 2000).

Rough-skinned Newt

In Oregon, adult newts were captured more frequently in riparian and wetland areas than in upslope habitats (Gomez and Anthony 1996) and were very common in alder stands (McComb et al. 1993, Cole et al. 1997b). Also in Oregon, this species was found most frequently in wetlands with the greatest extent of surrounding forest cover, measured within 1 km, and with the lowest road density within 1 km (Pearl et al. 2005). In contrast to most salamanders, newts commonly are active in unshaded terrestrial areas in daytime and sometimes move hundreds of meters between wetlands. In one study, harvest and herbicide applications appeared to have no detectable effects on capture rates of this species (Cole et al. 1997b) and they have been found in clearcuts (Grialou et al. 2000). However, neither study measured whether abundance of individuals differed between treatments, and results could have been confounded by differences in proximity to breeding wetlands (which were unreported). Similarly, after thinning treatments reduced Oregon conifer stands from 600 to 200 trees per hectare along streams, more newts were detected along stream reaches with thinned stands than along reference reaches; the streams had buffers of 6, 15, 70, and 145 m on each side (Olson and Chan 2005, Olson and Rugger 2007).

Long-toed Salamander

This pond-breeding species has been reported from a wide variety of habitats, e.g., semiarid sagebrush deserts, sub-alpine meadows, dry woodlands, humid forests, rocky shores of mountain lakes. Although forested areas were considered important to this species in northern Idaho (Goldberg and Waits 2009), dry moisture conditions in upland soils were found to be a greater barrier to movements than land cover (Goldberg and Waits 2010). An abundance of animal burrows and other microhabitats, such as talus slopes, that provide seasonal retreats or adequate moisture for the adults during their overland movements may be more important than the presence of forest, per se. In Alberta, adults were found in 3-year-old clearcuts as well as in 180-year-old forests, and occurred in areas that were being actively logged (Graham 1997). This species does not require permanently flooded wetlands for breeding. In fact, fishless wetlands that are inundated only temporarily each year may be favored (Pearl et al. 2005).

Dunn's, Van Dyke's, and Torrent Salamanders

Dunn's salamander was found in a clearcut (Grialou et al. 2000) but no information is available regarding its productivity there or in other habitats affected by forest practices. Both Dunn's and Van Dyke's salamanders are typically found in headwaters or otherwise very close to streams (Corn and Bury 1989, McIntyre et al. 2006, O'Donnell et al. 2007). It is likely that some vegetated stream microhabitats used by torrent salamanders (*Rhyacotriton* spp.) qualify as wetlands, but there are no data on wetland use by this species.

3.3.5 Effects on Wetland Birds and Mammals

As is true of plants, animal species can be classified as wetland-obligate (found almost exclusively in wetlands), facultative-wet (found mostly in wetlands but regularly in uplands as well), facultative (about equally frequent in wetlands and uplands), facultative-upland (found mostly in uplands but regularly in wetlands as well), or upland-associated. Excluding fish, most vertebrate species in the PNW would be classified as facultative-upland or upland-associated. However, local circumstances -- such as a scarcity of a favored upland food, presence of different competitors or predators, or extreme weather conditions during a particular month or year -- can cause a shift in the usual wetland dependency category of individuals of a species during at least some of their life stages.

This report focuses mainly on species that, under typically circumstances over most of their geographic range, would be classified as wetland-obligate or facultative-wetland. Wetland-obligate species can be further classified as mainly water-associated (e.g., loons, grebes, ducks, geese, swans, sandpipers, gulls, belted kingfisher) or vegetation-associated (e.g., herons, rails, marsh wren, willow flycatcher, common yellowthroat, Lincoln's sparrow). Birds that are not wetland obligates but sometimes associate disproportionately with streams, lakes, and wetlands in the PNW include cedar waxwing, tree swallow, veery, warbling vireo, and yellow warbler. In some locations this category also includes Pacific wren, western flycatcher, black-throated gray warbler, red-naped sapsucker, western wood pewee, Swainson's thrush, MacGillivray's warbler, song sparrow, and black-headed grosbeak (Lehmkuhl et al. 2007).

Contrary to expectations, bird richness (per unit area) in eastern Washington was found to be less in forested riparian areas than in forested uplands, and densities of individuals were about the same (O'Connell et al. 2000). In western Washington, stream riparian areas and uplands were nearly the same in terms of richness and abundance of birds (Pearson and Manuwal 2001), a finding echoed by riparian studies in British Columbia (Shirley 2005) . In northern Minnesota, species composition of bird communities did not differ significantly between seasonal wetlands and nearby forest (Hanowski et al. 2006).

Among the better-known mammal species that associate disproportionately with wetlands or wetland edges in forested landscapes of the Pacific Northwest are beaver, muskrat, mink, river otter, raccoon, moose, and many bats. Many other mammals, such as jumping mice, shrews, and their predators, can reach high population densities in unflooded wetlands and/or in riparian areas that adjoin more permanently flooded wetlands and streams (Anthony et al. 1987, Doyle 1990). In British Columbia, activity levels of bats were more than 40 times greater in riparian than in upland areas, due to greater abundance of emerging aquatic insects, and were significantly greater where stand complexity and extent of forest edges was greater; bat activity levels were not correlated with forest stand age (Grindal and Brigham 1999, Grindal et al. 1999). Flying insects and many songbird species also tend to concentrate along water edges, especially in landscapes where most remaining forest is in riparian buffers (Whitaker et al. 2000).

With rare exceptions, the geographic and elevational ranges of wetland-obligate and facultative-wetland species do not overlap parts of the region where wetlands are adjoined most frequently by timber harvests. The most strongly wetland-dependent species, such as shorebirds and waterfowl, occur in lowland landscapes dominated by agriculture or rangeland rather than forest cover. Some of these species might even benefit from harvesting trees in or surrounding wetlands in this region, where those trees hinder detection of predators or serve as perches for predatory birds. Also, if tree removal increases water yield and increases the extent, depth, and duration of surface water in wetlands during critical seasons (or temporarily creates new wetlands as described in section 3.1), then waterbird breeding habitat may benefit.

Dozens of studies in the PNW have examined the response of songbirds, and to a lesserextent mammals, to tree removal or tree cover generally. However, few if any studies have attempted to identify the sensitivity -- to various degrees and patterns of tree removal and forest roads -- of birds and mammals that associate strongly with the region's wetlands. None of the species that are commonly termed "forest interior specialists" – ones that have been found to occur mainly in unfragmented forests or wider buffers – have been shown to depend strongly on wetlands in this region.

As would be expected, immediately after clearcutting all forest-dwelling species disappear from the clearcut area unless some residual trees are left, and even then, not all formerly-present species will persist. Recent clearcuts are particularly devoid of birds in winter, but silvicultural treatments such as two-story and small-patch group-selection can lessen this effect somewhat, especially when sufficient snags, logs, and large trees are retained (Zarnowitz and Manuwal 1985, Chambers and McComb 1997, Steel et al. 1999, Zielke et al. 2008). Within a few years post-harvest, logging commonly results in greater shrub cover. Consequently, some wetland-associated songbird species that nest mainly in shrubs – such as willow flycatcher – respond positively in the short term to timber harvests (Chambers et al. 1999).

In British Columbia, Lance and Phinney (2001)compared nesting bird abundance and richness in 2 clearcuts, 2 partial retention sites, and 2 unlogged forest sites. Both bird metrics indicated high similarity between partial retention sites (15-22% of the stand was retained) and unharvested forest over a 3-year period (). The partial retention sites contained species from the forest, species from the clearcuts, and species found at neither of the other two site types. Some forest-dwelling species were missing from the partial retention sites, and some were less abundant, but others were more abundant at the partial retention sites. Another comparison study in Minnesota focused specifically on these treatments as applied near wetlands (Hanowski et al. 2006). A 17-m wide buffer was retained around the wetlands in all cases. Bird species composition in the partial retention sites (basal area reduced to 7-10 m^2 per hectare) was found to be more similar to uncut sites than to the clearcut sites. Another study by the same authors (Hanowski et al. 2005) found that when trees within riparian buffers were thinned to a basal area average of 17–25 sq. ft/acre, the number and variety of sensitive forest interior bird species declined in those buffers. The density of vegetation (e.g., basal area or percent canopy closure) in a buffer, corridor, or patch -- or in the landscape generally -- also influences habitat value for some species, perhaps as much or more than buffer width, corridor width, or patch size. In the Seattle metro area, the variety of breeding birds declined as forest canopy closure increased over the range of 45% to 100% (Donnelly and Marzluff 2006). That study found greater retention of native breeding birds where forests retained a tree density of at least 25 trees per acre.

Over the longer term, forest management practices in the PNW have favored conifers at the expense of deciduous trees. This may be a potential concern because a recent analysis of 42 years of PNW data on 12 songbird species indicated that birds associated with deciduous forest (chiefly maple, alder, oak) have declined at the greatest rates in this region (Betts et al. 2010). None of the studied species is strongly associated with wetlands, but many of the floodplain wetlands in this region have a large deciduous tree component important to birds generally (Lock and Naiman 1998). Depending on the species and scale of measurement (distance of 500 ft or 1640-6560 ft around nest site), between 1.35% and 24.5% cover of deciduous trees should be supported to sustain particular songbirds with declining populations in this region (Betts et al. 2010). Deciduous trees (particularly aspen, cottonwood, birch, and willow) are also important to American beaver and moose. These mammals often become established in landscapes disturbed by harvest or fire. In fact, one study in Ontario (Landriault et al. 2009) found 73% of beaver lodges adjacent to shorelines with clearcuts remained active, whereas only 34% of lodges with no shoreline clearcuts were active. The best predictor of lodge activity was the presence of a 21-35-year-old shoreline clearcut. That may have been the case because deciduous vegetation preferred by beaver reaches maximum density in clearcuts of approximately that age. However, another wetland-associated species -- mountain beaver – was found by Gyug (2000) to be sensitive to harvest activities that disturb soils, due partly to its habit of digging tunnels and dens in fine-textured soils that are subject to compaction from heavy machinery. (

Effects of forest roads on birds and mammals in wetlands have apparently not been studied in this region. Inadequately-culverted forest roads that block drainageways and thus sometimes create wetlands could increase habitat for waterbirds, wetland-associated songbirds, and wetland-associated mammals. Tree mortality resulting from an elevated water table on the uphill side of some unculverted forest roads could temporarily increase availability of snags for cavity-nesting wildlife, as could damage to uncut trees from increased windthrow on the edges of clearcuts, in small residual tree stands, and along forest roads. Windthrow or other sources of snags and down wood are a huge benefit to many wildlife species and support greater species richness of birds (Zarnowitz and Manuwal 1985, Żmihorski 2010). Thus, salvage harvesting can be detrimental to many species (Lindenmayer et al. 2008).

On the other hand, and at least historically, many small wetlands were permanently filled during the construction of forest roads, which commonly followed streams and lowlands where wetlands mostly occur (Pearson 2010). New forest roads can increase disturbance of a few wetland species that are highly sensitive to human intrusion during critical breeding periods (e.g., great blue heron, some raptors) as well as result in increased poaching and mortality from vehicle collisions. These impacts can be minimized to some extent by closing roads or restricting vehicle access during critical seasonal periods. However, for small mammals, the simple presence of a road, regardless of whether it is paved or the amount of traffic on it, has been shown to pose a significant barrier to movements. In one study in which animals were translocated, each road that chipmunks and mice had to cross reduced by half the number of individuals that crossed it (McGregor et al. 2008). Road widths varied from 6.8 to 14.4 m for the pavement width only, and from 6.8 to 17.8 m for the pavement plus gravel shoulders. Mean canopy cover ranged from 20 to 55 percent.

Foraging movements of some forest birds (none of them rare or known to be wetland-dependent) also can be constrained by large canopy gaps, perhaps including some of those caused by forest roads or timber harvests (Rail et al. 1997, St. Clair et al. 1998, Belisle et al. 2001, Belisle and Desrochers 2002, Shirley 2006, Tremblay and St. Clair 2009). Elk appear to avoid large areas near often-traveled forest roads (Rowland et al. 2000). Forest roads are expected to facilitate access of nest predators (e.g., ravens, skunks, squirrels) and nest parasites (brown-headed cowbirds) to nests of wetland birds, but long-term changes in local populations of prey or host species as a result of this have not been investigated in the PNW. A wetland study in coastal British

Columbia found that nest parasitism of song sparrow nests by brown-headed cowbirds was a significant drain on the local sparrow population (Rogers et al. 1997). Although that study did not specifically examine the role of fragmentation of forests by harvest, the association of both cowbirds and song sparrows with forest openings has been well documented. However, in central Pennsylvania, predation of forest bird nests was significant around clearcuts but not along forest roads, and predators did not appear to follow forest roads (Yahner and Mahan 1997). Edge effects (positive and negative) on terrestrial songbirds from timber harvests and roads, although perhaps relatively minor, appear to be greater in the more productive western parts of the PNW than in forests farther east (McWethey et al. 2009).

3.3.7 Effectiveness of Buffers for Maintaining Microclimate and Habitat Structure

Vegetated buffers, simply by adding structure that is more vertically and horizontally complex than that of recently logged areas, provide habitat to large numbers of terrestrial (upland) species. Buffers also can be designed to connect patches of important habitats, although for typically non-linear habitats such as wetlands, this happens more often by chance than design.

This section focuses mainly on the role of buffers in protecting those species that are most dependent on or strongly associated with *wetlands*, particularly in the Pacific Northwest. These include many plants, aquatic invertebrates, amphibians, and waterbirds, well as some fish and some terrestrial birds and mammals. Apart from maintaining wetland structure, it is also important to protect these species from detrimental changes in wetland microclimate, habitat fragmentation, and water quality degradation. Harvest impacts to microclimate are covered in section 3.3.1 and to water quality in sections 3.2.2 and 3.2.3.

<u>Buffers to Protect Microclimate and Wetland Vegetation</u>

Common objectives for wetland buffers for protecting wetland vegetation are:

- minimize the spread of invasive plant species into wetlands,
- maintain natural rates of windthrow of any wetland trees, and
- avoid impacts, especially to rare wetland plant species and communities, from altered microclimate and from increased sediment and nutrient inputs.

Apparently no studies have examined effects of harvest on wetland plants in the PNW, or the degree to which buffers minimize any undesired changes to wetland plant communities. In a Minnesota study, buffers 15 m wide surrounding seasonal wetlands lessened the effects of varied intensities of timber harvest in adjoining uplands, but did not eliminate the effects entirely (Palik and Kastendick 2010). With increasing canopy openness, there was an increase in the cover of sedges, grasses, willow, alder, and poplar. Along streams in western Washington that were surveyed 2 years after adjoining uplands were harvested, buffers of 15 and 30 m had more alder and greater cover of berry-producing shrubs, compared with control sites where adjoining upland forest had not been cut (Kelsey and West 2000a). Narrower buffers in British Columbia had more species of shrubs compared to wider buffers, but deciduous tree density was greater in wider buffers (Shirley 2004).

Logging of uplands next to wetlands accelerates windthrow rates in buffers and/or in unbuffered forested wetlands. This can reduce or nullify some functions of the buffer or the wetland. When trees are uprooted by wind, this stirs the subsurface soil, enhances microtopography (consequently diversifying the variety of soil soil moisture durations within the site), and potentially releases nutrients and exposes dormant seed banks. These can all diversify the wetland flora. However, increases in nutrient availability following windthrow are not inevitable (Keenan et al. 1994), and loss of trees can profoundly change the wetland microclimate over the long term, and over the short term if salvage logging is implemented. Along streams, wooded buffers of 75 ft width may be adequate in some cases to protect remaining trees from windthrow, according to a literature review by Pollock and Kennard (1998). When narrower than ~50 ft, buffers are more prone to wind damage (Lopez et al. 2006, Martin and Grotefendt 2007, Anderson and Meleason 2009). Amounts of downed wood measured from a wind-swept lakeshore up to at least 130 ft into the lakeside forest were greater than in forests farther from the lake (Harper and MacDonald 2001). In Oregon, the amount of downed wood in riparian buffers was unaffected by thinning operations in the adjoining upland forest unless the buffer was narrower than about 50 ft (Anderson and Meleason 2009). However, in California, researchers found that tree fall rates were abnormally high for a distance of at least 200 m from clearcut edges (Reid and Hilton 1998). One study found that within riparian buffers that adjoined clearcuts in Washington, tree fall rates were 26 times higher than normal for 3 years post-harvest, and may have caused the eventual replacement of conifers with deciduous hardwoods. A study in Southeast Alaska reported that cumulative stand mortality in the part of a stream buffer closest to a clearcut (i.e., 10-20 m from a stream) was more than double what occurred in uncut reference units. Future potential supply of large wood to the stream was diminished by 10% compared with unlogged areas (Martin and Grotefendt 2007). One survey reported that 11% of the harvest units experienced significant windthrow in their stream buffers (Martin and Grotefendt 2007). The amount of windthrow depends not only on buffer width, but on orientation of the cleared edge relative to wind, edge contrast (size differential of vegetation), the size of nearby clearings, tree species and age distribution, soil depth, and local topography (Ewers et al. 2007, Laurance and Curran 2008).

Buffers to Protect Aquatic Invertebrates and Fish

Buffers to protect naturally occurring assemblages of aquatic invertebrates and fish focus on protecting water quality and habitat structure needed by these taxa. Studies of the effectiveness of buffers for minimizing aquatic biological impacts of timber harvesting were reviewed by Hanson et al. 2010 and in meta-analyses of prior literature by Marczak et al. (2007, 2010).

Nearly all studies of buffer importance to aquatic invertebrates and fish have been conducted along streams rather than wetlands. The aquatic fauna of most wetlands, especially isolated wetlands, is quite different from that of streams. This is partly because most wetlands have less dissolved oxygen in their water and soil/sediment. Also, in non-riverine wetlands that lack inlet channels, nutrients and large woody materials are not replenished from upstream sources. Accumulations of large woody debris, whose continued long-term supply from riparian buffers can be important to aquatic invertebrates and fish in flowing waters, might be less critical to maintaining aquatic invertebrates and fish in wetlands because current velocities and scour risks are usually less. Cover can be provided in wetlands by structure-providing aquatic plants that normally occur more sparsely in flowing waters. Also, many wetlands contain surface water only briefly (if at all) during the growing season. Among wetlands that have limited surface water exchange and/or prolonged periods without surface water, the aquatic life would be expected to be more sensitive to (and/or adapted and resilient to) changes in shade, nutrients, and contaminants.

In a study of Minnesota wetlands, the retention of 15 m-wide forested buffers appeared to partially lessen the biological influence of logging further upslope (Miller 2001, Hanson et al. 2010). In Washington's Coast Range, following logging with buffers of less than 10 m on both sides of streams, no stream invertebrate group declined in the 3 summers following harvest, and sediment particle sizes differed little from reference streams despite extensive windthrow in buffers (Jackson et al. 2007). The influence of buffers on stream invertebrates in Ontario was found to be small compared to the influence of forest cover overall, measured at stream reach and watershed scales (Stephenson and Morin 2009). A study of 13 headwater streams in British Columbia found that uncut buffers of 30 m or more on both sides of the stream were needed to limit changes to invertebrates and algae, following clearcutting farther upslope (Kiffney et al. 2003). Tree buffers of 30 m provided more organic matter to streams than did buffers of 10 m for at least 8 years post-harvest (Kiffney and Richardson 2010). Streams with either buffer width received nearly as much organic matter as streams flowing through fully forested areas, although the organic matter from clearcut areas had a greater deciduous component, with consequent implications for the timing and amount of nutrients reaching the invertebrate communities in receiving waters.

Buffers to Protect Wetland Amphibians

Buffers for amphibians are intended to protect wetland microclimate, water quality, and appropriate habitat structure within the adjoined wetland. As explained in section 3.3.4, buffers also are intended to provide part of the suitable upland habitat which pond- or wetland-breeding amphibians require during their life cycle. To meet that need, some biologists have recommended wetland buffers of 538 ft (Semlitsch 1998) or even more than 1000 ft (Semlitsch and Bodie 2003). To date, nearly all studies that suggest a need for such large buffers are from streams (seldom from wetlands) in the eastern United States,. However, although there have been many fewer studies in the PNW, preliminary evidence (e.g., Hayes et al. 2008) suggests that large buffers that at least partially surround PNW wetlands will help ensure the survival of a few of this region's wetland-dependent amphibians. Likewise, the several studies that have been conducted of amphibian response to logging in the Pacific Northwest have focused only on stream-dwelling species (e.g., tailed frog, Pacific giant salamander) or on mainly terrestrial amphibians, e.g., Vesely and McComb 2002, Dupuis et al. 1995, Hawkes and Gregory 2012). Authors of a study of pond-breeding amphibians in Connecticut (Skelly et al. 2005) concluded, "conservation strategies dependent on universally applied, inviolate shoreline vegetation buffers may inadvertently contribute to species loss because species differ in their sensitivity to changes in canopy." And as noted by Cushman (2006), "The suggestion that *forest* cover in the [buffer] landscape benefits amphibians may not apply to all species that are fully aquatic or that depend on nonforested upland habitat." Nearly all the studies of amphibians and buffers published to date focus mainly on buffers near clearcuts (as opposed to partial cuts), and do not fully describe other connectivity factors that could be important to amphibians in the landscapes in which the harvests are located, e.g., density and pattern of logging roads, buffer slope, soil moisture, and ground cover.

Although buffers of 150 ft have been recommended along some Oregon streams (Vesely and McComb 2002), that recommendation was based mainly on needs of frog and salamander species that do not occur commonly in wetlands. In Maine, amphibians (none which occur in the Pacific Northwest) were more abundant in 35-50 ft forested riparian buffers than in adjacent clearcuts two years following harvest, indicating at least some benefit to retaining buffers of this width (Perkins and Hunter 2006). A meta-analysis of 31 studies of amphibian use of riparian buffers (Marczak et al. 2010) suggested that amphibian abundance may be less in buffers than in unharvested areas, and that abundance was unrelated to buffer width. Only two of the studies in that analysis involved pond-breeding species found in the Pacific Northwest. In the Washington Cascades, amphibians in wetlands monitored for 4 years appeared to be unaffected by uneven-aged harvests regardless of buffer width (from 0 to 61 m) around the wetlands (MacCracken 2005). The main species were Northwestern salamander and rough-skinned newt.

Of probably greater importance than buffer width is the suitability (quality) of the habitat within a buffer (Harper et al. 2008). During their upland phase, most amphibians appear to require extensive ground cover, large logs, burrows, and other places that maintain a moist microclimate even during dry periods (Kluber et al. 2008). Clearcuts not subjected to extensive slashburning and woody debris removal might partially provide that during the few years post-harvest. Thinned forests, windthrow areas, and regenerating clearcuts might also provide it, but data are lacking for the wetland species in this region.

<u>Buffers to Protect Waterbirds</u>

For purposes of this review, waterbirds include ducks, geese, swans, loons, grebes, herons, egrets, rails, bitterns, cormorants, sandpipers, plovers, and others that spend nearly all of their time foraging in or along standing water. For waterbirds, wetland buffers are intended to protect wetland water quality and, depending on the locally occurring species, to maintain habitat structure next to the wetland. In some cases, the buffers around wetlands are intended to hinder access of predators to nests of waterbirds (although their effectiveness for this has apparently never been tested), as well as limit disturbance from recreationists, livestock, and pets.

Most of this region's waterbirds seem not to need buffers that are forested, as suggested partly by their frequent use of wetlands amid agricultural lands (Hirst and Easthope 1981, Lovvorn and Baldwin 1996, Shepherd and Lank 2004, Slater 2004). For those species, trees that comprise a significant portion of the perimeter of small (<10 acre) wetlands sometimes discourage wetland use by swans, geese, and shorebirds, and it is surmised that is because those trees make convenient perches for avian predators (Shepherd and Lank 2004).

However, a few of this region's waterbirds nest occasionally or exclusively in trees, particularly trees that are of large diameter and/or very tall. An untested assumption is that the closer such trees are to wetlands or large areas of standing water, the more important they are to these species. In the PNW, these species include wood duck, common and Barrow's goldeneye, bufflehead, double-crested cormorant, green heron, and great blue heron. The first four of these species require nest cavities excavated previously by woodpeckers, particularly the big cavities created by pileated woodpeckers only in large-diameter trees (Aubry 2002, Hartwig et al. 2002). Thus, managing forests for long rotations and/or maintaining suitable large-diameter trees that attract and are used by pileated woodpeckers (which are not a wetland-dependent species) is essential to sustaining the four cavity-nesting ducks that *are* wetland obligates in the PNW. In British Columbia, nest cavities of Barrow's goldeneye averaged 90 m from permanent water (Evans et al. 2002). In northern Minnesota, wood duck nests averaged 80 m from water (Gilmer et al. 1978). These distances cannot be used to define preferred buffer widths around ponds, streams, and wetlands because it is unclear whether areas closer to those water bodies would have been used if more suitable cavity trees had been present closer. In fact, a few studies have found that nests in tree cavities or artificial nest boxes closer to water or over water were less successful (Richardson and Knapton 1993, Robb and Bookhout 1995). Other requirements of these ducks are detailed in a literature synthesis by Maggiulli (2009), who also created a Bayesian Belief Network (BBN) model based on the synthesis. Her report provides numeric definitions of high, moderate, low, and inadequate conditions for these ducks, as defined by specific combinations of tree diameter class and tree type (conifer/deciduous), snag density, canopy closure, and distance of these features to wetlands larger than 1.5 hectare, rivers, or fish-bearing streams.

When logging equipment or humans on foot approach individuals of some wildlife species, those species sometimes abandon their young or at least flee (termed "flushing") or interrupt their activities. When these disturbances occur regularly over periods of time, it reduces the food intake and weight of both adults and young. If chronic, that disturbance can eventually make their populations less competitive or put individuals at greater risk of predation or disease. The energy balance may be especially delicate for bird species that characteristically have annual migrations spanning multiple continents, such as many of the warbler and flycatcher species that are Neotropical migrants. However, it is the larger waterbird species (herons, swans) and perching hawks and eagles which tend to be the most wary, especially during nesting periods. Distances at which birds will or will not be disturbed by humans or noise vary depending on species, habitat, time of year, flock size, amount of visual screening by vegetation, and other factors (Korschgen and Dahlgren 1992). A wetland buffer of 30-100 m might be required to reduce disturbance of some waterbirds, and a few species sometimes take flight when humans or pets approach from as far as 200 m away. However, as long as they are not shot at, over time individuals of many waterbird species habituate to the presence of humans. A wetland buffer of dense shrubs, regardless of its width, can minimize disturbance of waterbird species that regularly inhabit wetlands such as shorebirds, herons, and cranes. To protect nesting waterbirds from disturbance, upland buffers appear to be necessary only for wetlands with extensive open water, as only those wetlands are used regularly by the larger nesting waterbirds.

Buffers to Protect Other Birds and Mammals in Wetlands

A meta-analysis of studies from many regions (285 data points) indicated that forest interior bird species overall do not necessarily prefer natural forest more than buffers, and wider buffers do not necessarily result in greater similarity between reference forest and buffer sites (Marczak et al. 2010). A meta-analysis by Price and McLennan (2002) reached similar conclusions. These analyses of bird responses originate mainly from studies of buffers along streams rather than wetlands. Also, data on mammal use of forested buffers are very limited. A majority of the studies published to date focus mainly on buffers near clearcuts as opposed to partial cuts. Also, most do not describe other connectivity factors that could be important to mammals and birds in the landscapes in which the harvests are located, e.g., density and pattern of logging roads, vegetation age and diversity, ground cover, slope aspect, clearcut width. Width of remaining forest patches has been shown to have much less effect on bird species composition in those patches than the overall proportion of a landscape that is forested (Rodewald and Bakermans 2006). For example, in southern Michigan, a study of forested depressional wetlands found that richness and abundance of songbird species which were considered generally wetland-dependent there were influenced less by wetland characteristics than by characteristics of the surrounding upland forest, e.g., total patch size, tree height diversity (Riffell et al. 2006).

In the PNW, a few studies have highlighted particular species that might be sensitive to buffer width and/or patch size in this region, but apparently none are wetland obligates. Brown creeper, golden-crowned kinglet, black-throated gray warbler, and Wilson's warbler in western Washington used buffers less than intact forests, and/or used 30-m buffers more than 14-m buffers (Kelsey and West 2000b). In terms of species turnover rates, buffers narrower than 14 m (on each side of a stream) did not maintain the pre-logging upland bird community, and black-throated gray warbler was not found in buffers narrower than 30 m.

Surveys in the forested landscape of the Cedar River watershed east of Seattle also found that golden-crowned kinglet, brown creeper, and black-throated gray warbler were more common in wider buffers or in uncut forest, and were more consistently present between years in those wider buffers. Riparian buffer widths of ~150 ft were needed for these species in order to attain equivalence with numbers found in unharvested areas, and occurrence of most other songbird species was associated with buffers of 100 ft but not 50 ft on each side of streams (Pearson and Manuwal 2001).

A study in the Oregon Coast Range that compared buffers of 0 to 75 m width on each side of streams found that brown creeper, hairy woodpecker, and chestnut-backed chickadee were more likely to be present in wider streamside buffers (Hagar 1999). Even the widest buffers (131-230 ft) failed to support Hammond's flycatcher, varied thrush, and golden-crowned kinglet. In another Oregon study, some of the nesting species whose numbers declined in stream buffers after logging were Pacific wren, brown creeper, golden-crowned kinglet, Wilson's warbler, and Swainson's thrush (Chambers et al. 1999). Birds associated with wider stream buffers in the Portland metropolitan area were Pacific wren, brown creeper, and Pacific-slope flycatcher (Hennings and Edge 2003). Based on bird data from the Oregon Cascades, buffers of 200 ft on each side of streams were deemed adequate to support corridor and refuge functions for birds in clearcut areas (Lehmkuhl et al. 2007).

A study in British Columbia compared stream buffer widths of 46, 121, and 230 ft, and found that Pacific (winter) wren, as well as golden-crowned kinglet, Townsend's warbler, Hammond's flycatcher, and varied thrush were detected more often in wider buffers (Kinley and Newhouse 1997). Also in British Columbia, stream buffers of ~150 m failed to support several species at densities equivalent to those in extensive uncut forests: brown creeper, pileated woodpecker, golden-crowned kinglet, varied thrush, and red-breasted sapsucker. However, at least 2 species -- warbling vireo and Swainson's thrush – were more common in buffers than in uncut forest. Pacific-slope flycatcher was mostly absent from streamside buffers narrower than ~50 m in logged watersheds (Shirley and Smith 2005). In clearcut areas in Southeast Alaska, the species peaked in riparian buffers of 250 m (Kissling and Garton 2008). That study also reported that brown creeper and hairy woodpecker might be sensitive to buffer width. The study found few other nesting songbirds whose presence was correlated with buffer width, but it did not examine buffers narrower than 100 m.

In Quebec, golden-crowned kinglet, and Swainson's thrush were seldom found in buffers narrower than 65 ft (Darveau et al. 1995). In Alberta, the narrowest riparian buffers in which several species nested were as follows (Hannon et al. 2002):

66 ft = yellow warbler, song sparrow, black-capped chickadee, western wood-pewee, yellow-rumped warbler, dark-eyed junco;
328 ft = Swainson's thrush, common yellowthroat, hairy woodpecker, brown creeper;
656 ft = western tanager, purple finch.

In the same Alberta study, forest-dependent bird species declined as buffer width narrowed from 200 to 100 m and narrower, and the authors concluded that 200 m wide buffers would be necessary to conserve all forest-dependent species from the pre-harvest bird community.

Most data on bird use of buffers come from streams and from regions other than the Pacific Northwest. Because those situations reflect very different faunas, those results cannot be validly extrapolated to this region. As explained by Schmiegelow et al. (1997) and Schmiegelow and Monkkonen (2002):

> "the magnitude of the fragmentation effects we documented is small compared with those observed elsewhere. Birds breeding in the boreal forest, where frequent small- and large-scale natural disturbances have occurred historically, may be more resilient to human-induced habitat changes, such as those caused by limited forest harvesting. "

And Tewksbury and Martin (1998) comment:

> "the effects of fragmentation are dependent on the habitat structure, the landscape context, the predator community, and the impact of parasitism. All of these factors may differ substantially in western ecosystems when compared to previously studied forests, making generalizations about the effect of fragmentation difficult."

Based on their extensive data from Vancouver Island, Schieck et al. (1995) concluded:

> "Most species of birds that occur in the Pacific Northwest may be less susceptible [than Eastern species] to adverse effects of forest fragmentation."

And finally, in a synthesis on this topic, Kremsater and Bunnell (1999) observed:

> "In the east and midwest many studies document increased predation and parasitism near edges; in the Pacific Northwest researchers have found little effect of patch area or negative edge effects"

Some studies have reported more *individual birds per unit area* in wider buffers (e.g., Kinley and Newhouse 1997, in British Columbia). In fact, most studies of birds and insects have found higher densities of birds in buffers than in areas of comparable size in the middle of extensive forests (Marczak et al. 2010). This could be because most buffer studies have been of buffers next to clearcuts containing unsuitable habitat, forcing birds with no other choice than to use remaining buffers or else move longer distances to find large forest patches. Several studies (e.g., Darveau et al. 1995, Hannon et al. 2002, Hanowski et al. 2006, Betts et al. 2006) have noted how clearcutting can crowd individual birds (presumably those that formerly nested in the now-clearcut forest) into remaining patches of forest (e.g., buffers) for at least 1-3 years post-harvest.

Also, among buffers of different widths, wider buffers are more likely to have higher bird and insect densities simply because of the greater likelihood that they possess a variety of vegetation types and size classes, which generally leads to higher avian abundance (Marczak et al. 2010). Also, wider riparian buffers in British Columbia happened to have a greater density of deciduous trees (Shirley 2004, 2005, 2006) which may partly explain why they often support more nesting bird species (Lock and Naiman 1998, Hagar 1999, Shirley 2004). Deciduous leaves often have higher nutrient levels (Roberts and Bilby 2009) and can support greater abundance and functional diversity of invertebrates (Piccolo and Wipfli 2002, Allan et al. 2003).

Studies are rare that compare buffer use by small mammals with small mammal use of undisturbed forests and clearcuts. Buffer studies involving larger mammals are even rarer. Changes in small mammal communities are notoriously difficult to separate from interannual variation due to climate (e.g., Hannon et al. 2002). A study in British Columbia found dusky shrews were less common in buffers than in larger forested areas. Significantly more deer mice and creeping voles were infested with bot flies at clearcut sites than at buffer sites, and none were infested at any of the control sites (Cockle and Richardson 2003). A meta-analysis of 69 small mammal buffer studies from throughout North America (Marczak et al. 2010) indicated that buffers tend to have lower densities of small mammals compared to larger undisturbed forests, but the results were not statistically significant and involved no species that is wetland-dependent in the Pacific Northwest.

3.3.8 Summary and Data Gaps: Effects on Microclimate, Vegetation, and Animals

The aforegoing review emphasizes that few if any peer-reviewed studies have measured directly the effects of various forest practices in the PNW on wetland microclimate, use by wetland-obligate birds and amphibian species, and viability of sensitive plants. Specific data gaps are described by the hypotheses in part 4 of Appendix A.

Tentative inferences have been made from the dozens of studies that have investigated logging effects on these ecosystem components in stream riparian areas of the PNW (e.g., Herlihey et al. 2005, Richardson 2008), as well as a few studies of timber harvests in or near wetlands in other northern regions (e.g., Palik and Kastendick 2010). What is most apparent from these or other studies is that removal of a significant part of a forest canopy in or around forested wetlands likely:

- increases light penetration and expands growth of algae in understory surface water, and consequently increases temporarily the abundance of aquatic invertebrates;

- heightens the risk of windthrow of trees;
- encourages invasion by non-native plants;
- eliminates some shade-intolerant plants and particular microclimate-sensitive mosses and lichens;
- facilitates colonization by wildlife species not present in the same forested wetland prior to harvest.

However, it is clear that no single, fixed-width buffer or canopy closure prescription will be adequate to protect all wetland-dependent species in all harvest operations (Richardson et al. 2012, Hruby 2013). Examination of buffer needs will have to consider scale-specific conditions and local landscape contexts.

4.0 Summary: Risks to Wetland Functions from Forest Practices

This review has clearly documented the paucity of well-designed (or any direct studies) of impacts to wetland functions from forest practices in the Pacific Northwest. This void is especially noticeable when placed in the context of the plethora of studies conducted of streams and riparian areas in this region. Despite the lack of direct studies of wetlands, this report has attempted to infer and hypothesize potential effects of forest practices on wetlands by considering what is known about forest practice effects on streams and, in a few cases, on different types of wetlands in other regions.

Perhaps the largest and **most probable** adverse effect of forestry operations on wetlands is the direct filling of small wetlands during the construction of logging roads. Although such roads occupy a seemingly small percentage of most watersheds, and road layout and designs have improved in recent years, the wetland losses that occur are essentially permanent. The extent of such losses has not been quantified at any scale in the PNW. At least historically, those losses were balanced somewhat by the acres of small wetlands that were created or expanded when logging roads intersected natural drainageways. A key question that remains is whether those created wetlands provide the same level of functions as natural wetlands.

With **reasonable certainty**, timber harvests in many PNW locations will result in a rise in local water tables, greater water yield, and warming of runoff. The degree to which these effects extend off-site and influence wetland functions depends on local geomorphic conditions. Also relatively probable is the fact that removal of a significant part of the forest canopy in or around forested wetlands will:

- increase light penetration and expand growth of algae in understory surface water, and consequently increases temporarily the abundance of aquatic invertebrates;
- heighten the risk of windthrow of trees;
- encourage invasion by non-native plants;
- eliminate some shade-intolerant plants and microclimate-sensitive mosses and lichens;
- facilitate colonization by wildlife species not present in the same forested wetland prior to harvest;
- increase soil erosion and export of suspended sediment from the logged site.

These effects usually diminish, in some cases exponentially, during the post-harvest years. At many locations the effects are undetectable after about 10 years post-harvest as vegetation succession and canopy closure occurs on logged sites. When canopy removal occurs outside a wetland boundary, the risk to a wetland depends mainly on the extent of canopy removal, its proximity to the wetland, and wetland size.

Most potential effects of forest practices on wetland functions have a moderate to low probability of occurrance. Rather than list all those here, they are described throughout this document and especially in the Hypothesis Appendix (A). Most notable among this category of potential effects are:

- the degree to which disturbances from logging operations mimic natural disturbances to wetlands in the PNW, and either add to or partially offset the effects of those on wetlands;
- effects of both wetlands and forest practices on the timing and seasonal persistence of surface water in downslope areas;
- effects of higher post-logging water tables on water detention times in wetlands, as that influences the pollutant processing capacities of wetlands, the reproductive success of pond-breeding amphibians, and fish access and growth;
- extent of small wetlands that experience faster sedimentation as a result of nearby logging operations, and the ecological consequences of that sedimentation;
- direct and indirect consequences (for salmon and other aquatic life) of changes (both immediate and as a progressive result of shorter rotations at catchment scales) in the amount, form, and timing of nutrients, large wood, and organic matter received and exported by wetlands;
- capacity of wetlands to continue to effectively process pollutants from logging runoff over the long term without adverse biological impacts to the wetlands;
- the optimal widths, configurations, and understory characteristics of upland buffers required for supporting particular wetland-dependent birds and mammals in various subregions and landscape settings;

- effects of logging-associated soil compaction, as well as canopy removal, on nonbreeding terrestrial habitat of wetland-breeding amphibians;
- the sublethal and indirect effects, in combination with other stressors, of commonly-used forest pesticides, on wetland fish, invertebrates, and amphibians;
- time required for tree stands to re-establish and regrow to their original condition after harvest in forested wetlands, and effects on other wetland functions attributable to possible time lags in this recovery;
- how all of the above are influenced by wetland type, connectivity, wetland position in a watershed, and other factors, especially factors that are subject to management;
- shifts that have occurred in gross vegetation structures (e.g., deciduous vs. conifer vs. herbaceous) across large portions of the region or watersheds, among forested wetlands that are recovering from logging many decades ago;
- shifts that have occurred in the mean size, connectivity, and distribution of wetlands of various hydrogeomorphic tyes or water regimes (e.g., proportionately fewer temporary-flooded vs. permanently-flooded wetlands; fewer lowland vs. headwater wetlands) across large portions of the region or watersheds, and the cumulative consequences of these shifts for wetland functions;
- the cumulative extent, compiled at multiple scales, of small wetlands in forested landscapes of the PNW, and the proportion of these wetlands exposed currently or historically to logging operations (on-site or off-site).

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Wetland Research and Monitoring Strategy: Forest Practices and Wetlands

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WASHINGTON STATE DEPARTMENT OF
Natural Resources
PETER GOLDMARK - Commissioner of Public Lands

December 2014

CMER #12-1203

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Washington State Forest Practices Adaptive Management Program

The Washington State Forest Practices Board (FPB) has established an Adaptive Management Program (AMP) by rule in accordance with the Forests & Fish Report (FFR) and subsequent legislation. The purpose of this program is to:

> *Provide science-based recommendations and technical information to assist the FPB in determining if and when it is necessary or advisable to adjust rules and guidance for aquatic resources to achieve resource goals and objectives. The board may also use this program to adjust other rules and guidance.* (Forest Practices Rules, WAC 222-12-045(1)).

To provide the science needed to support adaptive management, the FPB established the Cooperative Monitoring, Evaluation and Research (CMER) committee as a participant in the program. The FPB empowered CMER to conduct research, effectiveness monitoring, and validation monitoring in accordance with WAC 222-12-045 and Board Manual Section 22.

Report Type and Disclaimer

This technical report contains scientific information from research or monitoring studies that are designed to evaluate the effectiveness of the forest practices rules in achieving one or more of the Forest and Fish performance goals, resource objectives, and/or performance targets. The document was prepared for the Cooperative Monitoring, Evaluation and Research Committee (CMER) and was intended to inform and support the Forest Practices Adaptive Management program. The project is part of the Eastside Type F Riparian Effectiveness Program, and was conducted under the oversight of the Riparian Scientific Advisory Group (RSAG).

This document was reviewed by CMER and was assessed through the Adaptive Management Program's independent scientific peer review process. CMER has approved this document for distribution as an official CMER document. As a CMER document, CMER is in consensus on the scientific merit of the document. However, any conclusions, interpretations, or recommendations contained within this document are those of the authors and may not reflect the views of all CMER members.

Full Reference

Adamus, Paul Ph.D. 2014 Wetland Research and Monitoring Strategy: Forest Practices and Wetlands. Cooperative Monitoring Evaluation and Research Report CMER 12-1203. Washington State Forest Practices Adaptive Management Program. Washington Department of Natural Resources, Olympia, WA.

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Wetland Research and Monitoring Strategy: Forest Practices and Wetlands

December 2014

Prepared for:

The State of Washington
Forest Practices
Adaptive Management Program
Department of Natural Resources
Personal Service Contract #11-350

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Wetland Research and Monitoring Strategy: Forest Practices and Wetlands

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1.0 Introduction

The Washington Administration Code wetland rules (WAC 222) are intended, in summary, to achieve no net loss of wetland functions by avoiding, minimizing, or preventing sediment delivery and hydrologic disruption from roads, timber harvest, and timber yarding; and by providing wetland buffers (wetland management zones, or WMZs). The application of WAC 222 rules is assumed to achieve and protect aquatic conditions and processes that meet functional objectives and consequently achieve the four performance goals of the Forest Practices Habitat Conservation Plan. The four goals are:

1. Comply with the federal Endangered Species Act for aquatic and riparian-dependent species on state and private forestlands.

2. Restore and maintain riparian habitat to support a harvestable supply of fish.

3. Meet the requirements of the Clean Water Act for water quality.

4. Keep the Washington timber industry economically viable.

The key questions driving effectiveness research and monitoring in the adaptive management program can be summarized as:

> *Will the rules produce forest conditions and processes that achieve resource (functional) objectives as measured by the performance targets, while taking into account the natural spatial and temporal variability inherent in forest ecosystems?*

Collectively, the studies included in this Wetland Research and Monitoring Strategy are intended to answer this question as it relates to wetlands and wetland functions. At a project scale, effectiveness research and monitoring tests whether forest practices are successful at meeting certain Resource Objectives. Those are measured by Performance Targets. Resource Objectives and Performance Targets taken together highlight the primary wetland functions of interest in the Forest Practices Habitat Conservation Plan (FPHCP, Schedule L-1). The research strategy described herein accounts for Resource Objectives and Performance Targets while recognizing that not all Performance Targets listed in the FPHCP are fully developed. This research strategy includes recommendations for some new wetland performance targets that will better inform the degree to which Resource Objectives outlined in the FPHCP are being met.

CMER's systematic review of literature on effects of forest practices on wetlands of the Pacific Northwest identified several key data gaps. To begin with, although many research projects have examined effects of forest practices on streams, none have examined effects of forest practices targeted specifically on wetlands. In some cases extrapolations of specific findings from studies of the effectiveness of forest practices rules in protecting streams are fraught with many interpretive difficulties. Past investigations of streams and forest practices have used a wide variety of sampling and analytical methods. Most studies have been of short duration, with some studies only evaluating post-harvest conditions. Even when pre- and post-harvest conditions have been compared, between-year differences in the amount and timing of precipitation and temperatures between years has sometimes confounded inferences one might make from the data. This interpretive problem is especially acute if unharvested reference (control) sites were not part of the study. Likewise, even when harvested vs. non-harvested landscapes are compared; differences in soils, topography, vegetation, specific harvest practices and their configuration, and other factors can limit inferences that might otherwise be made. Moreover, many studies have occurred in landscapes that were harvested previously, and for which the precise histories of harvest may be ambiguous or unknown, which limits effective comparisons between current and historical distributions of plants, amphibians, and other organisms. Too often, biological studies have considered only the presence or absence of a species, rather than analyzing its degree of dependence on wetlands and upland buffers. Few studies have measured the reproductive success and long-term sustainability of populations of species, rather than frequency of capture/detection, abundance, or density.

Studies with pre- and post-treatment data may also be affected by time lags. Effects on groundwater quantity and quality may occur distantly in space and time. Similarly, the longevity of selected wetland species may result in treatment effects not being manifest for several years following harvest. Few attempts have been made to measure the adaptability and resilience of individual members of a species to potentially harmful impacts of timber harvest. Also, some forest practice rules in the PNW have improved over the last two decades, and information about responses to current management rules is very limited.

1.1 Problem Statement

CMER needs a logical framework (Wetland Research and Monitoring Strategy) that prioritizes and organizes wetland research projects. TFW Policy directed CMER to prioritize wetland research based on the highest risk to wetlands and wetland functions that relate to meeting Clean Water Act Assurance targets. Currently the CMER Work Plan lists multiple wetland research projects but these projects are not organized into a strategy for implementation. There is a need to examine the current wetland research objectives and critical questions to determine if there are more efficient ways to combine and organize them into discrete research projects than what is currently presented in the CMER Work Plan.

1.2 Purpose of the Wetland Research and Monitoring Strategy

The purpose of the Wetland Research and Monitoring Strategy is to provide a logical framework for conducting research and monitoring on the effectiveness of forest practices rules at protecting wetlands and wetland functions. One of the primary goals of the research strategy is to identify where efficiencies can be found in the current Wetlands Protection Rule Group section of the CMER Work Plan by combining or revising research projects. For example, the current work plan suggests stand-alone research studies to examine downstream temperature effects, hydrological connectivity, buffer effectiveness, and post-harvest changes to forested wetlands. A revised strategy might examine downstream temperature effects and connectivity as part of evaluating the effects to forested wetlands directly.

The research strategy incorporates and reflects TFW policy directives, CMER Adaptive Management Performance Targets, different levels of protection provided to wetlands in the Forest Practice rules, and existing scientific knowledge. The Wetlands Research and Monitoring Strategy will do the following (at a minimum):

- Identify a research strategy that efficiently and appropriately combines the research objectives of all of the wetland studies into discrete studies to accelerate their implementation.
- Recommend a prioritized list of projects based on satisfying the research objectives of the identified Clean Water Act Assurance priority projects (see below).
- Illustrate in a flow chart the relationship of the research projects to each other and to the goals of the adaptive management program.

The Wetlands Research and Monitoring Strategy will evaluate, revise, add/replace, and prioritize projects listed in the CMER Work Plan. Research projects will consider priority application of Testable Hypotheses from the Wetlands Systematic Literature Review. An explanation will be provided describing the rationale for how these projects are timed and the prioritized list of hypotheses they will address. The research strategy will illustrate in a flowchart how outcomes from the studies will be used in the Forest Practices Adaptive Management Program, either by testing the effectiveness of the forest practice rules at meeting Resource Objectives and Performance Targets and protecting wetland functions and/or by informing scoping and designing follow-up projects.

The Wetland Research and Monitoring Strategy will include a description of projects and justification of the prioritization for each project. It will ultimately provide a newly revised WetSAG timeline to guide individual project implementation.

2.0 Critical Research Questions

In concept, the proposed projects will address three main questions:

1. To what degree do specific forest practices (see list below)[2] in or near wetlands affect the magnitude, duration, frequency, and timing of water quantity and quality (including temperature):
    a) in the wetland,
    b) in Typed Waters located up- or down-gradient (upslope, upstream, downslope, or downstream), and
    c) in the surface and groundwater connections between the two, if any.

2. To what degree are plants and animals in the wetland and in Typed Waters near the wetland (downgradient or upgradient) affected by the listed forest practices.

3. To what degree are the effects (#1) and responses (#2) influenced by:
    a) harvest type & configuration (cut area, remaining tree density & pattern, timing of harvest)

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[2] The "specific forest practices" are timber harvest, road construction, and application of silvicultural chemicals (fertilizers, pesticides)

b) wetland type & configuration (e.g., size, position in the landscape, HGM type, vegetation type)
c) connectivity between (a) and (b) as defined by:
    - separation distance, if any
    - water table depth (local groundwater)
    - soil runoff coefficient
    - presence of channels connecting harvest area with downslope wetland
    - frequency, duration, magnitude, seasonality of runoff, or flow in connecting channels and local groundwater paths
    - characteristics of the WMZ (if a Type A, B, or bog wetland)
d) landscape context, as defined by:
    - climate and region
    - underlying geology
    - position in watershed (elevation, distance from divide)
    - ratio of wetland size to size of wetland's contributing basin/sub-basin area.

Most of the functions that wetlands normally provide and which are to be protected from unmitigated adverse effects of forest practices can be categorized as:

> *Hydrologic Maintenance functions*: Maintain stream flow and channel forms; flood peak reduction and attenuation; groundwater recharge and discharge.
>
> *Water Quality Maintenance functions*: Maintenance of natural regimes of water temperature, dissolved oxygen, and pH; retention of suspended sediment; substrate stabilization; nutrient retention or removal; detoxification of contaminants.
>
> *Habitat Maintenance functions*: provision of food, cover, movement corridors, and special features necessary to sustain populations of fish, amphibians, vegetation, and other biological components and processes, e.g., primary productivity, carbon export, microclimate maintenance.

3.0 Wetland Research and Monitoring Strategy

Under the Wetlands Protection Rule Group the existing CMER Work Plan identifies several research programs and projects that address wetlands. They are:

Forested Wetland Effectiveness Program:
Project: Wetland/Stream Water Temperature Interactions
Project: Wetland Hydrologic Connectivity

Wetland Management Zone Effectiveness Monitoring Program:
Project: Wetland Management Zone Effectiveness Monitoring

Wetlands Intensive Monitoring Program:
Project: Wetlands Intensive Monitoring

Wetlands Mitigation Program:
Project: Wetlands Mitigation Effectiveness

TFW Policy and the Forest Practices Board (Board) consider the projects in the Forested Wetland Effectiveness and Wetland Management Zone Effectiveness programs as critical for attaining Clean Water Act Assurance targets. The Assurances were described by Washington Department of Ecology (1999 and 2009). The other wetland programs and projects were given a lower priority and are not discussed further in this document. Unless reprioritized, the latter programs will be addressed by Policy and the Board after completion of this proposed strategy.

Considerable waste of limited fiscal resources would occur, and critical interactions would remain poorly understood, if each program and project were to be conducted independently of the others, using different research sites, methods, and/or schedules. This strategy proposes three projects that integrate the first two of the above programs:

A1. Effects of Timber Harvest That Occurs Within Forested Wetlands:
Effects on forested wetland water regime, water quality, vegetation, fish and wildlife, and connectivity to downgradient and upgradient waters.

A2. Effects of Timber Harvest That Occurs Outside of Wetlands:
Effects on wetland water regime, water quality, vegetation, fish and wildlife, and connectivity to downgradient and upgradient waters.

B. Effects of Forest Roads Near Wetlands:

Effects of roads located upgradient and downgradient of wetlands on wetland water regime, water quality, vegetation, fish and wildlife, and connectivity to downgradient and upgradient waters.

An additional and separate project considered of lower immediate priority is:

C. Effects of Applying Silvicultural Chemicals In or Near Wetlands

Project proposed to not proceed further at present time:

Wetland Mitigation Effectiveness Project

4.0 Project Prioritization and Integration

Based on TFW Policy's prioritization process, it is proposed that the Wetlands Mitigation Effectiveness Project not proceed further at the present time. It is most closely related to Project B above, but was originally envisioned primarily as a survey rather than an experimental research study.

It is proposed that specific projects and their objectives related to the Wetlands Intensive Monitoring program be deferred until A1 and A2 are completed. It is expected that the knowledge gained in conducting these studies will be crucial to identifying any gaps in the science which need to be filled with intensive or cumulative effects level research.

The project selection and priorities described herein have been informed by best available science as reflected in the CMER Wetlands Systematic Literature Review completed in 2013. Also, the design of the projects described below may be informed by data being collected (e.g. headwater wetlands) for the Type N Riparian Prescriptions Rule Group.

Integration of the projects is proposed as follows:

- The existing project "Wetland/Stream Water Temperature Interactions" will be covered under the broader topic of "water quality effects" by all three newly proposed projects (A1, A2, and B). To the extent possible, they will examine separately the changes in temperature and selected other water quality parameters associated with timber harvest within forested wetlands (section 3.2.1.1 of the Wetland Literature Synthesis), harvest upgradient from the WMZ's of non-forested wetlands (section 3.2.1.3 of the Wetland Literature Synthesis), and from forest roads near wetlands (section 3.2.1.2 of the Wetland Literature Synthesis).

- The existing project "Wetland Hydrologic Connectivity" will be covered under the broader topic of "hydrologic effects" by all three newly proposed projects (A1, A2, and B). To the extent possible, they will examine separately the changes in connectivity between wetlands and downgradient and upgradient waters as related to timber harvest within forested wetlands (section 3.1.1 of the Wetland Literature Synthesis), harvest upgradient from the WMZ's of non-forested wetlands (section 3.1.3 of the Wetland Literature Synthesis), and from forest roads near wetlands (section 3.1.2 of the Wetland Literature Synthesis). Changes in connectivity are especially important to fish passage, water quality, and mobility of silvicultural chemicals. Design of this project may be informed by data being collected for the Type N Riparian Prescriptions Rule Group.

- The existing project "Wetland Management Zone Effectiveness Monitoring" will be incorporated into *all* proposed projects except A1. It does not apply to project A1 because that project addresses only the timber harvests occurring within forested wetlands, as they are not required to be buffered in the Forest Practices Rules. It will address the degree to which WMZs lessen the impacts of upslope forest practices to functions of FPA Type A, B, and Bog wetlands.

The interrelationships among the proposed projects are shown in Figure 1. It is proposed that project A1 (Effects of Timber Harvest That Occurs Within Forested Wetlands) would be initiated first to isolate effects of wetland harvest from effects of upland harvesting. As data from that project begin to become available, the data would inform the design of projects A2 and B, to the degree that effects from forest roads and harvest outside of wetlands might resemble effects from harvest within wetlands. The Wetlands Intensive Monitoring Program would build on findings from earlier priority projects and their results. The Wetland Intensive Monitoring Program could seek to assess cumulative impacts of forest practices on wetlands at broader scales as well as address specific questions more quantitatively: such as what are the effects of silvicultural chemicals in or near wetlands on in wetlands and downstream functions.

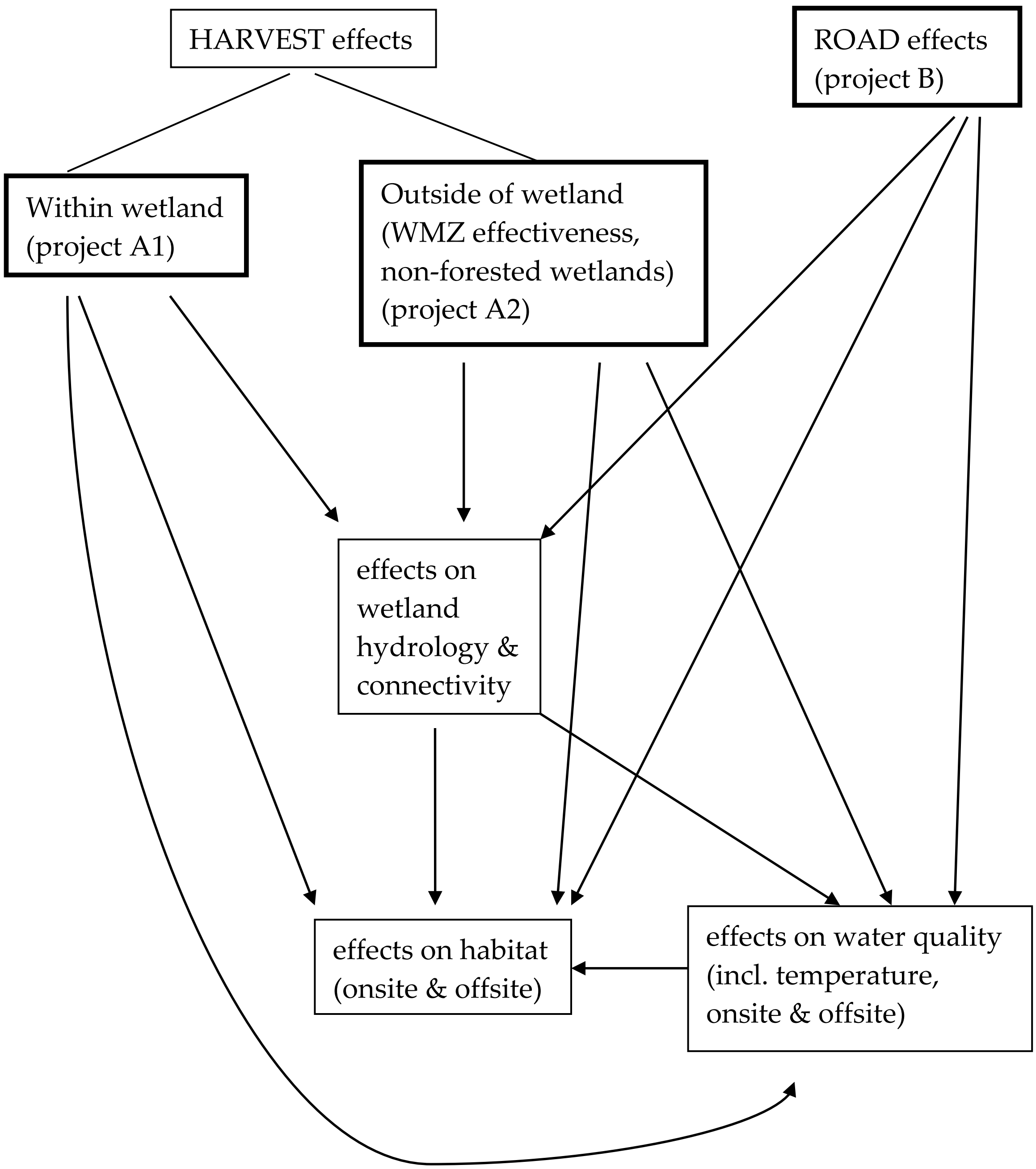

Figure 1. Interrelationships of the proposed projects (in darker boxes)

5.0 Research Design

This section does not present a detailed research design, but rather describes process and principles that will apply to the future development of such a design.

The proposed research and monitoring will focus initially on *forested* wetlands because these receive less protection under the current FPA and the TFW Policy has prioritized this project. Among forested wetlands, the proposed research and monitoring may focus on those belonging to the slope, flat, and depressional hydrogeomorphic (HGM) classes. These wetland types are suspected of being more sensitive to impacts from forest practices than are riverine wetlands, and many or most riverine wetlands receive some protection under current FPA Riparian Rules.

An essential first step is to conduct a desktop characterization of functionally relevant attributes (e.g., number, size, distribution) of each mapped wetland within the study area. This will provide context to create a sample frame for stratifying and selecting research sites in a statistically sound manner. It also provides a coarse initial characterization of wetland exposure to forest practices across the entire study area, and locations of wetlands that may be most impacted by forest practices. Such an initial characterization was completed to address the latter objective and to inform the development of this Wetland Strategy. Results are summarized in Appendix C.

Different types of wetlands, in different landscape settings, are anticipated to respond differently for forest practices. Therefore, the final selection of research and monitoring sites should identify and consider differences in the likely sensitivity of various types of wetlands to forest practices, as well as the likelihood and extent of offsite impacts. By "sensitivity", we mean the intrinsic resilience and resistance capacity of particular wetland types, i.e., their capacity to remain unaltered when exposed to some kinds of stresses, and if impacted, the speed and completeness with which they recover. Factors that may influence this include the following:

- Likely degree of groundwater vs. surface runoff influence on each wetland's water levels;
- Hydrologic connectivity (outflow volume, variance, duration, and peaks, by season), especially to fish-bearing streams, as potentially influenced by climate, slope, soils, geology, and position in watershed;
- Wetland type (HGM and/or Forest Practices Act type, vegetation community)
- Climate, specifically: local runoff regime[3] and growing degree-days[4];

[3] Throughout Oregon, scientists from the USEPA have defined and mapped 5660 “hydrologic landscape units” with an average size of 44 km^2, useful for predicting hydrologic behavior. The units were defined using cluster analysis of data on flow seasonality, snowmelt contribution, climate, aquifer permeability, terrain, and soil type (Wigington et al. 2013). An effort in Washington with somewhat similar objectives

- Wetland size;
- Size of the wetland's catchment (and ratio of that to wetland size);
- Disturbance history (management and natural).

Where feasible and appropriate, the research projects addressing different hypotheses should be implemented on the same research sites. This is because the effects of timber harvest on water quality (e.g., temperature) and on habitat functions are intricately related to effects on wetland water regimes. Using the same sites to test multiple priority hypotheses will help ensure the research is cost-effective.

The proposed research should consider using a, manipulative experimental approach to facilitate examining causal relationships between forest management and changes to wetlands functions. The literature synthesis shows that this type of literature is extremely limited in the Pacific Northwest.

6.0 Literature Cited

Reidy Liermann, C. A., J. D. Olden, T. J. Beechie, M. J. Kennard, P. B. Skidmore, C. P. Konrad, and H. Imaki, H. 2012. Hydrogeomorphic classification of Washington State rivers to support emerging environmental flow management strategies. River Research and Applications 28(9): 1340-1358.

Washington Department of Ecology. 1999. Forests and Fish Report. Washington Department of Ecology, Olympia, WA.

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but different methods (Reidy Liermann et al. 2012) has classified all streams and rivers in that state. A map of such landscape units (or a simpler aggregation of them) could be a particularly relevant stratifier when applied to selection of research sites intended to span regional hydrologic gradients. This would improve significantly on classifying sites geographically as merely "eastside" or "westside".

[4] http://pnwpest.org/wea/index.html

Wigington, P.J. Jr., S.G. Leibowitz, R.L.Comeleo, and J.L. Ebersole. 2013. Oregon hydrologic landscapes: a classification. JAWRA Journal of the American Water Resources Association 49(1):163-182.

Appendix A. Description of the Proposed Projects

Project A1. Effects of Timber Harvest *Within* Forested Wetlands, Critical Question A1.1**:** ***To what degree does timber harvest in forested wetlands alter water regimes in those wetlands, in downgradient waters, and the connectivity between them?***

Potential Hypotheses:
a) Timber removal in a wetland increases the water level depth, spatial extent of inundation, seasonal persistence (duration), and/or through flow persistence of surface water, and/or alters the seasonal timing of inundation.
b) In doing so, it increases the connectivity of some wetlands with down gradient waters during specific times and at different frequencies and durations.

Research Objectives : To quantify the hydrologic effects in and downgradient of forested wetlands, of timber harvest occurring within the wetlands. This should be done in a manner that isolates or minimizes any hydrologic effects resulting from associated upland timber harvest and roads, and from unrelated confounding factors that simultaneously affect water regime in and downgradient from forested wetlands.

Key Covariates:

a) groundwater (water table level and seasonality)
b) harvest type & configuration (cut area, remaining tree density & pattern, timing of harvest)
c) wetland type & configuration (area, HGM type, vegetation type)
d) soil type, surficial geology, watershed position
e) ratio of wetland size to size of wetland's contributing area
f) distance to downslope waters and type of connectivity
g) the pre-harvest duration, frequency, magnitude, and seasonal pattern of connection.

Linkage to Current CMER Work Plan: This project elaborates on the following question in the current CMER work plan:

> *Does timber harvest in forested wetlands alter hydrology sufficiently to affect wetland functions?*

Wetland Functions Addressed: Water Storage, Streamflow Maintenance. See Appendix B for a list of specific metrics that could be used to represent or measure these functions.

Existing Performance Target(s): (a) No net loss in the hydrologic functions of wetlands, (b) West side: Do not cause a significant increase in peak flow recurrence intervals resulting in scour that disturbs stream channel substrates providing actual or potential habitat or potential habitat for salmonids, attributable to forest management activities.

Suggested Performance Target(s): Return to pre-harvest levels of these functions.

Focal Wetland Types: Forested wetlands on slopes or in depressions, with and without offsite hydrologic connections. Initial emphasis should be on forested wetlands with at least intermittent connection to fish-bearing streams (e.g. Type F), or have potential for such connection (e.g. Type N).

Rationale & Outcomes: Trees are the defining component of forested wetlands, so their harvesting them has direct effects on wetland structure and function. The specific types of effects, their duration, and mitigating factors are poorly understood. Especially in headwater locations in western Washington, timber harvest occurs commonly in forested wetlands in both headwater and lowland valley locations in western Washington. As a result of potential post-harvest rising of local water tables, regeneration success and tree growth rates may be less than on non-wetland sites, but data are sparse. Also, little is known about the effects of harvest on connectivity among wetlands. Such connectivity has the potential to profoundly affect water quality as well as salmonid populations. Post-harvest changes in connectivity can limit or extend the accessible habitat space and available food resources during salmonid rearing phases. The proposed research would clearly attribute post-harvest changes in water tables, wetland connectivity, downgradient flows, and salmonid rearing habitat to timber harvest within wetlands.

Project A1. Effects of Timber Harvest Within Forested Wetlands, Critical Question A1.2, ***To what degree does timber harvest in forested wetlands alter water quality in those wetlands and in downgradient waters?***

Potential Hypotheses:

Timber removal in a wetland:

- increases water temperature* in those wetlands and in downgradient waters
- decreases dissolved oxygen* in those wetlands and in downgradient waters
- causes the wetland to shift from being a net retainer to a net exporter of suspended sediment

- increases phosphorus levels within the harvested wetland and causes the wetland to shift from being a net retainer to a net exporter of phosphorus
- increases dissolved nitrogen levels within the harvested wetland and causes the wetland to shift from being a net remover to a net exporter of dissolved and particulate nitrogen
- causes the wetland to shift from being a net source to a net sink for dissolved and particulate carbon (including large woody debris)
- alters the level and stability of pH in those wetlands and downgradient waters.
  * = see Appendix B for list of specific parameters that would be monitored

Research Objectives: To separate the effects on water quality in and downgradient of forested wetlands, specifically of timber harvest within the wetlands, from water quality effects resulting from associated road construction and operation, and from unrelated confounding factors that simultaneously affect water quality in and downgradient from forested wetlands.

Key Covariates:

a) harvest type & configuration (cut area, remaining tree density & pattern, timing of harvest)
b) wetland type & configuration (size, position in the landscape, HGM type, vegetation type)
c) groundwater level and chemistry, soil type, surficial geology, watershed position
d) distance to downslope waters
e) the pre-harvest duration, frequency, magnitude, and seasonal pattern of connection.

Linkage to Current CMER Work Plan: In part, this project elaborates on the following specific question in the current CMER work plan:

Does timber harvest in forested wetlands affect water temperature sufficiently to negatively affect stream temperatures in connected streams?

Wetland Functions Addressed: Thermoregulation, Water Quality Maintenance.
Existing Performance Target(s): For connected waters: State water quality standards—current and anticipated in next triennial review. Provide complex and productive instream and wetland habitat by recruiting large woody debris and litter.

Suggested Performance Target(s): For the wetland: anti-degradation. No net loss of the above functions. Return to pre-harvest levels of these functions.

Focal Wetland Types: Forested wetlands on slopes or in depressions, with and without offsite hydrologic connections.

Rationale & Outcomes: Trees are the defining component of forested wetlands, so harvesting them can directly affect wetland structure and function. Little is known regarding effects of harvesting forested wetlands on water temperature and other water quality parameters, the duration and downgradient extent of such effects, and mitigating factors. In headwater and lowland valley locations in western Washington, timber harvest occurs commonly in forested wetlands and temporarily removes shade, thus allowing slow-moving water to be heated rapidly. The proposed research would clearly attribute post-harvest changes in water temperature and other parameters to harvest of trees within wetlands.

Project A1. Effects of Timber Harvest Within Forested Wetlands, Critical Question A1.3, ***To what degree does timber harvest in forested wetlands alter habitat functions in wetlands, in connected waters, and in surrounding uplands?***

Potential Hypotheses: Timber removal in a wetland results in reduced growth and survival of re-established trees, as well as decreases* in native plants, aquatic invertebrates, fish, amphibians, waterbirds, and/or songbirds in the wetland, connected waters, and/or in surrounding uplands.
* = see Appendix B for list of specific parameters that would be monitored

Research Objectives: To separate the effects on habitat in and downgradient of forested wetlands, specifically of timber harvest in the wetlands, from effects on habitat resulting from associated road construction and operation, and from unrelated confounding factors that simultaneously affect habitat in and downgradient from forested wetlands.

Key Covariates: Species & life stage. Structure, age, & pattern of pre-harvest timber. Survival and growth of regenerating trees.

Linkage to Current CMER Work Plan: In addition to the critical question noted above, this project will address the following questions in the current CMER work plan:

Are forested wetlands regenerating sufficiently to maintain wetland functions?

How does the post-harvest stand composition compare to pre-harvest condition?

Wetland Functions Addressed: Habitat Functions

Existing Performance Target(s): For connected waters, the Habitat Conservation Plan (HCP) performance targets (pool frequency, etc.) for those waters may be applicable.

Suggested Performance Target(s): No net loss of native species diversity. No loss of state-listed Sensitive species or communities. No net loss of habitat functions. Return to pre-harvest levels of these functions.

Focal Wetland Types: Forested wetlands on slopes or in depressions, with and without offsite hydrologic connections.

Rationale & Outcomes: Especially in headwater locations in western Washington, timber harvest occurs commonly in forested wetlands. Trees are the defining component of forested wetlands, so their harvest can directly affect wetland structure and habitat function. Little is known regarding long term effects of harvesting forested wetlands on the vegetation composition, amphibians, birds, and mammals that use these wetlands. These resources can be affected by changes in wetland hydrology and water quality described above. The proposed research would clearly attribute post-harvest changes in vegetation and wildlife use of previously-forested wetlands to the hydrologic, water quality, and/or structural changes wrought by the harvest of trees within the wetlands.

A2. Effects of Timber Harvest Upslope From Wetlands, Critical Question A2.1, ***To what degree does timber harvest upslope from wetlands alter the water regime of these wetlands?***

Potential Hypotheses: Timber removal upslope from a wetland increases the water level, depth, spatial extent of inundation, seasonal persistence, and/or throughflow persistence of surface water, and/or alters the seasonal timing of inundation.

Research Objectives: To separate the hydrologic effects in wetlands, specifically of timber harvest located upslope, from hydrologic effects resulting from associated road construction and operation, and from unrelated confounding factors that simultaneously affect water regime in forested wetlands.

Key Covariates: Harvest proximity, type, & configuration (cut area, remaining tree density & pattern, timing of harvest). Structure, age, & pattern of pre-harvest timber. WMZ width and configuration (for FPA wetland types A, B, and bogs). Soil runoff coefficient and partitioning of water sources as groundwater vs. surface flow. Presence of channels connecting harvest area with downslope wetland. Frequency, duration, magnitude, seasonality of runoff and flow in connecting channels. Climate, position in watershed (elevation), ratio of wetland size to size of wetland's contributing area.

Linkage to Current CMER Work Plan: This does not link explicitly with the Wetlands Protection Rules component of the current Work Plan. However, it has some characteristics in common with the Type N Riparian Effectiveness Program under the Type N Riparian Prescriptions Rule Group.

Wetland Functions Addressed: Wetland Hydroperiod Maintenance, Water Storage

Existing Performance Target(s): (a) No net loss in the hydrologic functions of wetlands, (b) West side: Do not cause a significant increase in peak flow recurrence intervals resulting in scour that disturbs stream channel substrates providing actual or potential habitat or potential habitat for salmonids, attributable to forest management activities.

Suggested Performance Target(s): No net loss of this function. Return to pre-harvest hydroperiod. Do not cause a significant increase in peak flow recurrence intervals of downgradient streams such that scour disturbs stream channel substrates providing actual or potential habitat for salmonids.

Focal Wetland Types: Wetlands on slopes or in depressions. Emphasis on wetlands in watersheds with high potential for water table rise following timber harvest.

Rationale & Outcomes: This requires a watershed-scale approach because wetlands are not alone in being affected by the upland processes that would be investigated by this project.

A2. Effects of Timber Harvest Upslope From Wetlands, Critical Question A2.2, ***To what degree does timber harvest upslope from forested wetlands alter the water quality of these wetlands?***

Potential Hypotheses:
Timber removal upslope from a wetland

- decreases dissolved oxygen* in those wetlands
- increases water temperature* in those wetlands
- causes the wetland to shift from being a net retainer to a net exporter of suspended sediment
- increases phosphorus levels within the harvested wetland and causes the wetland to shift from being a net retainer to a net exporter of phosphorus
- increases dissolved nitrogen levels within the harvested wetland and causes the wetland to shift from being a net remover to a net exporter of dissolved and particulate nitrogen
- causes the wetland to shift from being a net source to a net sink for dissolved and particulate carbon

* = see Appendix B for list of specific parameters that could be monitored

Research Objectives: To separate the water quality effects in forested wetlands, specifically of timber harvest located upslope, from water quality effects resulting from associated road construction and operation, and from unrelated confounding factors that simultaneously affect water quality in forested wetlands.

Key Covariates: Harvest proximity, type, & configuration (cut area, remaining tree density & pattern, timing of harvest). Structure, age, & pattern of pre-harvest timber. WMZ width and configuration (for FPA wetland types A, B, and bogs). Soil runoff coefficient and partitioning of water sources as groundwater vs. surface flow. Presence of channels connecting harvest area with downslope wetland. Frequency, duration, magnitude, seasonality of runoff and flow in connecting channels. Climate, position in watershed (elevation), ratio of wetland size to size of wetland's contributing area.

Linkage to Current CMER Work plan: This does not link explicitly with the Wetlands Protection Rules component of the current Work Plan. However, it has some characteristics in common with the Type N Riparian Effectiveness Program under the Type N Riparian Prescriptions Rule Group.

Wetland Functions Addressed: Water Quality (both within wetland and downstream)

Existing Performance Target(s): For connected waters: State water quality standards—current and anticipated in next triennial review. Provide complex and productive instream and wetland habitat by recruiting large woody debris and litter.

Suggested Performance Target(s): For the wetland: anti-degradation. No net loss of water quality functions. Return to pre-harvest levels of temperature and water quality. One specific objective is to provide cool water by maintaining shade, groundwater temperature, flow, and other watershed processes controlling stream temperature. Another is to provide complex and productive instream and wetland habitat by recruiting large woody debris and litter.

Focal Wetland Types: Wetlands on slopes or in depressions. Emphasis on wetlands in watersheds with high potential for water table rise following timber harvest.

Rationale & Outcomes: This requires a watershed-scale approach because wetlands are not alone in being affected by the upland processes that would be investigated by this project.

A2. Effects of Timber Harvest Upslope From Wetlands, Critical Question A2.3, ***To what degree does timber harvest upslope from forested wetlands alter the habitat functions of these wetlands?***

Potential Hypotheses: Harvesting of upslope timber results in decreases* in native plants, aquatic invertebrates, fish, amphibians, waterbirds, and/or songbirds in wetlands.
* = see Appendix B for list of specific parameters that would be monitored

Research Objectives: To separate the effects on habitat in forested wetlands, specifically of timber harvest located upslope, from effects on habitat resulting from associated road construction and operation, and from unrelated confounding factors that simultaneously affect habitat in forested wetlands.

Key Covariates: Harvest proximity, type, & configuration (cut area, remaining tree density & pattern, timing of harvest). Structure, age, & pattern of pre-harvest timber. WMZ width and configuration (for FPA wetland types A, B, and bogs). Soil runoff coefficient and partitioning of water sources as groundwater vs. surface flow. Presence of channels connecting harvest area with downslope wetland. Frequency, duration, magnitude, seasonality of runoff and flow in connecting channels. Species & life stage. Survival, growth, and composition of regenerating vegetation.

Linkage to Current CMER Work plan: This does not link explicitly with the Wetlands Protection Rules component of the current Work Plan. However, it has some characteristics in common with the Type N Amphibian Response Program (Effectiveness) under the Type N Riparian Prescriptions Rule Group.

Wetland Functions Addressed: Habitat Functions

Existing Performance Target(s): For connected waters, the Habitat Conservation Plan (HCP) performance targets (pool frequency, etc.) for those waters may be applicable.

Suggested Performance Target(s): No net loss of native species diversity. No loss of state-listed Sensitive species or communities. No net loss of habitat functions. Return to pre-harvest levels of these functions.

Focal Wetland Types: Wetlands on slopes or in depressions. Emphasis on wetlands in watersheds with high potential for water table rise following timber harvest.

Rationale & Outcomes: This requires a watershed-scale approach because wetlands are not alone in being affected by the upland processes that would be investigated by this project.

B. Effects of Forest Roads Near Wetlands, Critical Question B, ***To what degree does forest road construction and operation near wetlands alter the water regime, water quality, and habitat functions of the wetlands?***

Potential Hypotheses:

1. Forest roads upslope from a wetland:

- decrease the water level, depth, spatial extent of inundation, seasonal persistence, and/or throughflow persistence of surface water, and/or alters the seasonal timing of inundation.
- increase water temperature* in those wetlands
- decrease dissolved oxygen* in those wetlands
- cause the wetland to shift from being a net retainer to a net exporter of suspended sediment
- increase phosphorus levels within the harvested wetland and causes the wetland to shift from being a net retainer to a net exporter of phosphorus
- increase dissolved nitrogen levels within the harvested wetland and causes the wetland to shift from being a net remover to a net exporter of dissolved and particulate nitrogen

- cause the wetland to shift from being a net source to a net sink for dissolved and particulate carbon

2. Forest roads downslope from a wetland decrease the water level, depth, spatial extent of inundation, seasonal persistence, and/or throughflow persistence of surface water, and/or alters the seasonal timing of inundation.

Research Objectives: To separate the effects on water regime, water quality, and habitat in wetlands, specifically from forest road construction and operation, from effects on these functions resulting from timber harvest in or upslope of the wetland, and from unrelated confounding factors that simultaneously affect these functions.

Key Covariates: Road proximity, age, configuration, type of surface, soil runoff coefficients. WMZ width and configuration (for FPA wetland types A, B, and bogs). Soil runoff coefficient and partitioning of water sources as groundwater vs. surface flow. Presence of ditches or channels connecting road with downslope wetland. Frequency, duration, magnitude, seasonality of runoff. Flow in connecting channels. Climate, position in watershed (elevation), ratio of wetland size to size of wetland's contributing area.

Linkage to Current CMER Work Plan: Relevant to Roads Rule Group as well as Wetlands Protection Rule Group.

Wetland Functions Addressed: Water Storage, Streamflow Maintenance, and Habitat

Existing Performance Target(s): For connected waters: water quality standards. The wetland WMZ and road prescriptions are also intended to accomplish the following stated FP HCP functional objectives under the Hydrology Resource Objective as stated in Schedule L-1:
Maintain surface and groundwater hydrologic regimes (magnitude, frequency, timing, and routing of stream flows) by disconnecting road drainage from the stream network, preventing increases in peak flows causing scour, and maintaining hydrologic continuity of wetlands. Prevent increases in peak flows causing scour, and maintain hydrologic continuity of wetlands.

Consideration should be given to adapting at least some of the performance targets from the Roads Rule Group if they apply to wetlands or connected waters that could be impacted by forest practices in wetlands, for example:
- Road sediment delivered to streams: New roads — Virtually none.

- Ratio of road length delivering to streams/total stream length (miles/mile): Old roads not to exceed — Coast (spruce zone), 0.15–0.25; west of crest, 0.15–0.25; east of crest, 0.08–0.12.
- Ratio of road sediment production delivered to streams/total stream length(tons/year/mile): Old roads not to exceed — Coast (spruce zone), 6–10 tons/yr; west of crest, 2–6 tons/yr; east of crest, 1–3 tons/yr.
- Fines in gravel: Less than 12% embedded fines (< 0.85 mm).
- Road runoff: Same targets as road-related sediment; significant reduction in delivery of water from roads to wetlands.

For connected waters, the Forest Practices Habitat Conservation Plan (HCP) performance targets (pool frequency, etc.) for those waters may be applicable.

Suggested Performance Target(s): For the wetland: anti-degradation. No net loss of native species diversity. No loss of state-listed Sensitive species or communities. No net loss of the above functions. Return to pre-harvest levels of these functions.

Focal Wetland Types: Wetlands on slopes or in depressions. Emphasis on wetlands in watersheds with high potential for water table rise following road construction.

Rationale & Outcomes: The results of this study would inform rule effectiveness at a site scale while contributing to the understanding of cumulative effects at the watershed scale.

C. Effects of Applying Silvicultural Chemicals, Critical Question C: ***Do the pesticide rules protect water quality and native vegetation within forested wetlands?***

Potential Hypotheses: Chemical applications result in decreases* in non-target native plants, aquatic invertebrates, fish, amphibians, waterbirds, and/or songbirds in the wetlands.
* = see Appendix B for list of specific parameters that would be monitored

Research Objectives: To separate the effects on wetland plants and animals of applying silvicultural chemicals (a) within forested wetlands, (b) in nearby upland forests, and/or (c) along forest, from unrelated confounding factors that simultaneously affect plants and animals in forested wetlands.

Key Covariates: Species, life stages. Type and dose of the applied chemical. WMZ width & configuration. Soil runoff coefficient, presence of ditches or channels connecting application area with downslope wetland. Frequency, duration, magnitude, seasonality of runoff. Climate, position in watershed (elevation, distance to divide), ratio of wetland size to size of wetland's contributing area.

Linkage to Current CMER Work plan: Relevant to Pesticides Rule Group as well as Wetlands Protection Rule Group.

Wetland Functions Addressed: Water Quality, Habitat Functions

Existing Performance Target(s): Excluding fertilizer and Bt: (a) No chemical entry into surface waters for large droplets; minimized for small droplets (drift), (b) No significant harm to native vegetation in core and inner zone of WMZs.

Suggested Performance Target(s): Anti-degradation. No net loss of native species diversity. No loss of state-listed Sensitive species or communities.

Focal Wetland Types: Wetlands on slopes or in depressions, with and without offsite hydrologic connections.

Rationale & Outcomes: The results of this study would inform rule effectiveness at a site scale while contributing to the understanding of cumulative effects at the watershed scale.

Appendix B. Potential Metrics and Parameters for Quantifying Forest Practice Effects on PNW Wetland Functions

Table 1. Potential metrics and parameters for quantifying forest practice effects on PNW wetland functions

This list is not intended to be comprehensive.

Major Indicator Variable	Most Relevant to Functions:	Spatial Context (where to measure)	Temporal Context (how to describe the condition)	Associated Parameters
Water volume & velocity	Water Storage	in-wetland (surface)	frequency, duration, seasonality, flow-through time	extent, water level, distribution pattern (patchiness)
	Low Flow Support	in-wetland (subsurface)	percent exceedence: frequency, duration, seasonality, rate of change	depth to saturation
	Water Cooling	input (surface)		min, max flow volume (peak flow, low flow)
	Habitat	output (surface & ET)		
		downstream		
Water & Air Temperature	Water Cooling	input (surface)	percent exceedence: frequency, duration, seasonality, rate of change	daily min, max (7 day average max), seasonality
	Fish Habitat	in-wetland (surface)		
	Amphibian Habitat	in-wetland (subsurface)		
	Aq. Invertebrate Habitat	output (surface)		
		downstream		
Dissolved Oxygen/ Redox	Phosphorus Retention	input (surface)	percent exceedence: frequency, duration, seasonality, rate of change	daily min, max --> seasonality
	Nitrate Removal	in-wetland (surface)		
		in-wetland (soil/ sediment)		
		output (surface)		
		downstream		
Suspended Solids and Toxins	Sediment Retention	input surface	percent exceedence: frequency, duration, seasonality	TSS, turbidity, algal-generated toxins, chytrid fungus, spawning gravel
	Fish Habitat	in-wetland		
	Amphibian Habitat	output surface		
	Aq. Invertebrate Habitat	downstream		
Sediment / soil	Sediment Retention	in-buffer	deposition rate (short & long-term)	bulk density, penetrability/ percolation, particle size distribution, herbicides, metals, enzymes, CEC, Ca, extractable Fe, Al
		in-wetland		
Phosphorus	Phosphorus Retention	input (surface)	percent exceedence: frequency, duration, seasonality	TDS, TP, SRP concentrations, adsorption/ desorption rate
		in-wetland (surface)		
		in-wetland (soil/ sediment)		
		output (surface)		
		downstream		

Major Indicator Variable	Most Relevant to Functions:	Spatial Context (where to measure)	Temporal Context (how to describe the condition)	Associated Parameters
Nitrogen	Nitrate Removal	input (surface) in-wetland (surface) in-wetland (soil/ sediment) output (surface) downstream	percent exceedence: frequency, duration, seasonality	TDS, TN, NO3, NH3 concentrations, nitrification & denitrification rate, N fixation rate (esp. if alder)
Carbon	Carbon Flux Nitrate Removal	input (surface) in-wetland (surface) in-wetland (soil/ sediment) output (surface) downstream	frequency, duration, seasonality	LPOM, FPOM, DOC, DIN concentrations, rates of decomposition & peat accumulation
Aquatic Invertebrates (nekton, neuston, aerial, benthic/ subsurface) (emphasizing ones most & least likely to be harmed by forest practices)	Habitat	in-wetland	by season	abundance/density, biomass, taxa & functional group richness, colonization rate, deformity rates
Fish (by species)	Habitat	in-wetland	by season	abundance/density, biomass, growth & survival rate, residence time, deformity rates
Amphibians & Turtles (by species & life stage, emphasizing ones most & least likely to be impacted by forest practices)	Habitat	in-wetland in buffer in treatment areas	by season	abundance/density, biomass, egg mass counts, growth & survival rate, dispersal distance & direction, deformity rates
Waterbirds (by guild, emphasizing ones most & least likely to be impacted by forest practices)	Habitat	in-wetland	monthly	abundance/density, species richness, nesting success, frequency-duration of use
Songbirds (by species, emphasizing wetland-dependent ones most & least likely to be impacted by forest practices)	Habitat	in-wetland in buffer in treatment areas	monthly monthly	abundance/density, species richness, nesting success, frequency-duration of use

Major Indicator Variable	Most Relevant to Functions:	Spatial Context (where to measure)	Temporal Context (how to describe the condition)	Associated Parameters
Wetland Plants (by species, native/ exotic/ invasive, WIS status, annual/ perennial, vascular vs. non)	Habitat	in-wetland		percent cover, richness, germination rate, Floristic Quality score (Rocchio 2011)
Vegetation Structure	Habitat	in-wetland		age-height-diameter relationships & class diversity, basal area, canopy closure, ground cover (bare), growth rate (tree rings etc.), LWD & snags (#, decay stage, dimensions), patchiness of veg communities and water within wetland.
		in buffer		
		in treatment areas		
Qualitative Characterization of Functions	All	in-wetland		scores for hydrologic, water quality, and habitat functions using Washington's Rating System (Hruby 2004) or other function assessment methods (e.g., Adamus et al. 2011) in other states or provinces where appropriate

Appendix C. Results of a Preliminary GIS Intersect of Forest Practice Permits and Possible Wetlands Throughout Washington

Using GIS (Geographic Information Systems), an intersect was performed using the polygon boundaries of FPA (Forest Practices Act) permit areas and mapped wetlands in most of western Washington. Given the severe limitations of the data, the purpose was only to provide a preliminary qualitative estimate of interrelationships between forest practices and wetlands in western Washington. This step is important for adding context to the recommendations of CMER's Wetland Strategy and for helping prioritize future research.

The task was performed by Evergreen College student Krystle Keese working under the direction of Greg Stewart of the WDNR and Dr. Paul Adamus. Metadata and a summary description of methods are available in a separate document. For wetlands, we used not only the FPWET and FPARS layers maintained by the WDNR (building upon previous wetland maps by the NWI), but also a modeled wetlands layer (WetWRIA) for western Washington. That modeled layer includes locations of wetlands larger than 1 acre that were not identified previously from aerial imagery by the NWI.

The GIS overlay identified 691,342 mapped wetland polygons in the western Washington region. It also determined that 11,279 mapped wetlands are present within an FPA or within 200 feet of an FPA boundary.

The following tables are presented without interpretation and summarize only part of the results. The database resulting from the intersect is available separately as an Excel spreadsheet that can be queried by anyone familiar with creating Excel pivot tables. It contains several data fields not shown in the compilations below. Also, any of the compilations below could be broken out more finely by county, watershed (WAU), and a host of other co-factors.

Table 2. Number of FPA permits within or near mapped wetlands of western Washington, and area of FPA and wetland involved, by wetland class

Wetland Class	# of FPAs in Wetland	# of FPAs within 200 ft of Wetland	Acres of Wetland in FPAs	Acres of Wetland within 200 ft of FPA
Estuarine Emergent Wetland	104	295	95.95	260.23
Estuarine Forested Wetland	-	1		0.22
Estuarine Scrub/Shrub Wetland	2	3	0.14	0.44
Palustrine Aquatic Bed	75	269	29.37	132.08
Palustrine Emergent Wetland	8,241	18,527	3555.70	7712.44
Palustrine Forested Wetland	33,992	67,359	22211.52	49995.89
Palustrine Scrub/Shrub Wetland	21,176	48,129	7629.40	17685.93
Potentially Disturbed Wetlands	5,147	13,305	1818.07	4895.57
Unconsolidated Shore	456	1,743	241.82	1213.86
Water	1,775	6,721	871.33	4066.67
Grand Total	70,973	156,396	36454.68	85972.72

Table 3. Average distance to mapped streams of wetlands within or near FPA permit areas

Wetland Class	Average of Distance to Nearest Stream (ft)	Average of Distance to Nearest F or S type Stream (ft)
Estuarine Emergent Wetland	15	24
Estuarine Forested Wetland	133	133
Estuarine Scrub/Shrub Wetland	100	100
Palustrine Aquatic Bed	53	65
Palustrine Emergent Wetland	164	332
Palustrine Forested Wetland	96	285
Palustrine Scrub/Shrub Wetland	120	313
Potentially Disturbed Wetlands	244	549
Unconsolidated Shore	30	40
Water	44	69

Table 4. Number of FPA permits having mapped wetlands, by associated wetland class and WDNR water body types

Wetland Class	Fish Habitat	Non-fish Habitat	Designated Shorelines	Unknown Water Type	Not Defined as a Typed Water
Estuarine Emergent Wetland	23		195	7	
Estuarine Forested Wetland			1		
Estuarine Scrub/Shrub Wetland			2		
Palustrine Aquatic Bed	19	11	188	2	
Palustrine Emergent Wetland	4819	2329	5778	745	90
Palustrine Forested Wetland	19596	8463	14948	2183	214
Palustrine Scrub/Shrub Wetland	15269	6227	11423	1761	159
Potentially Disturbed Wetlands	4023	2521	2990	681	59
Unconsolidated Shore	48	22	1346	17	2
Water	176	171	4695	31	4
Grand Total	43974	19745	41604	5428	528

Table 5. Number of FPA permits having mapped wetlands, by associated wetland class and WDNR stream types

	WDNR Stream Types						
Wetland Class	0	1	2	3	4	5	9
Estuarine Emergent Wetland	192	3		10	2	4	14
Estuarine Forested Wetland	1						
Estuarine Scrub/Shrub Wetland	2						
Palustrine Aquatic Bed	183	3	4	8	2	4	16
Palustrine Emergent Wetland	4875	969	362	2675	1240	1508	2132
Palustrine Forested Wetland	11760	3488	1362	12279	5301	5704	5510
Palustrine Scrub/Shrub Wetland	8549	3047	1170	9381	3827	4334	4531
Potentially Disturbed Wetlands	2364	677	224	2181	1230	1637	1961
Unconsolidated Shore	1261	84	5	18	8	11	48
Water	4421	243	56	72	59	107	119
TOTAL	33646	8514	3183	26625	11669	13309	14333

Table 6. Information reported in FPA Permits (number of permits, by zone)

	Sitka Spruce Zone	Western WA	Eastern WA	Total
Forested Wetland	1134	6089	219	7442
Not Forested Wetland	3522	14075	1277	18874
Type A Wetland	580	3396	169	4145
Not Type A Wetland	4076	16768	1327	22171
Type B Wetland	545	2769	143	3457
Not Type B Wetland	4111	17395	1353	22859
Wetland or WMZ Reported in FPA	956	4626	186	5768
No Wetland or WMZ Reported in FPA	3700	15538	1310	20548
Any of Above Wetlands Reported	1570	8249	339	10158
None of Above	3086	11915	1157	16158
Hydric Soil	932	3363	9	4304
Not Hydric Soil	3724	16801	1487	22012
Small Forest Landowner	364	3105	256	3725
Not a Small Forest Landowner	4292	17059	1240	22591
Proposed Land Use Conversion	72	1169	27	1268
Not a Proposed Land Use Conversion	4584	18995	1469	25048

WASHINGTON STATE DEPARTMENT OF
Natural Resources

PETER GOLDMARK
Washington State Commissioner of Public Lands

MEMORANDUM

July 30, 2015

TO: Forest Practices Board

FROM: Hans Berge, Adaptive Management Program Administrator

SUBJECT: CMER Membership and Co-Chair

The Washington Department of Fish and Wildlife has nominated Dr. Marc Hayes to be designated as a CMER member, filling a vacant position. As you are aware, Dr. Hayes has been a contributing participant in many CMER studies and is an important asset to the program. As his curriculum vitae (attached) demonstrates, his particular area of expertise is in the aquatic environments, with an emphasis in stream associated amphibians.

After 4 years of service as CMER co-chair, Mark Hicks has stepped down from the position. Doug Hooks was nominated and approved by CMER as the new co-chair on 28 July 2015. Doug has experience working as a forester and currently works for the Washington Forest Protection Association as the Director of Forest and Environmental Programs. Mr. Hooks will not be seeking approval as an official CMER member, which is not required of a co-chair.

HB/

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State of Washington
DEPARTMENT OF FISH AND WILDLIFE

Mailing Address: 600 Capitol Way N · Olympia, WA 98501-1091 · (360) 902-2200, TTY (800) 833-6388
Main Office Location: Natural Resources Building · 1111 Washington Street SE · Olympia, WA

August 3, 2015

TO: Hans Berge, Adaptive Management Program Administer

FROM: Terry Jackson, WDFW, Forest Habitats Section Manager

SUBJ: CMER Member Nomination of Dr. Marc Hayes

The Washington Department of Fish and Wildlife would like to nominate Dr. Marc Hayes as an official CMER voting member. Marc is a Senior Research Scientist within WDFW's Habitat Program and has vast experience in both leading and conducting research projects. He has also published many peer-reviewed scientific publications. Marc has been an active participant in CMER and is co-chair of the Landscape and Wildlife Scientific Advisory Group (LWAG).

cc: Tim Quinn
Marc Hayes

MARC PHILIP HAYES

Senior Research Scientist
Washington Department of Fish and Wildlife · Habitat Program · Science Division
600 Capitol Way North · Olympia · USA· 98501-1091
Phone: (360) 902-2567 · E-mail: Marc.Hayes@dfw.wa.gov

Dr. Hayes is a research ecologist and herpetologist with 40 years of field experience with amphibians and reptiles. Dr. Hayes has supervised >70 projects addressing the ecology and habitat needs of amphibians and reptiles in California, Florida, Oregon, Washington, Costa Rica, and Mexico. He has worked with diverse entities ranging from the US Forest Service; the California Department of Fish and Game; the Oregon Department of Fish and Wildlife; the Washington Department of Fish and Wildlife; US Fish and Wildlife Service; the Nature Conservancy; Stillwater Sciences, Inc.; the California Academy of Sciences, and a suite of additional private entities. His research has focused on the ecology of amphibians and reptiles, including stillwater breeding ranid frogs and toads; plethodonid salamanders; and stream-associated amphibians in timber-managed landscapes.

EDUCATION

1991 PhD Herpetological Ecology, University of Miami, Miami, Florida.
Dissertation: Attendance in the tropical, leaf-breeding frog (*Centrolenella fleischmanni*): A study in parental care.

1975 MA Biological Sciences (Herpetology emphasis), California State University, Chico.
Thesis: Systematics of the California mountain kingsnake (*Lampropeltis zonata*)

1972 BA Biology (Marine Sciences major, Entomology minor), University of California, Santa Barbara

1970 AA Biological Sciences, Yuba College, Marysville, California

PROFESSIONAL EMPLOYMENT AND AFFILIATIONS

2006-	Senior Research Scientist	Washington Dept of Fish & Wildlife, Olympia
2002-	Affiliate Curator, Herpetology	University of Washington, Burke Museum
2000-06	Research Scientist	Washington Dept of Fish & Wildlife, Olympia
1992-	Adjunct Professor	Portland State University, Portland, Oregon
1992-98	Instructor, Biological Sciences	Portland Community College, Portland, Oregon
1991-99	Contract Environ. Consultant	Self-employed, Beaverton and Hillsboro, Oregon
1991	Postdoctoral Res. Associate	Oregon State University, Corvallis, Oregon
1985-91	Contract Environ. Consultant	Gaby and Gaby, Inc., Miami, Florida
1982-84	Maytag Fellow	University of Miami, Florida
1978-81	Teaching Assistant	University of Southern California, Los Angeles
1975-78	Instructor, Biological Sciences	Butte Community College, Oroville, California
1973-75	Teaching Assistant	California State University, Chico

SELECTED PUBLICATIONS

Groff, K.S., S.B. Marks, and M.P. Hayes. *in press*. Difference in flight initiation distance between recently metamorphosed Oregon Spotted Frogs (*Rana pretiosa*) and American Bullfrogs (*Lithobates catesbeianus*). *Herpetological Conservation and Biology.*

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Bullfrogs (*Lithobates catesbeianus*). *Herpetological Conservation and Biology* 8(2):426-434.

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Palmeri-Miles, A.F., K.A. Douville, J.A. Tyson, K.D. Ramsdell and M.P. Hayes. 2010. Field observations of oviposition and early development of the Coastal Tailed Frog (*Ascaphus truei*). *Northwestern Naturalist* 91(2):206-213.

Hayes, M.P., C.J. Rombough, G.E. Padgett-Flohr, L.A. Hallock, J.E Johnson, R.S. Wagner, and J.D. Engler. 2009. Amphibian chytridiomycosis in the Oregon spotted frog (*Rana pretiosa*) in Washington State, USA. *Northwestern Naturalist* 90(2):148-150.

Hayes, M.P; T. Quinn; K.O. Richter; J.P. Schuett-Hames; and J.T. Serra Shean. 2008. Maintaining Lentic-Breeding Amphibians in Urbanizing Landscapes: The Case Study of the Northern Red-Legged Frog (*Rana aurora*). Pp. 445-461. *In*: Mitchell, J.C., R.E. Jung Brown, and B. Bartholomew (editors), *Urban Herpetology*, Society for the Study of Amphibians and Reptiles, Herpetological Conservation 3. [Book chapter]

Quinn, T.; Hayes, M.P.; D.J. Dugger; T.L. Hicks; and A. Hoffmann. 2007. Comparison of two techniques for surveying headwater stream amphibians. *Journal of Wildlife Management* 71(1):282-288.

Hayes, M.P; T. Quinn; D.J. Dugger; T.L. Hicks; M.A. Melchiors; and D.E. Runde. 2006. Dispersion of coastal tailed frog (*Ascaphus truei*): An hypothesis relating cccurrence of frogs in non-fish-bearing headwater basins to their seasonal movements. *Journal of Herpetology* 40(4):531-543.

Hayes, M. P., M. R. Jennings, and G. B. Rathbun. 2006. *Rana draytonii* (California Red-legged Frog). Prey. *Herpetological Review* 37(4):449.

Rombough, C. J., and M. P. Hayes. 2005. Novel aspects of oviposition site preparation by female foothill yellow-legged frogs (*Rana boylii*). *Northwestern Naturalist* 86:157-160.

Eaton-Mordas, A., E.P. Urling, M.P. Hayes, D.J. Dugger, and T. Quinn. 2003. *Plethodon dunni*, *Plethodon vehiculum* (Dunn's Salamander, Western Red-backed Salamander). Behavior. *Herpetological Review* 34(1):54-55.

Bull, Evelyn; and M.P. Hayes. 2002. Overwintering of Columbia spotted frogs (*Rana luteiventris*) in northeastern Oregon. *Northwest Science* 76(2):141-147.

Bull, E.L., and M.P. Hayes. 2000. Livestock effects on reproduction of the Columbia spotted frog. *Journal of Range Management* 53(3):291-294.

Over 100 additional peer-reviewed publications and project reports are available upon request.

Cooperative Monitoring, Evaluation, and Research Committee (CMER)
Membership Roster
August 2015

Name	**Representing**	**Approved**
Mark Mobbs	Tribal	2/13/2001
Todd Baldwin	Tribal	11/9/2010
Debbie Kay	Tribal	8/14/2012
Vacant	Tribal	
Mark Hicks	State/DOE	6/6/2007
Vacant	State/DNR	
Marc Hayes	**State/DFW**	**8/11/2015***
Doug Martin	Landowner	2/13/2001
Julie Dieu	Landowner	2/22/2008
A.J. Kroll	Landowner	5/11/2010
Chris Mendoza	Conservation Caucus	11/10/2004
Vacant	USFWS	
Harry Bell	WFFA	8/12/2014
Bill Ehinger	State/DOE Alternate	2/8/2006
Vacant	State/DFW Alternate	
Nancy Sturhan	Tribal Alternate	2/22/2008
Vacant	Tribal Alternate	

*****Pending approval by the Forest Practices Board on 11 August 2015

Cooperative Monitoring, Evaluation, and Research Committee (CMER)
Membership Roster
November 2014

Name	**Representing**	**Approved**
Mark Mobbs	Tribal	2/13/2001
Todd Baldwin	Tribal	11/9/2010
Debbie Kay	Tribal	8/14/2012
Vacant	Tribal	
Mark Hicks	State/DOE	6/6/2007
Leslie Lingley	State/DNR	8/12/2009
Vacant	State/DFW	
Doug Martin	Landowner	2/13/2001
Julie Dieu	Landowner	2/22/2008
A.J. Kroll	Landowner	5/11/2010
Chris Mendoza	Conservation Caucus	11/10/2004
Vacant	USFWS	
Harry Bell	WFFA	8/12/2014
Bill Ehinger	State/DOE Alternate	2/8/2006
Vacant	State/DFW Alternate	
Nancy Sturhan	Tribal Alternate	2/22/2008
Vacant	Tribal Alternate	

WASHINGTON STATE DEPARTMENT OF
Natural Resources

PETER GOLDMARK
Washington State Commissioner of Public Lands

MEMORANDUM

July 30, 2015

TO: Forest Practices Board

FROM: Hans Berge, Adaptive Management Program Administrator

SUBJECT: Adaptive Management Program Quarterly Staff Report

This update includes a summary of work to date on the pilot LiDAR hydrologic model evaluation, best practices of protocol surveys, project updates at CMER, and a summary of our strategy to keep the budget and master project schedule on track for the biennium.

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 May, I have continued to work with stakeholders and GIS staff at DNR to identify two pilot basins and relevant datasets. After consideration of several basins on both sides of the state, we identified the Mashel (westside) and Darland Mountain (eastside) as the two watersheds for the study. I am working on a scope of work with Dr. Monika Moskal at the University of Washington's Precision Forestry Lab to complete the work and produce a report by the end of fiscal year 2016.

Best Practices of Protocol Surveys

The TFW Policy committee asked the AMPA to convene a group of technical experts to address the Board motion from 11 February 2014 on the Type F/N break. The motion focus is on "best practices" of protocol electrofishing surveys, and includes elements that seek to minimize site-specific impacts and its overall use. Direction was given to accomplish these tasks through the formation of a technical subgroup and included a provision to evaluate relevant literature. At this time, I am working with Policy to develop a purpose statement to focus the effort of the technical group. After the scope is approved, stakeholders will nominate members of the technical group based on their experience and demonstrated subject matter expertise.

CMER Updates

With the approval of the Adaptive Management Program's (AMP's) biennial budget comes a great deal of responsibility in keeping projects on schedule and budget in each fiscal year. In order to accomplish those tasks, it will require more capacity, accountability, and flexibility.

In recognizing the need for great capacity in the AMP, the Board approved the addition of two key positions. The first position is for an additional CMER scientist with expertise in geology and hydrology. This position will play an important role as a principal investigator carrying out scientific investigations surrounding unstable slopes, hydrology, and erosion relevant to forest practices. The second position is for an environmental planner to support the work of project managers in tracking progress of CMER projects as well as supporting the program by updating the website, working with the information management system, and supporting elements CMER's Lean process.

Project managers are responsible for meeting schedule and budget milestones for each project. In order to stay on schedule, monthly check-ins on each project will be required. All project team members will be held accountable for their duties and project managers will help identify if and when additional resources are needed.

If current projects get behind schedule, CMER will need to work to identify projects that can be initiated earlier than anticipated in the Master Project Schedule. For example, scoping and study design phases of projects that have been previously vetted and contained in CMER's approved work plan could have phases sequenced early to take advantage of funds that are available now. CMER and Policy will need to work together to identify those projects that could be eligible if such a situation arises.

Four chapters of the Type N Experimental Buffer Treatment in Basalt Lithologies (Hard Rock) Study are currently in review by the Independent Science Peer Review (ISPR) process. The others are expected to be submitted to ISPR later this summer. These experiments were designed to examine the effectiveness of current riparian buffer prescription on non-fish bearing streams in protecting aquatic resources. As the review process is completed, the reports will be approved by CMER and submitted to Policy later this year.

We continue to seek opportunities to collaborate with scientists outside of our AMP stakeholders on mutually beneficial research and have been reaching out with scientists at Washington State University, University of Washington, Utah State University, NOAA Northwest Fisheries Science Center, and the Rocky Mountain and Pacific Northwest Research Stations of the USDA Forest Service.

HB/

WASHINGTON STATE DEPARTMENT OF
Natural Resources

PETER GOLDMARK
Commissioner of Public Lands

MEMORANDUM

July 23, 2015

TO: Forest Practices Board

FROM: Marc Ratcliff
Forest Practices Policy and Services Section

SUBJECT: Board Manual Development Update

Staff will request the Board's approval on amendments to Board Manual Section 16, *Guidelines for Evaluating Potentially Unstable Slopes and Landforms* at the August Board meeting. This includes the recommendations from the stakeholder group for amending material from the November 2014 amendments to this section. The stakeholder group will continue discussions for incorporating guidance for conducting delivery assessments with an anticipated approval in November.

Amendments to other Board Manual sections are anticipated for 2015, but is 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

WASHINGTON STATE DEPARTMENT OF
Natural Resources
Peter Goldmark - Commissioner of Public Lands

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MEMORANDUM

TO: Forest Practices Board

FROM: Garren Andrews, Compliance Monitoring Program Manager

SUBJECT: Current status of the Compliance Monitoring Program

The Compliance Monitoring program completed the spring field reviews in June. Fall field reviews will commence September 2015.

The 2014 *Interim* Compliance Monitoring report stakeholder review has been completed. Results from the report will be presented at the November Forest Practices Board meeting.

The 2010-2014 trend analysis project is in progress.

The Compliance Monitoring Program is currently scheduling an August stakeholder committee meeting.

Monica McMackin has vacated the Compliance Monitoring Field Coordinator position. Recruitment is ongoing in order to fill the vacant position.

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

July 23, 2015

TO: Forest Practices Board

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

SUBJECT: 2015 Rule Making Activity

At this time there is no active rule making.

At your last meeting the initiation of the RMZ clarification rule making was moved to 2016. DNR staff is meeting with stakeholders to discuss the details of the proposed clarifying language and the data collected from approved Forest Practices Applications supporting the need for a rule making. This rule making will be reflected in the Board's 2016 Work Plan.

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

ME/

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WASHINGTON STATE DEPARTMENT OF
Natural Resources

PETER GOLDMARK
Commissioner of Public Lands

MEMORANDUM

July 24, 2015

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 May 5th and July 7th, 2015. Issues discussed and presented included:

- A presentation to the Committee of the draft update of the DNR's Statewide Forest Resource Assessment & Strategy (Forest Action Plan).
- A presentation from the Natural Resources Conservation Service regarding resources available to small forest landowners.
    - The Environmental Quality Incentives Program (EQIP) provides financial and technical assistance to landowners on agricultural and non-industrial private forestland. Financial assistance is provided for forestry activities such as pre-commercial thinning, reforestation, stream crossings, riparian area enhancement, sediment reduction from forest roads, pruning for disease and fire, invasive treatments, and fuel breaks.
- A presentation from the Dept. of Revenue regarding the Washington Designated Forestland Program.
- A presentation from WFFA on the proposed Alternate Harvest Prescriptions for Small Forest Landowners in Western Washington.

Forestry Riparian Easement Program (FREP)
The legislature appropriated FREP at $2 million for the FY13-15 biennium. With this $2 million the program was able to purchase 25 conservation easements encompassing 285 acres. Additionally, per program requirements, the qualifying timber on 39 additional FREP applications in the queue were cruised and a value was determined for these easements.

Since FREP began, funding has not kept up with demand. There has been a backlog of applications waiting for sufficient funding to acquire the easements. During the FY13-15 biennium, 55 new applications were received. There are now 130 forestry riparian easement applications on the list waiting for compensation. Since the beginning of the program, FREP has acquired 328 conservation easements encompassing 5,339 acres. The State Capital budget appropriated $3.5 million for FREP in the FY15-17 biennium.

Rivers and Habitat Open Space Program (R&HOSP)
The Legislature appropriated $500,000 to the R&HOSP for the FY13-15 biennium. This funding allowed the purchase of one easement for $460,000. The conservation easement, purchased from Hancock Timber Resource Group, sets aside approximately 25 acres as permanent northern spotted owl (NSO) habitat. It is the first R&HOSP conservation easement to protect upland critical habitat for northern spotted owls and other species of concern designated by the state's Forest Practices Board. See the attached DNR Press Release for more information on this easement acquisition. Since the beginning of the program, the R&HOSP has acquired 16 channel migration zone and one NSO conservation easements encompassing over 1,000 acres. The State Capital budget appropriated the R&HOSP $1 million for the FY15-17 biennium.

Family Forest Fish Passage Program (FFFPP)
In 2014, the FFFPP received the largest number of applications since the beginning of the program (over 100 applications). This is due in large part to the concentrated outreach effort conducted by FFFPP staff. In 2013, the FFFPP received $10 million from the Jobs Now Act. Additionally, the Legislature appropriated $2 million to program for the FY13-15 biennium. With these dollars, in FY13-15, the FFFPP removed 100 fish passage barriers reconnecting 261 miles of habitat for fish. Since the beginning of the program in 2003, the FFFPP has eliminated 343 fish barriers reconnecting 763 miles of habitat for fish. The State Capital budget appropriated the FFFPP $5 million for the FY15-17 biennium.

Long Term Applications (LTA's)
There are now a total of 195 approved long term applications; which is an increase of 4 approved applications since the end of the last reporting period (04/14/2015).

LTA Applications	**LTA Phase 1**	**LTA Phase 2**	**TOTAL**
Under Review	7	4	**5**
Validated	0	22	**26**
Approved	2	195	**197**
TOTAL	**9**	**221**	**228**

Forest Stewardship
In the past year, DNR's Landowner Assistance Foresters/Wildlife Biologist conducted almost 3,000 landowner technical assistance site visits. These site visits included technical assistance to help landowners meet their land management objectives or to create a Forest Stewardship Plan. These visits also included assistance implementing the federal cost share program for eastside landowners to implement practices to improve the health of their forest and reduce the risk of damage from threats like wildfire and insect and pests. These Landowner Assistance Foresters also worked with over 10,000 landowners who contacted them with technical questions via, email or phone calls.

DNR is currently able to fund only two Landowner Assistance Foresters in western Washington. These Foresters helped landowners complete a total of 121 new Forest Stewardship Plans covering over 12,000 acres in the past year. Because of such a high demand for technical assistance, there remains a backlog of landowners waiting for site visits from the Landowner Assistance Foresters in western Washington.

DNR's Forest Stewardship Program also supports WSU Forestry Extension educational programs which, in the FY 13-15 biennium, were attended by more than 3,200 landowners. This past year two Forest Owners Field Days were attended by ~350 landowners at each event. In total, since their inception, the Forest Owners Field Day events have reached over 13,000 landowners at 34 different venues.

Upcoming Landowner Events

The WSU Forestry and Wildlife 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 course teaches landowners how to assess your trees, avoid insect and disease problems, and attract wildlife. State experts will help you develop your own Forest Stewardship Plan to keep your woods on track to provide enjoyment and income for years to come.

- Preston - Tuesday evenings starting September 22
- Whidbey Island - Thursday evenings starting October 8

Forest Owners Field Days - Field days feature a whole suite of our most popular forest stewardship workshops. The state's top forestry specialists will be offering hands-on field sessions throughout the day on a variety of topics that will help you to better understand, protect, enhance, and enjoy your forest.

- Western Washington (Francis) - August 15, 2015
- North Puget Sound (Conway) – August 29, 2015
- San Juan Islands (Orcas Island) – September 26, 2015

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

WASHINGTON STATE DEPARTMENT OF
Natural Resources
Peter Goldmark - Commissioner of Public Lands

NEWS RELEASE

July 13, 2015

DNR buys conservation easement to protect northern spotted owl habitat

OLYMPIA – The Washington State Department of Natural Resources (DNR) has purchased a permanent conservation easement to protect critical wildlife habitat on a privately owned parcel of forestland in eastern King County.

The easement setting aside approximately 25 acres as permanent wildlife habitat was purchased from Hancock Timber Resource Group for $460,000. It is the first conservation easement purchased through the expanded Rivers and Habitat Open Space Program, which the Washington Legislature funds to protect upland critical habitat for northern spotted owl and other species of concern designated by the state's Forest Practices Board.

"This purchase is an example of how DNR and the private sector can work together to protect endangered species while retaining an economically viable forest industry," said Commissioner of Public Lands Peter Goldmark, who leads DNR.

"These lands contain some of the best northern spotted owl habitat available on non-federal lands in Washington state and now they will remain that way," said Joe Stohr, deputy director, Washington State Department of Fish and Wildlife.

"As a forest manager, we have a strong interest and a long history in working with other partners to create conservation easements on lands with such high ecological value to threatened and endangered species," said Tim McBride, wildlife biologist for the Hancock Timber Resource Group.

In addition to forestland and open space, the Rivers and Habitat Open Space Program allows DNR to purchase conservation easements on properties where a river's active channel meanders – known as channel migration zones. These islands of timber tend to have high ecological value to species like salmon and steelhead.

Since 2002, the state of Washington has invested more than $4 million to purchase conservation easements on more than 1,000 acres of private forest land through the program. DNR also accepts donations of land for conservation easements.

Rivers and Habitat Open Space Program

The Rivers and Habitat Open Space Program ensures the long-term conservation of aquatic resources and upland habitats by acquiring conservation easements on lands and timber within a specific type of channel migration zone and habitat of threatened and endangered species. DNR screens applications, prioritizes qualifying applications, and acquires land based on available funding from the state legislature. DNR ranks applications in priority for funding based on habitat quality, risk of habitat loss, occupancy, landscape continuity, known presence of other threatened or endangered species, and other criteria.

Landowners who wish to learn more about the program may reach Dan Pomerenk, conservation easement program manager, at 360-902-1427 or by email at dan.pomerenk@dnr.wa.gov

More information about the program is on the DNR website at: http://www.dnr.wa.gov/programs-and-services/forest-practices/small-forest-landowners/rivers-and-habitat-open-space

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State of Washington
Department of Fish and Wildlife

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July 17, 2015

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.

Northern Spotted Owl
1988: State listed as endangered
1990: Federally listed as threatened
2012: Designation of revised critical habitat

Current Status:
WDFW is currently drafting a periodic status review for the Northern Spotted Owl. The draft will be going out for public review in August. The results of the status review are scheduled to be presented to the Fish and Wildlife Commission in January 2016.

USFWS also initiated a status review for the Northern Spotted Owl in April of 2015. This status review is in response to a positive 90-day finding on petitions to uplist the species, and also serves as the 5-year review for the species. Based on the status review, a 12-month finding will be issued, which will address whether or not the petitioned action (uplisting to a federal endangered status) is warranted.

Fisher
1998: State listed as endangered
2014: Federally proposed to be listed as threatened.
2016: Final decision on listing is expected in April 2016

Current Status:
WDFW, along with USFWS and private and tribal stakeholders, has developed a draft Candidate Conservation Agreement with Assurances (CCAA). The draft will soon go through the NEPA process, including a public comment period. WDFW and USFWS have worked closely with WFPA, small forest landowners, and interested tribes to develop appropriate conservation measures. After going through the NEPA and approval processes, landowners will then be able to sign on to the agreement, committing to the conservation measures for the species. By doing

so, they will not be subject to additional requirements beyond those in the CCAA, should the proposed listing of the species become final in April of 2016 or at a later date.

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

Current Status:
WDFW:

- Is currently drafting a periodic status review for western gray squirrels (WGSs). After internal and external peer review, it will go out for a 90-day public review period in August. The final report will then be presented to the Fish and Wildlife Commission for any recommended action in January 2016. The report will summarize past and recent scientific information on the status, biology, and threats for the species in Washington. The last report of this type was the WDFW WGS recovery plan published in 2007.
- Continues to screen FPAs for possible impacts to western gray squirrels.
- Continues to conduct nest surveys as needed, and works with landowners to develop voluntary management plans.
- Documents/tracks information on FPAs having potential impacts in order to better assess the effectiveness of the voluntary protection approach.

Canada Lynx
1993: State listed as threatened
1996: Board established voluntary protection approach
2000: Federally listed as threatened
2014: Revised federal critical habitat designation

Current Status:
WDFW is:

- Continuing to work with DNR to implement, as well as to revise and update, their 2006 Lynx Habitat Management Plan for DNR managed lands.
- Assessing lynx habitat included within the critical habitat designation on private lands owned by small forest landowners in order to develop habitat management plans as appropriate.
- Working with the two large landowners and other appropriate stakeholders to revise and update their lynx habitat management plans.
- Continuing to screen FPAs for possible conflicts and work with landowners as necessary to ensure adequate protection is afforded to lynx and their habitats.

Oregon Spotted Frog
1997: State Endangered
2014: Federally listed as threatened
2015: Expected federal designation of critical habitat

As mentioned in earlier updates, the species is not generally dependent on forested landscapes; therefore, it was not included in the list of covered amphibian species in the Forest Practices HCP. Possible areas of concern are limited to a very small subset of lands subject to the Washington State forest practices rules, and adverse effects from forest practices are likely minimal. USFWS and WDFW will be working with specific landowners, as deemed appropriate, on specific conservation and/or restoration efforts to benefit the species.

Future Updates to the Board

The forest practices rules require that when a species is listed by the U.S. Secretary of the Interior or Commerce, the Department of Natural Resources (DNR) consults with the Department of Fish and Wildlife (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: Penny Becker
Gary Bell
Marc Engel
Sherri Felix
Gerald Hayes
Julie Henning

FOREST PRACTICES BOARD
2015 WORK PLAN

TASK	COMPLETION DATE/STATUS
Adaptive Management Program	
• CMER Master Project Schedule Progress*	May
• Effectiveness of Riparian Management Zones in Providing Habitat for Wildlife Study*	May
• Effects of Forested Roads and Tree Removal In or Near Wetlands of the Pacific Northwest Literature Synthesis	May
• Program Funding	On-going
• Review and Synthesis of Literature on Tailed Frogs with Special Reference to Managed Landscapes	August
• Temperature and Solar Radiation/Effective Shade Study*	August
• Type F*	~~November~~August
• Type N*	November
• Wetland Research and Monitoring Strategy: Forest Practices and Wetlands Report	May
• **Proposal Initiation for Alternate Plan Template Timeline***	May
Annual Reports	
• Clean Water Act Assurances	August
• Compliance Monitoring Annual Report	August
• Northern Spotted Owl Conservation Advisory Group	May
• 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~~	~~November~~2016
• Section 16, Evaluating Potentially Unstable Slopes and Landforms	August
• Section 23 (Part 2), Guidelines for Field Protocol to Locate Mapped Divisions Between Stream Types and Perennial Stream Identification*	November
CMER Membership	As needed
Rule Making	
• Unstable slopes information on Forest Practices Applications	February
• ~~RMZ Clarification~~	~~November~~2016
Cultural Resources Roundtable Recommendations	August
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	~~May~~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 *Last update May 2015*

**= TFW Policy Committee*

FOREST PRACTICES BOARD
2015 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 2016	November