MASS WASTING PRESCRIPTION-SCALE EFFECTIVENESS MONITORING PROJECT (POST-MORTEM)

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Prepared by

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EXECUTIVE SUMMARY

Landslides are a natural occurrence on the forest landscape of Washington State, but certain forest practices, including sidecast road construction, poor water management along forest roads and clearcut harvest of potentially unstable slopes, can increase landslide rates. In the face of limited scientific knowledge about the complete impacts of landsliding on public resources, Forests & Fish Rules are designed to prevent landsliding in excess of natural background rates. The Mass Wasting Prescription-Scale Effectiveness Monitoring Project (this study) has been designed to determine if the Forests & Fish Rules - including rules for harvest on potentially unstable slopes, road construction and maintenance rules, and Road Maintenance and Abandonment Plans (RMAP) - are effective at limiting landslides from forest practices. This study is designed to evaluate effectiveness at the "prescription scale" or site scale, which might consist of a single clearcut, unstable landform, or culvert.

The study as currently proposed will occur as soon as possible after a storm event that has generated a sufficient population of landslides for statistical analysis. Investigating landslides soon after their occurrence maximizes diagnostic value by reducing the obscuring effects of re-vegetation, road repair or other post-landslide processes. By analyzing storm-related landsliding in areas that contain a variety of management treatments, this study seeks to compare the effectiveness between various treatment categories. Harvest treatments include unstable landforms that were clearcut, buffered, or are covered with immature trees, while road treatments include active roads that meet Forests & Fish standards, as well as substandard, mitigated, abandoned, and orphaned roads (see Section 2.2 for details). Upon study approval, contracts will be created for aerial photography and field data collection to expedite post-storm mobilization. These in-place contracts and the rest of the study will be initiated immediately after a large storm has occurred. Aerial photographs will be analyzed to map landslides as well as harvest and road treatments. Procedures for the study are discussed more fully in the Appendices to this document.

Once mapped, treatments will be used as sampling strata for field determination of landslide densities and triggering mechanisms. Based on post-storm landslide studies in Oregon, 13 to 27 sample blocks of 4 mi^2 are needed to provide a sufficient number of landslides and representation of strata. Field crews will locate landslides not evident on photos by traversing the stream network. Landslides that delivered to streams will be mapped and triggering mechanisms will be evaluated at the point of landslide initiation. Field crews will also drive the road network in the treatment block, identifying all road-related landslides, triggering mechanisms, and sediment delivery.

Differences in landslide density among treatment types will be evaluated using ANCOVA with normalizing variables incorporated as covariates. Pairwise comparisons of ordered treatments will be performed using the step-down bootstrap resampling method provided in SAS MultTest. Data on triggering mechanisms will be analyzed to determine trends in landslide density between and among treatment types. This study is expected to cost between $539,000 and $731,000, depending on the number of sample blocks needed to achieve appropriate statistical strength and on the relative ease or difficulty of field travel and access. We anticipate that results may either affirm or indicate a need for changes to forest practices rules or board manual guidance, as explained further in Section 5.

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1 ADMINISTRATIVE CONTEXT

1.1 CMER Context

The Upslope Processes Scientific Advisory Group (UPSAG), a subcommittee of Cooperative Monitoring, Evaluation and Research (CMER), previously scoped and received CMER approval for the *Mass Wasting Prescription-Scale Effectiveness Monitoring Project*, also known as the Post-Mortem Study. This project is listed in the FY 2007 CMER Work Plan under Unstable Slopes Rule Group (Table 4, line 72; (2007) http://dnr.wa.gov/forestpractices/adaptivemanagement/cmer/cmerworkplan07.pdf) and was given a rating of "urgent." The following represents a final combined scoping/study design document. The review steps have been: 1) CMER review, edits and approval; 2) An open Independent Scientific Peer Review with initial comments, a teleconference, the development of response matrix and approval to make the proposed edits; and 3) Final CMER review and approval.

1.2 Problem Statement and Background

The Forests & Fish Rules include specific measures designed to reduce management-related landslides; these measures are described in detail below. The Forests & Fish Report (FFR) calls for an Adaptive Management process that requires that the effectiveness of these measures be evaluated by CMER. This study design for the Mass Wasting Prescription-Scale Effectiveness Monitoring Project has been developed to determine whether mass wasting prescriptions (i.e., rules and best management practices) are effective at reducing landslides triggered by forest practices. [Note: This document uses the word "trigger" to discuss factors, including specific forest practices, which appear to have contributed to the initiation of a landslide. This use of the word "trigger" does not obscure the understanding that a large precipitation event is usually the most immediate and primary driver of landslide initiation.] In conjunction with the Mass Wasting Landscape-Scale Effectiveness (MWLSE) Monitoring Project (partially scoped by UPSAG), the most basic question "Are we attaining the FFR performance objective of not accelerating mass wasting beyond the natural rate?" will be answered. The following paragraphs describe the set of landslide reduction efforts that this project will evaluate for effectiveness.

Potentially unstable landforms which occur throughout the state were identified through a review of watershed analyses and relevant scientific literature during the FFR negotiations. These landforms are defined by WAC 222-16 and described in further detail in Chapter 16 of the Forest Practices Board Manual. [Note: This document generally refers to "unstable landforms" and "unstable slopes" as those areas that meet the definitions provided in WAC 222-16 and Chapter 16, recognizing that individual sites are "potentially" unstable without consistently using the word "potentially."]

Rules relating to unstable slopes include WAC 222-16-050 and WAC 222-10-030, which describe classes of forest practices and the Washington State Environmental Policy Act (SEPA) process respectively. Unstable slopes rules require that unstable landforms are completely identified during the development and review of forest practices applications, and that if a forest practice is proposed on an unstable slope, the risks associated with proposed operations are reviewed through the SEPA process. Land managers and regulators are expected to be trained in unstable landform identification. Most commonly, these slopes are avoided in harvest-unit layout and road engineering, thus avoiding the Class IV-Special review (WAC 222-16-050 (1(d))).

Two FFR-identified projects have been designed to map unstable landforms. The Regional Landform Identification Project (RLIP) has been completed. That project identified and mapped regional landforms (i.e., not state-wide, rule-identified landforms) at 1:24,000. The Landslide Hazard Zonation Project (LHZ) is an ongoing project to map landslides and unstable landforms. This mapping is performed at the watershed administrative unit (WAU) scale, and the focus is rule-identified landforms, RLIP-identified landforms, and other landforms of concern. Results from both of these projects are being used as a screen for unstable slopes to assist with the implementation of the unstable slopes rules.

Industrial FFR landowners and other large landowners are required to submit RMAPs for all their lands by 2006, and are required to completely implement work identified in the RMAPs by 2016. A key environmental objective of RMAPs is to reduce landslide potential from existing roads. All RMAPs must identify work needed to reduce landslide potential on existing roads that were built with older construction techniques or that have other landslide potential. (Small, private landowners follow a different set of RMAP requirements, a difference that should not interfere with the results of this study because their collective land base lies predominately at lower elevations and on gentle topography in Western Washington.)

1.3 Integration within the CMER Programs

The Post-Mortem Study will be strongly linked to other projects listed in the 2007 CMER Work Plan including the MWLSE Monitoring Project (Table 4, line 74) and the Effectiveness of Unstable Landform Identification Project (Table 4, line 70, recently renamed the Testing the Accuracy of Unstable Landform Identification Project in response to CMER review). This project also has linkages to the Road Subbasin Monitoring Project (RSBM) (Table 4, line 89), the LHZ Project (Table 26, lines 80 and 81) and several headwater stream studies including the Eastside Type N Characterization Project (Table 4, line 15). Relationships between the Post-Mortem Study and these other CMER projects are discussed in detail in the following paragraphs.

This study seeks to determine if unstable slopes rules and best management practices are reducing landslide rates. If it appears that FFR has met its performance objectives and landslide rates in areas treated under the FFR Rules are comparable to rates observed in mature second growth, the MWLSE Monitoring Project may be significantly revised. If landslide rates under FFR appear to be significantly greater than rates observed in mature second growth, then data, protocols and sites developed for this study will likely be used in the MWLSE study.

The Post-Mortem Study may also link directly to UPSAG's Testing the Accuracy of Unstable Landform Identification Project (study design in review). This project may identify a population of landslides within unidentified unstable landforms, but it is the Testing the Accuracy of Unstable Landform Identification Project that will provide the context for understanding how widespread or uncommon the basic situation of unidentified landforms is across the landscape. Furthermore, field sites established for the Testing the Accuracy of Unstable Landform Identification Project could be used for long-term monitoring of prescription-scale best management practice (BMP) implementation, when an activity such as a yarding corridor or road construction has been proposed on an unstable slope. This opportunity will be particularly useful within the study area of the Post-Mortem Study, because we may already have extensive knowledge of BMPs implemented in individual harvest units.

This project is expected to show the degree to which RMAPs are effective at reducing road-related landslides relative to pre-FFR road treatments, results that will complement the work of the RSBM Project. This project will not evaluate the effectiveness of individual RMAPs, but instead will evaluate the effectiveness of BMPs associated with RMAPs. Data on BMPs may be used to improve future RMAP work focused on decreasing landslide potential.

This project will incorporate data developed by previous and ongoing Timber/Fish/Wildlife (TFW) slope stability projects including the Slope Stability Model (SLPSTAB) (TFW118) and LHZ. SLPSTAB has already been utilized to identify watershed administrative units (WAUs) with a sufficient percentage of land in unstable slopes to provide quality sample sites. If the study includes basins where LHZ has been completed, data collected as part of this study could be used to evaluate LHZ predictive capabilities. Additionally, it could provide landslide inventory data to the LHZ Project in areas where mapping has not yet occurred.

There is also an indirect link to the headwater streams studies where the volume of mass wasting in headwater streams and/or watersheds may be used for developing sediment budgets. One example is the Eastside Type N Characterization, where sediment storage in streams is a critical attribute. Sites identified during the Post-Mortem Study also could be used to determine how post-landslide recovery of headwater streams occurs and, thus, might be incorporated in a cumulative effects study.

2 DESIGN OBJECTIVES

2.1 Purpose

The Mass Wasting Prescription-Scale Effectiveness Monitoring Project has primarily been developed to test whether our collective mass wasting prescriptions are effective at reducing landslides from forest practices, in accordance with FFR goals. The study will also provide insight into the relative effectiveness of individual rules and BMPs; these results are unlikely to be statistically rigorous and will be considered secondary to the primary purpose.

2.2 Objectives

The primary objectives of the Mass Wasting Prescription-Scale Effectiveness Monitoring Project are to determine if there are differences in landsliding among different forest prescriptions at the harvest-unit scale and among different road types at the road-segment scale. [Note: Harvest-unit scale includes both the unstable landforms and the presumed stable areas within a harvest unit (described as “neighboring hillslope”).] Secondary objectives are to identify the site-scale triggers and attributes associated with specific management actions to help in the development or improvement of the rules and BMPs. Specifically, Objectives 1 and 2 are primary; Objectives 3 and 4 are secondary.

1. Determine whether there are statistically significant differences in landslide numbers or initial volumes per unit area originating from the following timber harvest strata:

A. **Clearcut**: Pre-FFR rules where both the unstable landforms and neighboring hillslopes are clearcut (stand-age 20 years or less);

B. **Partial Harvest**: Post-FFR rules or equivalent where the unstable landforms are partially harvested (e.g., thinned or yarding corridors, or some landforms are completely harvested and some are buffered), and the neighboring hillslopes are clearcut (stand-age 20 years or less);

C. **Buffered**: Post-FFR rules or equivalent where the unstable landforms are in mature timber, and the neighboring hillslopes are clearcut (stand-age 20 years or less);

D. **Sub-mature**: Pre-FFR rules where both the unstable landforms and the neighboring hillslopes are in intermediate age timber (stand-age 21-40 years); and

E. **Mature**: Pre-FFR rules baseline where both the unstable landforms and the neighboring hillslopes are in mature timber (stand-age 41+ years).

In recognition of a possible paucity of Strata B and D, they are considered non-critical strata that may not be rigorously evaluated. Strata A, C, and E are considered critical strata and must be present at all sample sites.

2. Determine whether there are statistically significant differences in landslide numbers or initial volumes per road length originating from the following forest road strata:

A. **Substandard**: Active roads not meeting FFR forest practices standards;

B. **Orphaned**: Unused for forest practices since 1974;

C. **Standard**: Active roads that meet FFR forest practices standards;

D. **Mitigated**: Active roads with completed instability hazard reduction efforts (drainage and/or unstable material removal); and

E. **Abandoned**: Roads with extensive maintenance designed to best reduce all existing environmental hazard (DNR-approved or equivalent).

In recognition of a possible paucity of Strata B and E, they are considered non-critical strata that may not be rigorously evaluated. Strata A, C, and D are considered critical strata and must be present at all sample sites.

3. Measure or count the forest road attributes that may contribute to statistically significant differences in landslide numbers or initial volumes. The reporting indices (X by Y of certain measures or counts) are described in Appendix – Sampling Strategy.

4. Identify site-scale landslide triggers and/or natural landscape factors (e.g., hillslope form or gradient) that can be viewed collectively (if not statistically) to inform the evaluation of specific site-scale management practices. Hypotheses guiding such secondary issues are detailed in Appendix – Micro Hypotheses.

2.3 Critical Questions

To provide meaningful feedback to the Adaptive Management process, UPSAG is interested in determining whether road improvements and prescriptions associated with unstable landforms (identification and mitigation or avoidance) are effective in reducing landsliding and the volume of sediment delivered from landslides. In addition, this study will attempt to evaluate the relationship between site-specific triggers and individual treatments.

The following is a list of critical questions to be addressed in this study:

1) Are FFR rules effective in reducing the numbers and the volume of sediment delivered by management-induced landslides?
2) Is the greatest proportion of management-induced landslide delivery from hillslopes or roads?
3) Which harvest unit prescriptions or road improvements are performing well? Which are performing poorly?
4) What are the site-scale triggering mechanisms for landslides?

5) Do those triggering mechanisms differ between harvest or road types?

The answers to these critical questions are embedded in the hypotheses as presented in Section 3. Hypotheses reflect *a priori* predictions of the study results.

3 STUDY DESIGN METHODOLOGY

3.1 Study Approach

UPSAG's approach to this study requires a storm event of sufficient magnitude to trigger a large population of landslides in forest lands subject to Forests & Fish Unstable Slopes Rules to quantify differences in landsliding between treatments. Because the timing of major storms cannot be predicted, this document lays out sampling and data collection protocols that can be implemented quickly after a storm. The sample population will be derived from FFR lands that occur in WAUs with steep topography. These lands will be screened following the event to identify those with appropriate landslide populations (more than one slide per square mile from roads and harvest). Aerial photographs will be acquired for the study area to facilitate final delineation.

At this point, a multi-stage sampling scheme will be employed to identify subpopulations for data gathering and statistical analysis. These randomly selected subpopulations will be called "clusters." The first stage of the sampling will involve selecting sample clusters consisting of four public land survey sections. Clusters will be identified through random selection of enumerated section corners that identify cluster centers.

Within each cluster, all forest harvest blocks and road types will be categorized into one of the five road or harvest strata using aerial photographs, RMAP information, local landowner and regulator information, and field work. If an individual stratum is not contained within a cluster or it occupies less than 5% of the total road network length or harvest area, the cluster will be augmented by adding one mile on each side (twelve additional sections). Within the augmented cluster area, a section will be randomly selected and canvassed for underrepresented strata. Sections will continue to be selected in a counter-clockwise direction until the 5% threshold is reached or the 12 additional sections have been used up. If a census of the augmented cluster fails to identify enough of the critical strata to meet the 5% threshold, the Appendix – Sampling Strategy does provide additional guidance for both harvest and road under-representation. The cluster may be discarded and a new one selected from the randomly generated list.

A total of 21 clusters containing both landslides and critical strata will be identified. Overall differences in landslide counts will be analyzed using an ANCOVA GLM which incorporates normalizing variables (e.g., precipitation and topography) as covariates. If overall differences between strata are detected at α=0.1, multiple comparisons between individual strata will be conducted using the step-down bootstrap resampling method of Westfall and Young (1993). The ordered-heterogeneity testing procedures of Rice and Gaines (1994) will be used when evaluating p-values among ordered hypotheses.

3.1.1 **Rationale for study approach**

To clearly evaluate the effectiveness of FFR unstable slopes rules and BMPs, it is important to identify individual triggering mechanisms of individual landslides. This study approach has been informed by the recognition of several key issues that can limit the ability to determine triggering mechanisms of individual landslides.

Evaluating landslides to determine triggering mechanisms is complicated by several issues: 1) the ability to determine landslide triggers declines rapidly in time; 2) most landslides are triggered by large hydrologic events that occur infrequently (annual probability of 10% or less); 3) both triggering and resisting forces associated with landslides are spatially variable; and 4) the ability to map landslides from aerial photography is related to both their size (big ones are easier to map) and canopy cover (it is easier to see landslides in clearcuts than in mature forest) and triggers are difficult to resolve during aerial photo inventory.

1. *The ability to determine landslide triggers with confidence declines rapidly following a storm event*. Roads are often rebuilt and drainage problems are fixed. Evidence of a focused water source may disappear or be obliterated. Alder trees and other vegetation quickly become established. It is important to survey a significant population of recent landslides if we are to evaluate triggering mechanisms. As such, a landslide census requires that field crews be on the ground as soon as possible after the storm.

2. *Unfortunately, it is nearly impossible to predict in advance when a given area will experience a large enough population of landslides to make up a statistically viable sample*. As such, we have proposed to wait for a storm producing more than one landslide per square mile as verified by initial reconnaissance and the use of satellite imagery (e.g., QuickBird), and then quickly mobilize to take advantage of the situation. Inherent in the evaluation of landslide triggers is the concern that a big storm which produces sufficient landslides for statistical analysis may not be representative of smaller storms where secondary triggers such as forest practices may have a more significant impact on landslide initiations (Robison et al., 1999). It may be possible to mitigate for this potential bias by selecting for study those WAUs on the edges of a big storm rather than in the area of highest precipitation and impacts; decisions of this nature will best be made after initial reconnaissance.

3. *Landslides and their triggers are spatially variable*. A large block of land is needed to homogenize variability associated with small-scale differences in storm intensity. Information is available from field surveys following the large storms in 1996 (Robison et al., 1999) that can be used to evaluate required sample area for a prescription-scale study.

4. *While most landslides can be mapped from the air, the probability of mapping any given landslide decreases with landslide size, overhead (canopy) cover, and increasing time since the failure (Brardinoni et al., 2003), and the assignment of triggering mechanisms from aerial photography inventory is difficult and inaccurate.* Prescription-scale land management activities can be mapped from the air, but not all landslides or site-scale triggers can be identified. Because prescription-scale treatments can be determined prior to field sampling, they can be used to stratify and increase statistical power for the purpose of resolving differences in landsliding between treatments. However, some landslides cannot be identified and many site-scale triggers cannot be resolved from aerial photography.

3.1.2 **Rejected study approaches**

UPSAG evaluated a number of approaches when designing this Post-Mortem Study. Study approaches that were evaluated and rejected include:

1) *Evaluating effectiveness using landslides from past storm events identified on aerial photos*. Landslide identification from aerial photographs alone presents a number of problems. Recent landslides are easier to identify than older slides, and small slides are often missed as are slides in dense forest. In addition, this approach limits evaluation of on-site triggers. Knowing why landslides are occurring under Forests & Fish Rules is a secondary objective of this study.

2) *Sample landslides at specific locations at regular intervals over time*. This approach has several problems: 1) evidence of landslide triggers is quickly obscured and many landslides in a given location are likely to be old; 2) the sample would include many areas with few landslides, reducing statistical inference; and 3) the proportion of the landscape in any one treatment changes through time. It is the rejection of this study approach, for these very good reasons, that leads to the necessary introduction of potential bias, specifically that a large storm may not perfectly represent the impact of forest practices on landslide initiation from smaller storms.

3) *Study landslide response after all RMAPs are implemented in 2016.* Although this would provide a broad sample of sites where RMAP prescriptions have been implemented, the results would become available too late to inform ongoing RMAP work.

4) *Study individual management treatments (e.g., sidecast pullback*). Any given location may have received multiple treatments and to isolate the effects of single treatments would be very difficult and might exclude an important proportion of the landscape. Also, attaining any degree of statistical significance between individual treatments is likely to be cost-prohibitive.

3.2 Data Requirements

Prior to the initiation of the study, existing information will be used to identify areas vulnerable to landsliding. This information includes data from existing and completed mass wasting projects such as the SLPSTAB (TFW118) and the LHZ Project; in fact these data sources were critical in identifying the WAUs that are appropriate study sites (see Section 4.1.2).

In the first spring after a large storm has occurred, flights to acquire aerial photography will occur. See Appendix – Sampling Strategy. A landslide inventory from these photos will be accomplished following the LHZ Protocol (http://dnr.wa.gov/forestpractices/lhzproject/lhz_protocol_v2_1_final.pdf) where individual landslides are mapped and basic tabular data are collected.

Clusters will be established by random site selection followed by stratification into the five harvest strata and five road strata (see Appendix – Sampling Strategy). The harvest stratification will create a GIS polygon layer; the road stratification will provide attributes to an existing or updated GIS road layer. These layers will establish designated study areas, be used to randomly select road segments of each strata before the collection of data that will characterize differences between these strata, and, after data collection, will underpin landslide data analyses.

Field analysts will search for additional landslides within the designated study areas (see Appendix – Sampling Strategy). Basic site data will be collected for each landslide (see Appendix – Field Forms), and those landslides not observed on the aerial photographs will be mapped and the tabular data for the LHZ Protocol will be collected. Basic site data include size of the initiation site, hillslope gradient, hillslope form, forest stand and understory characteristics, and delivery.

Following the collection of basic site data, the field analysts will proceed to fill out one of three field forms for each landslide encountered. These forms will guide collection of objective data to characterize past and current management activities on or near the site and lead to the identification of one or more site-scale triggers. These three forms are Hillslope (Non-Road), Midslope Road, and Stream-Crossing Road, which reflect the general locations of landslide initiations (see Appendix – Field Forms).

3.3 Hypotheses

Hypotheses in this Post-Mortem Study are grouped into two categories: macro hypotheses and micro hypotheses. Macro hypotheses pertain to the harvest unit or road segment-scale. The study is designed to statistically test macro hypotheses, which are described in detail below. Micro hypotheses pertain to individual site treatments. They reflect the authors' assumptions and predictions at the time the study was developed, but are not intended to be tested statistically. Micro hypotheses are listed and described in Appendix – Micro Hypotheses.

Macro Hypotheses

Harvest Hypothesis

H_O: Stratum A will have a greater density of landslides and greater volumes of delivered sediment than B, C, D, and E respectively. Stratum B will be more unstable than C which will be more unstable than D which will be more unstable than E.

Strata are defined in Section 2.2., (page 4); the definitions are explained more fully in the Appendix - Sampling Strategy.

Forest harvest has the potential to significantly increase landslide rates (Jakob, 2000; Guthrie and Evans, 2004). The contribution of logging to landsliding is largely understood from a mechanical perspective. In steep terrain, forest harvest increases landsliding by: (1) modifying soil moisture regime (Adams et al., 1991; Dhakal and Sidle, 2004; Jones and Post, 2004); (2) changing root cohesion of the soil mantle (Sidle, 1991; Schmidt et al., 2001); and (3) altering soil permeability (Sidle et al., 2001). All three vary through time with the highest landslide rates predicted 3-15 years after harvest (Sidle et al., 2006). The Forests & Fish Rules governing potentially unstable slopes typically result in full buffer protection or limited operation (e.g., yarding corridors) in an attempt to reduce landslide rates to levels approximating natural processes. Additionally, avoiding unstable areas will ensure that if these areas do fail, the landslide may deliver large woody debris thus improving the function of the landslide. Pre-FFR harvest units will therefore experience higher rates of landsliding than post-FFR harvest units, post-FFR harvest units with managed buffers, and unharvested forests respectively. In summary, the harvest strata represent meaningful age categories that are readily available on FFR lands. The apparent stand age differences between pre-FFR and post-FFR may be resolved by the presence of older post-FFR harvest units permitted before 2000 under watershed analysis prescriptions (see Appendix – Sampling Strategy). The 41+ year age class represents conditions of full root strength and hydrologic recovery (Sidle, 1992), and provides a “baseline” of landslide response against which the other strata can be compared. Unfortunately, the 41+ year age class does not represent old growth conditions and cannot be used to evaluate natural background; this will be addressed in the MWSLE Study.

We expect this hypothesis to be formally tested, particularly with respect to the three critical strata – A, C, and E. Statistical differences in landslide density and delivered volume between harvest types will be determined with an ANCOVA to assess overall differences. The ANCOVA will incorporate normalizing variables (e.g., precipitation and topography) as covariates. If the ANCOVA identifies differences between strata at $\alpha=0.1$, pairwise differences will be determined using the step-down bootstrap resampling method of Westfall and Young (1993). The ordered-heterogeneity testing procedures of Rice and Gaines (1994) will be used when evaluating p-values of among ordered hypotheses. ANCOVA and pairwise-comparisons will represent significant study findings.

Road Hypotheses

A. H_O: Road stratum A will have the highest landslide density (landslides per mile of road) and the highest volumes of delivered sediment followed by B, C, D, and E respectively, and –

B. H_O: Road strata D and E will have significantly lower landslide densities and significantly lower volumes of delivered sediment than A, B, and C.

Strata are defined in Section 2.2. (page 4); the definitions are more explained more fully in the Appendix - Sampling Strategy.

Forest roads in steep terrain have long been associated with elevated landslide rates (Haupt, 1959; Dyrness, 1967; Megahan and Kidd, 1972; McCashion and Rice, 1983; Amaranthus et al., 1985; Sidle et al., 1985). Several factors associated with forest roads increase their susceptibility to landsliding, but perhaps the greatest is surface/subsurface water flow interception and alteration (Montgomery, 1994; Borga et al., 2004). The FFR attempted to address this issue by prioritizing "repair or maintenance work to improve hydrologic connectivity." Thus, roads that do not meet forest practice standards will be most likely to fail, followed by roads that were orphaned prior to 1974. Roads that meet forest practice standards will have an intermediate number of landslides, while roads with recently completed instability hazard reduction measures and those abandoned under the Forests & Fish Rules or equivalent will experience the fewest landslides.

We expect these hypotheses to be formally tested, particularly with respect to the three critical strata, which are A, C and D. Statistical differences in landslide rates (landslides per mile of road) will be determined with an ANCOVA, using normalizing variables as covariates. If the ANCOVA identifies differences between strata at α=0.1, pairwise differences will be determined using the step-down bootstrap resampling method of Westfall and Young (1993). The ordered-heterogeneity testing procedures of Rice and Gaines (1994) will be used when evaluating p-values of among ordered hypotheses. ANCOVA and hypothesis test results will represent significant study findings.

3.4 Relationship of Hypotheses to Critical Questions

Macro hypotheses relating to the first critical question (see Section 2.3) are the focus for the statistical design of this study and it is fully expected that the study will provide unambiguous answers to that critical question. Micro hypotheses related to the other critical questions will also be evaluated (see Appendix – Micro Hypothesis), though statistical significance of those findings remains an unknown and the results are likely to be expressed using descriptive statistics and relative rankings. Relationships between the hypotheses, data to be gathered and analyses are summarized in the linkages table in the Appendix – Linkages.

4 STUDY METHODS

4.1 Sampling Strategy and Analytical Procedures

The Post-Mortem Study has been designed to occur after a storm that generates an average of one slide per square mile of industrial forest land over an area of at least three WAUs. Following the storm, fourteen to twenty-two four-square-mile clusters will be stratified by treatment. Landslides will be identified by mapping from newly acquired aerial photography, by driving or walking all roads, and by walking all streams. Detailed data will be field collected for each identified landslide. Rationales for the study design, including the number and size of the clusters, are presented below; additional details are provided in Appendix – Sample Size Analysis.

4.1.1 Study initiation

The Post-Mortem Study is designed to occur after a large, landslide-generating storm event in Washington State. As part of the study design, a literature review of landslide initiation thresholds was performed. The literature reviewed showed that several factors including antecedent moisture, rainfall intensity, and rain-on-snow are important factors in predicting regional storm-induced landsliding (Dai and Lee, 2003; Jakob and Weatherly, 2003; Dhakal and Sidle, 2004; Gabet et al., 2004; Iida, 2004; Godt et al., 2006).

Because of the difficulty associated with remotely assessing antecedent moisture and rain-on-snow across Washington State, UPSAG decided to use river discharge as a proxy. River discharge is responsive to changes in antecedent moisture, rainfall, and snowmelt; and real-time information is available from the United States Geological Survey (USGS) for rivers across the state. To correlate river discharge with regional landsliding, UPSAG attempted to use a method similar to Reid (1998) where historic landslide densities for photo periods were calculated from landslide inventories and correlated against peak-specific discharge at nearby gages. Unfortunately, this analysis was non-determinative given the relatively short duration of most gage records, the low temporal resolution of aerial photo landslide inventories, and noise most likely associated with landslide initiation thresholds varying in time and with forest practice standards.

As such, the current sampling plan calls for CMER staff to monitor river discharge in select basins as part of their winter office duties. CMER staff and UPSAG members will be generally alert to news reports, precipitation records and "word-of-mouth" information that suggests a landslide population may have been created. Whenever a storm event of potential interest occurs, CMER staff and UPSAG members will contact local stakeholders (e.g., landowners, tribal personnel, and forest practices foresters) seeking anecdotal information about the numbers and spatial extent of landslides.

If this initial analysis suggests that a population of landslides that meets study requirements (Section 3.3.2) may be present, CMER or agency staff or UPSAG members will travel to the area and assess the situation. Landslide distribution and severity will be assessed by vehicle to the extent possible, but an observer plane flight at low elevation prior to leaf-out may be necessary. Initial field assessments are likely to take up to five days of staff time and may involve several false starts before an acceptable population is identified.

If reconnaissance efforts confirm that a sufficient population of slides is present, UPSAG will initiate the contract for 1:12,000 aerial photographs to be collected over the affected WAUs. Collection of aerial photography is expected to be completed as soon as seasonal conditions permit (preferably before or during April) following the storm.

4.1.2 **Study requirements and analytical procedures**

The primary objective of this study is to determine whether there are statistically significant differences in the number of landslides delivering sediment to streams associated with different forest prescriptions at the harvest unit or road segment scale. In traditional statistical hypothesis testing, the significance level of a statistical test represents the probability that the null hypothesis will be rejected in error (a decision known as a Type I error). The null hypothesis is a hypothesis set up to be nullified or refuted in order to support an alternative hypothesis. In practice, the null has become identified with the "null hypothesis", which states that "there is no phenomenon." In this study, significance therefore represents the probability of declaring there is a difference in landslide rates between strata when no such difference exists. The level of significance for a statistical test (α) is determined before the data are analyzed.

Table 1 Power as a function of sample size, a=0.1

Clusters	Power
12	0.636
13	0.679
14	0.717
15	0.751
16	0.782
17	0.81
18	0.834
19	0.856
20	0.875
21	0.892
22	0.906

The **power** of a statistical test represents the probability that the test will reject a false null hypothesis and not make a Type II error. Type II errors occur when we fail to reject a null hypothesis that will have been rejected. In addition to a low alpha, we require that our study have a high power so that we don't fail to identify a difference in landslide densities between strata if one exists. Power is dependent on the type of test and increases with increasing sample and effect size, and declines with increasing sampling variance.

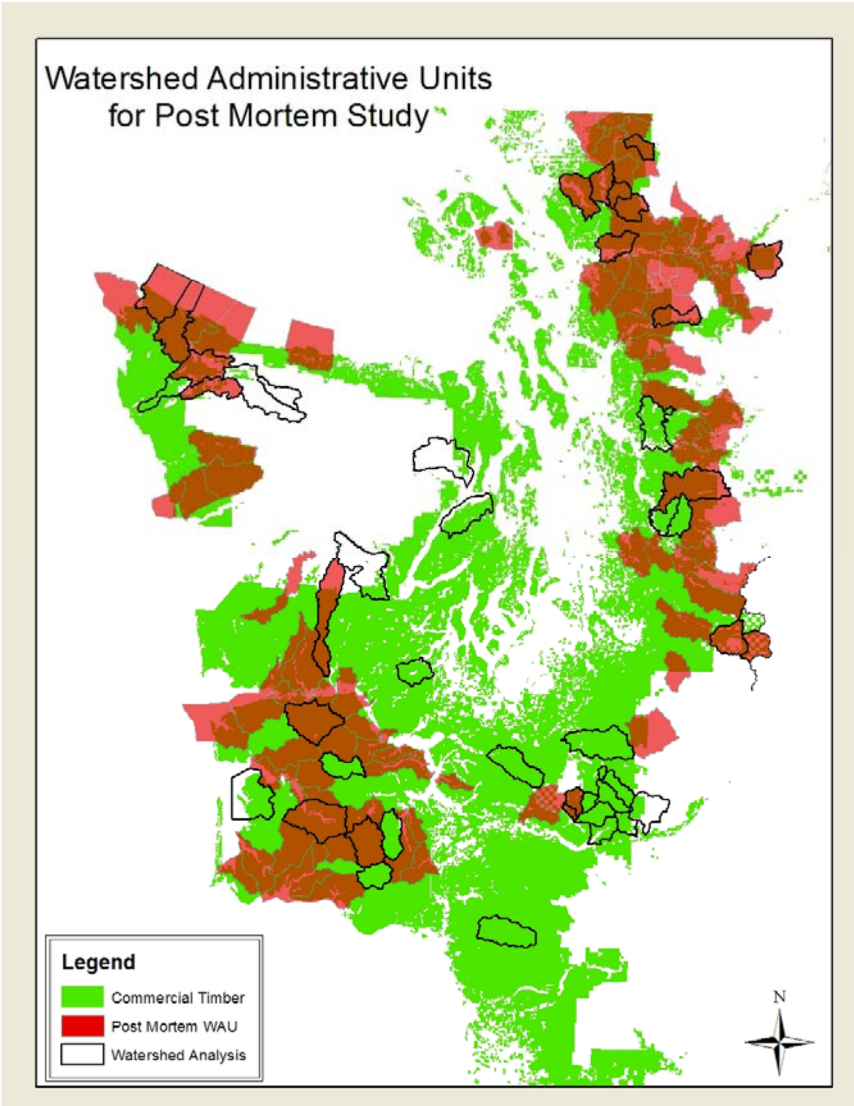

Figure 4-1. Map showing WAU's with steep topography (red) and pre-FFR watershed analyses (outline) superimposed on the area of commercial forest lands. WAUs appropriate for the Post-Mortem Study are listed by name in Appendix 9

The sample size required to get statistically significant results with different levels of power can be calculated prior to a study if the effect size and variance can be estimated (Appendix – Sample Size Analysis). In this study, we used data collected after the 1996 storm in Oregon to estimate the sample size needed to identify differences in landslide rates among strata in a one-way ANOVA. In the Oregon data, the three forest strata identified were open forest, mixed forest, and mature forest (Miller and Burnett, in press). Power analysis of these data in a one-way ANOVA shows that a minimum of 12 clusters are required to get a significant result at $\alpha=0.1$. At 12 clusters, power is 0.64 (roughly 36% chance of identifying no difference when a difference exists). With 22 clusters, power exceeds 0.9, which provides a balance in the Type I and Type II error rates (Table 1).

The number of potential study sites is a function of cost and available sample area. Sample area is a known limiting condition because landslides are unlikely to occur in areas of low relief and large portions of the state are not subject to forest practice rules. In order to estimate the potential sample area, we identified WAUs where at least 12% of the total watershed area has a high landslide potential and at least 33% of the watershed area is subject to forest practice regulation (either HCP or FFR – see Figure 1). These WAUs roughly represent the potential study population. The average area of these 103 WAUs is 39 square miles, so a storm would need to produce significant landsliding in at least three different WAU's in order to yield 22 clusters required to reveal significant differences with a power of 0.9.

Sample size estimates presented here assume the following: 1) All critical strata are present in each cluster; 2) landslide density is at least 1 landslide per square mile; and 3) the distribution of landslide counts is roughly Poisson, not binomial.

An analysis of Forest Practice Applications (FPA) revealed that less than 10% of west-side forests have been harvested under current forest practice rules or watershed analysis prescriptions (Harvest Stratum C – a critical stratum). As such, there is an 18% chance that a randomly placed four-square-mile cluster would contain no lands harvested under current rules (this percentage will decrease through time). Therefore, multi-stage cluster sampling scheme is recommended for this study. Cluster sampling will be used to maximize sampling efficiency and reduce spatial variance associated with storm intensity. Stratified random sampling will be used to augment clusters to make sure that all critical strata are present. Initial screening to verify the presence of Harvest Stratum C will be done with FPARs, a part of the Washington Department of Natural Resources website where forest practices applications spanning the past several years are available. The presence of older units meeting the description of Harvest Stratum C because of watershed analysis prescriptions will not be apparent on FPARs, so care must be taken to not use this screen as an automatic denial of the cluster.

Within each randomly selected four-square-mile cluster, all forest harvest blocks and road types will be categorized into one of the five harvest or road strata using aerial photographs, RMAP information, local landowner and regulator information, and field work. If an individual stratum is not contained within a cluster or it occupies less than 5% of the total road network length or timber harvest area, the cluster will be augmented by adding one mile on a side (twelve additional sections). Within the augmented cluster area, a section will be randomly selected and canvassed for underrepresented strata. Sections will continue to be selected in a counter-clockwise direction until the 5% threshold is reached or the twelve additional sections have been used up. If a census of the augmented cluster fails to identify enough of the critical strata to meet the 5% threshold, the Appendix - Sampling Strategy does provide additional guidance for both harvest and road under-representation. The cluster may be discarded and a new one selected from the randomly generated list.

Both the four-square-mile cluster size and the 5% threshold were chosen to give inherent differences in landslide density the opportunity to be expressed. Given an average density of 1 landslide per square mile, a stratum representing 5% of a four-square-mile cluster would have just a 20% chance of having a slide occur. If the area in any given strata were to decrease, landslides would become relatively rare and their distribution would begin to look binomial. Data from the 1996 event, in which overall landslide densities were about one per square mile, were Poisson distributed. Log-transformation of the Poisson distribution allowed for parametric statistics to be used in the sample size analysis and the findings are based in this distribution. It is likely that clusters smaller than four-square miles, or landslide densities less than one per square mile, would require a greater sample size to achieve the same significance and power.

Forest stand and landslide data from the 1996 storm event in Oregon (Burnett et al., in press) do not include roads so no power analysis could be conducted for the road strata. Generally speaking, landslide rates are much higher for roads than forest hillslopes (Larsen and Parks, 1997; Guthrie, 2002). Given that the primary limiting sample size issue for the forest strata was landslide counts, we feel that the current sampling scheme will provide enough data to identify differences between road strata if any exist. Without pre-existing data on road-related landslides and their relationship to road management prescriptions, it is not possible to explicitly evaluate the required sample size or to know how much power the study will have to resolve differences in landslide rates among road strata.

4.2 Field Protocols

As soon as possible after the storm event, field analysts will visit the four-square-mile blocks to stratify road segments into the five strata and begin data collection along randomly selected segments (for characterizing road indices) and at all landslide sites. In particular, landslide data from drivable roads must be collected as soon as possible so that maintenance activities do not reduce the analyst's ability to determine landslide triggers. Data for landslide sites on non-drivable roads can be collected at a more leisurely pace, or can occur simultaneous with the data collection needed for the harvest strata.

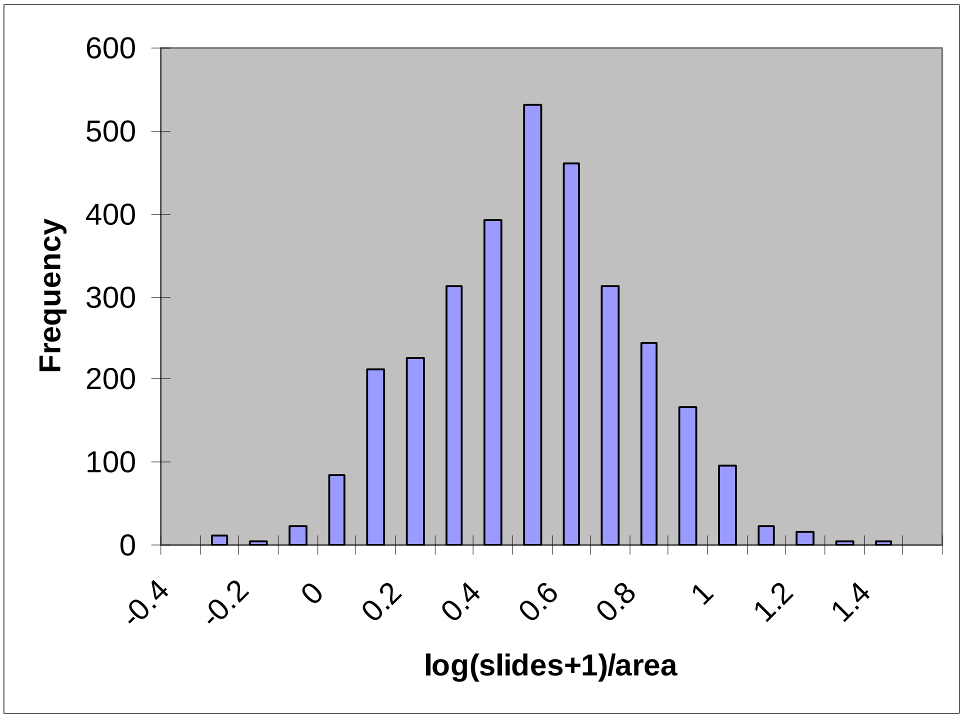

Figure 4-2. Log/normal distribution for landslide density from 1996 Oregon landslide study.

Data collection for individual landslide sites within the harvest strata must wait until the aerial photographs have been acquired, the landslide inventory following the LHZ Protocol has been accomplished, and the harvest strata have been delineated. Landslides within harvest strata will be located by traversing the channel network to find all delivering landslides. Non-delivering landslides that initiate within the harvest strata (i.e., non-road-related failures) that are observed during the aerial photo inventory, during the data collection of road-related failures or during the stream traverses will also be evaluated.

Data collection at an individual landslide site will occur as a three-part process. First, the data collected during the aerial photography assessment must be finalized. This will include verification or correction of the harvest stratum designation for the harvest unit, and may include mapping and collection of the data necessary to satisfy the LHZ Protocol if the landslide was not inventoried from aerial photography. Second, basic data about the landslide and about the site characteristics will be collected. Third, data that assist with the identification of potential landslide triggers will be collected; the data collected are situation specific in one of three broad categories of hillslope failures, midslope road failures and stream-crossing failures.

With the assistance of Oregon Department of Forestry (ODF) personnel who participated in the evaluation of the 1996 storm (Robison et al., 1999) and other interested parties, UPSAG will finalize the exact list of data to be collected, and draft a Field Manual and field forms. The Field Manual and field forms will be finalized in collaboration with the contractor. The contractor will be responsible for the development of a database, subject to UPSAG review. This work will be completed before the start of field data collection, but may occur simultaneous to efforts described in Appendix – Sampling Strategy. Actual field experience will likely lead to subsequent changes to the field data collection methods; these must be approved by UPSAG.

Development of a QA/QC procedure will also be the responsibility of the contractor, but the RSBM Project will serve as a guiding example. This will be subject to UPSAG review and approval before implementation, and the contract will be written to include this requirement. Data entry will be the responsibility of the contractor.

Details about data collection, entry and storage are provided in the Appendix – Field Forms.

5 RESULTS, INTERPRETATION, AND POTENTIAL ADAPTIVE MANAGEMENT

This study, the Mass Wasting Prescription-Scale Effectiveness Monitoring Project, is unlikely to lead to large changes to the FFR unstable slopes rules unless findings refute the scientific underpinnings of specific rules or reveal conditions where current BMP's are counter-productive. If the MWLSE Project shows that forest practices rules are not achieving or trending towards performance targets, then at that time this project might inform significant rule change.

However, there is a high likelihood that the results of this project alone will lead to small modifications to the unstable slopes rules, BMPs and the SEPA process because this detailed assessment of BMPs and prescriptions is likely to showcase some as very effective and others as ineffective. The critical questions below are expected to assist in the development of a nuanced response.

"Are FFR rules effective in reducing the volume of sediment delivered by management-induced landslides?" Forest practice rules were designed to reduce the volume of sediment delivered to streams as a result of forest management, but their effectiveness has never been critically examined. This study will directly evaluate effectiveness through an examination of landsliding associated with different management practices.

"Is the greatest proportion of landslide delivery from harvest units or roads?" Prior to FFR, road systems created the most number of landslides that delivered to public resources. Knowing whether roads continue to be the primary source of landslides is likely to prove useful to policy makers tasked with prioritizing projects for the development of sediment reduction BMP's.

"Which harvest unit prescriptions or road improvements are performing well? Which are performing poorly?" This information will inform policy makers as to which practices and related rules work, and which do not. Based on this information, policy and rule-making priorities may be altered.

"What are the site-scale triggering mechanisms for landslides?" It is understood how and why landslides occur on a landscape level, but site-scale linkages between forest practices and landslide triggering mechanisms remain poorly understood. Analysis of apparent triggering mechanisms may elucidate the effects of specific forest practice prescriptions on landslide initiation. In cases where the trigger is common and its occurrence can be remedied, policy makers may choose to initiate rule change.

"Do those triggering mechanisms vary between harvest unit or road types?" It is understood that the triggers are different between harvest and roads, but whether they differ within the harvest types is not yet known. If results suggest strong differences in landslide susceptibility between different road or harvest types, policy may choose to alter rules to reflect these differences.

6 COST AND IMPLEMENTATION

6.1 Cost Estimates

The cost to undertake this project is broken into several basic categories: air photo collection, photo interpretation, stratification and basic data collection, field data collection, data compilation and statistical manipulation, and quality control and reporting. Due to the variability in identifying total sample size and area needed, cost ranges to implement this project are included.

Costs for continued participation of the study design's authors who are not CMER or agency staff are not included because their continued participation as this project is implemented will be volunteered by their various employers (as is their basic participation in UPSAG and the CMER process).

Air Photo Collection: *(Photos to be collected on the area of interest as soon as possible in the spring after the event. Cost depends on area flown.)*	$60,000 – 81,000
Photo Interpretation, Stratification and Basic Data Collection: *(assumes a team of 4-6 will be doing this work over a 2 month period; includes training on stratification)*	$84,000 – 95,000
Field Data Collection: *(assumes several (3-5) two-person teams for four months @ $10,000/person/month; includes training)*	$255,000 – 415,000
Initial Site Selection, Landowner Identification and Access Permission:	$60,000
Data Compilation, Statistical Manipulation, Quality Control, Reporting: *(assumes work is contracted)*	$80,000
Total range of cost	**$539,000 – 731,000**

6.2 Implementation Considerations and Schedule

Prior to the initiation of this project, we will have contractors under contract, one for the collection of photos and one or more for the photo interpretation, stratification and physical field work. Site selection and access permission, data compilation, statistical manipulation, and reporting are expected to be handled by agency or CMER staff, or contracted out if necessary. This project will be started when there is a storm of sufficient size to trigger a set of landslides large enough to make sampling worthwhile (as described in Section 4.1, Sampling Strategy and Analytical Procedures). We will then authorize the photos to be taken at the earliest possible window. Depending on the weather, this can occur in the mid-to-late spring. It can take up to a month to receive photos from the contractor, but more typically it is within two weeks.

Another contract already in place will be with the principal investigator (PI) and the data collection team. As soon as the clusters are established and the aerial photographs are ordered, the data collection team will be authorized to go onsite to stratify road segments and collect road-initiated landslide information. It is critical that this team gets on the ground as soon as possible, as the road network is likely to be repaired quickly. Once the photos are in hand, a small team of photo analysts will map and collect basic data for all new landslides and pre-stratify the areas of concern, to optimize the area of field data collection necessary. It is anticipated that this will take two months.

Once the photo analysis is done, the field work will commence for the harvest units, through the summer and early fall months. The data collection team members will check in weekly with the designated team leader. The data collection team leader will compile their data weekly, ensure that the quality assurance steps are being implemented, and address any questions of protocol that might arise. A monthly report of all data will be presented to UPSAG. The entire field data collection effort could span six to nine months.

Monthly updates to UPSAG will be in verbal or written form during regular UPSAG meetings. At the end of the data collection phase, the PI, who may have been the data collection team leader, will work with UPSAG and CMER or agency staff to develop summary and exploratory statistics to test the hypotheses described in Section 3.2. The PI will develop a report that describes the outcomes of the project, including issues and solutions identified with the protocol, quality control issues and solutions, and statistical inferences of the hypotheses. This report will be submitted to UPSAG for review, potential editing, and final approval.

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8 APPENDIX – MICRO HYPOTHESES

Hypotheses in this document are grouped into two categories: macro hypotheses and micro hypotheses. Macro hypotheses pertain to the harvest unit or road segment-scale; micro hypotheses pertain to individual site treatments. Micro hypotheses reflect authors' assumptions and predictions and are intended to be evaluated, but are not intended to be tested statistically. Micro hypotheses are included because they reflect the thinking of the study authors at the time the study was developed and because 'interesting' study findings are commonly those that are completely unexpected or contrary to expectations.

Harvest Micro Hypotheses

H1. Landslides that originate in post-FFR-harvested unstable landforms do not deliver to protected resources.

Current forest practice rules do not protect unstable slopes that have no potential for delivery. As these areas presumably are not avoided, there may be failures that do not reach streams and have no potential for aquatic resource damage.

H2. Delivering landslides occur on rule-identified unstable slopes that were harvested.

Rule-identified unstable landforms were established during the FFR negotiations by reviewing watershed analyses. Correct implementation of the FFR strategy for unstable slopes requires that unstable landforms be completely identified during the development and review of forest practices applications. Although tools and trainings have been developed since the FFR negotiations to help managers identify unstable slopes, it is expected that there are still some landforms missed both during unit layout and FPA review.

H3. Landslides occur in landforms that were not rule-identified (e.g., glacial terrace faces or weakly convergent hillslopes).

Current rule-defined landforms are based on a review of watershed analyses conducted in Washington State as well as the best available science of the time. However, the definitions of these rule-identified landforms were created for use across the entire state and may not fully represent local conditions (e.g., local slope or curvature minima for creating instability may be different than the rule definition). Furthermore, during rule negotiations, it was recognized that other areas of instability of regional or statewide significance might exist that were not identified in areas where watershed analyses were performed.

H4. Triggering mechanisms may not be identifiable for all landslides.

In previous studies, land use has been used as a proxy for triggering mechanisms when it is not clear why a landslide occurred. This is because most previous studies have relied on remote sensing with limited field review to interpret landslide occurrence. Even when careful field evaluation is conducted, there may be multiple interacting factors which can make it difficult or impossible to clearly identify one or more triggering mechanisms.

H5. Landslides will occur in association with buffer blowdown.

Numerous studies have documented an increase in rates of shallow-rapid landslides after timber harvest (O'Loughlin, 1972; Fiksdal, 1974; Swanson et al., 1977). This increase is largely attributed to the decay of tree roots, because the roots of trees (and shrubs) stabilize the soil layer on steep hillslopes by increasing soil cohesion and by anchoring the soil layer to the underlying bedrock. Blowdown within buffers on potentially unstable slopes reduces at least some of the rooting strength. We expect to find increased landslide rates in buffered areas subject to significant blowdown as compared with rates in buffered areas with little to no blowdown.

H6. Harvest upslope of unstable landforms will increase landsliding.

Timber harvest has been demonstrated to create an increase in total water availability due to the loss of evapo-transpiration and canopy-held water as well as an increase in snowpack and snowmelt (Coffin, 1992; Keppeler et al., 1994). This increase in water availability directly affects the groundwater table, increasing the volume and timing of groundwater to downslope areas (Sias, 2003). This increase in soil moisture may affect slope stability, principally by increasing the instantaneous point pore pressure (Sidle et al., 1985; Iverson, 2000). Certain lithologies may be more responsive to this process.

H7. Landslide delivery will be inversely proportional to buffer/riparian stand width and density.

Tree composition/density in buffers affects sediment delivery. Studies directly addressing this hypothesis are limited, but there is some evidence that debris flows in clearcuts travel farther than debris flows in forested areas (Ketcheson and Froehlich, 1978; Robison et al., 1999; May, 2002; Lancaster et al., 2003). It is thought that trees, and in particular large trees, are effective at slowing or stopping debris flows near the initiation point and again in the zone of deposition (Benda et al., 1998; Ishikawa et al., 2003). If true, then it is reasonable to hypothesize that denser stands of larger trees will be more effective at limiting both the numbers of landslides that deliver and the total delivery volumes than sparser stands of smaller trees.

H8. Landslides that route through standing timber will deliver large woody debris.

Research has shown that landslides which mobilize wood in their path push the wood along in front of the flow (Hogan et al., 1998; Lancaster et al., 2003);. This bulldozing effect suggests that events which travel through buffers often entrain the wood and deposit it in the stream ahead of the sediment.

H9. Focused water from upslope roads will be associated with hillslope landslides.

Roads transform slow subsurface flow to rapid surface flow, increasing the timing and volume of water availability to the hillslope (Megahan, 1972), which in turn increases the instantaneous pore pressures downslope of the road. Less drainage area is needed to initiate channels below road drainage than in natural areas (Montgomery, 1994), and roads can facilitate gully development below road drainage structures such as ditch relief culverts, waterbars, or rolling dips (Wemple et al., 1996; Croke and Mockler, 2001). A population of hillslope landslides will be associated with just such focused road drainage.

H10. Landslides will occur along yarding corridors.

Landslides may be more common along yarding corridors within clearcut areas, due to changes in vegetation (and thus root cohesion) and soil moisture. Similarly, increased landslide frequency may be observed where yarding corridors cross forested leave areas on unstable landforms. In this situation, a minimal number of trees are normally cut from the leave area to allow log passage. Depending on the number of trees cut, this may reduce rooting strength and influence landslide susceptibility as discussed in Hypothesis H6 above, even though harvest occurs at a smaller scale.

Road Micro Hypotheses

R1. Landslides will occur on planar slopes with no or insufficient pullback.

While most harvest-related landslides initiate in naturally unstable slopes such as those that are rule-identified, road-related failures can be triggered outside of naturally unstable landforms by the placement of excess fill on a steep slope, by excess concentration of water, or commonly by a combination of both triggers. Debris slides and debris flows triggered from the road edge commonly travel 200-300 feet down a planar slope, and further if the initial volume is very large such as failures from perched landings. However, these sites may be overlooked during pullback operations because they do not meet definitions of unstable slopes.

R2. Small stream-crossing pipes will be associated with landslides.

Undersized stream-crossing structures can contribute to landsliding when water is diverted around the structure and onto unstable soils. The unstable material may consist of the road fill over the crossing, the road fillslope further down the road, or a hillslope below the road if the road ditch diverts overflow farther from the overwhelmed or impaired crossing (Furniss et al., 1991). This is commonly observed after major storms (Robison et al., 1999; Wemple, 1999), which typically deliver greater flows of water, wood and sediment than what the structure has successfully passed during previous smaller storms.

R3. Inadequate water control measures will be associated with landslides.

a. Pirated waters
b. Too few drainage structures

c. Inadequate ditch design and construction
d. Ditch not flowing to an appropriate point

The connection between misdirected road runoff and erosion in the Northwest has been documented for many decades (Haupt, 1959; Dyrness, 1967). Roads can divert road runoff onto steep hillslopes that have been stable when receiving precipitation and/or snowmelt only. The "pirating of waters" involves the redirection of streamflow by a road from one channel into another (Furniss et al., 1998) contributing to channel incision and/or destabilization. Sufficient numbers of drainage structures are required to disperse ditch flow (Piehl et al., 1988), especially where subsurface flow is being intercepted. Likewise, inadequate ditches can overflow or become obstructed, allowing water onto steep slopes that become unstable due to added moisture (Dyrness, 1967). In some cases, the hillslope where ditchwater is released becomes destabilized during large storms (Montgomery, 1994).

R4. Poor tread maintenance or inappropriate road geometry will be associated with landslides.

Excess water as concentrated by road drainage is a key landslide trigger (Dyrness, 1967; Megahan, 1972; Sidle et al., 1985). Ponded water anywhere within a road prism provides evidence that excess water is accumulating at a particular site. Common examples of ponded water that may help trigger landslides include: 1) Wheel ruts in an inadequately maintained road; 2) Silt traps placed either in the ditch or in the fillslope; and 3) Isolated low places in the ditch that do not flow towards a drainage structure.

R5. Triggering mechanisms may not be identifiable for all landslides.

It can be difficult or impossible to clearly identify triggering mechanisms. Road-related landslides are especially problematic, because often the road is repaired as soon as possible. In those cases, the trigger or triggers may have been removed or obfuscated by earth movement related to the repair.

9 APPENDIX – SAMPLING STRATEGY

9.1 Step 1 - Identify Storm of Probable Size

Who: Staff and UPSAG

Results: Decision to implement and permissions

Staff* will monitor river discharge in select basins as part of their winter office duties, and Staff and UPSAG members will be generally alert to news reports, precipitation records and "word-of-mouth" information that suggests a landslide population may have been created. Whenever a storm event of potential interest occurs, Staff and UPSAG members will contact local stakeholders (e.g., landowners, tribal personnel, and forest practices foresters) seeking anecdotal information about the numbers and spatial extent of landslides.

If this initial analysis suggests that a population of landslides that meets study requirements (Section 3.3.2) may be present, Staff or UPSAG members will travel to the area and assess the situation. Landslide distribution and severity will be assessed by vehicle to the extent possible, but an observer plane flight at low elevation prior to leaf-out may be necessary. Initial field assessments are likely to take up to five days of staff time and may involve several false starts before an acceptable population is identified. When an acceptable population of landslides has occurred, UPSAG members will secure appropriate permissions from CMER, FFR Policy and the Forest Practices Board while proceeding with Step 2.

*"Staff" in this appendix means CMER staff or state agency personnel who participate in or assist with CMER projects.

9.2 Step 2 - Validate/Map Landslide Concentration with Respect to WAU Clusters

Who: Staff and UPSAG

Results: GIS layer and appropriate maps showing delineation of one or more study areas

While securing permission to implement with study (described above in Step 1), UPSAG members, with the help of other geologists, landowners, and Staff, will begin to develop a map that displays the WAUs listed in Table 9-1 that are believed to have a landslide concentration of at least one per square mile needed for the statistical requirements of this study. This preliminary map will guide the purchase of QuickBird satellite imagery or equivalent. Final delineation of the study area will utilize this imagery and will be guided by the following:

- The identification of those WAUs meeting the basic criteria of sufficient FFR lands and sufficient steep ground (Table 9-1) that contain sufficient density of landslides will be confirmed. Each individual WAU will be included entirely unless it is clear from landslide distributions that a large portion of a WAU experienced much lower storm intensity.

- The boundaries of the study area will be expanded by adding headwater areas of neighboring WAUs that did not meet the basic criteria for inclusion in Table 9-1 IF these headwater areas are predominately steep FFR lands AND there is sufficient landslide density. The inclusion of such headwater areas will bolster the land base available for the study.

- Final delineation of the study area will use WAU boundaries and major topographic features such as rivers, ridgetops or hillslope/terrace intersections. Final delineation will not exclude small, irregular areas of few or no landslides that lie within the broad outline of the study area as these areas may reflect good management practices rather than lower storm intensity.

This study design may be implemented on one or more study areas simultaneously. All appropriate study areas as controlled by the geographic extent of the storm will be delineated and considered, and final decisions about which study areas to utilize will be made by UPSAG with advice from CMER.

Table 9-1. List of WAUs with 12% high landslide potential and a minimum of 33% of area subject to forest practice rules.

Acme	Gilligan	Lower NF Stillaguamish	Skamokawa
Grays Bay	Grandy	Lower Sauk	Skookum Creek
Alder	Hansen Creek	Lower Suiattle	Skykomish River
Bear River	Hazel	Lower Willapa	Smith Creek
Big Creek	Hoko	Lower Wishkah	Sol Duc Valley
Blakely Island	Howard Creek	Middle Hoh	Sooes
Boulder Creek	Howard Hansen	Mill Creek	Spada Lake
Bremer	Hutchinson Creek	Mitchell Creek	Stillwater
Canyon Creek	Independence Creek	Mowich-Puyallup	Sumas River
Chehalis Headwaters	Jackman Creek	Naselle Headwaters	Tiger
Chehalis Sloughs	Jim Creek	NF Calawah	Tolt
Chester Morse	Johns River	NF Snoqualmie River	Upper Chehalis/
Clallam River	Jordan-Boulder	NF Tilton	Rock Creek
Clearwater	Klickitat Meadows	Nookachamps	Upper Clearwater
Kalaloch Ridge	Lake Cavanaugh	North Headwaters	Upper Green River
Clearwater Creek	Lake Creek	Olney Creek	Upper Wallace River
Connelly	Lake Shannon	Pilchuck Mtn	Vedder
Corkindale	Lake Whatcom	Porter Canyon	Vesta-Little North
Cypress Island	Lester	Pysht River	Warnick
Day Creek	Lincoln Creek	Racehorse Creek	WF Grays River
Deer Creek	Lower Chehalis/	Raging River	WF Satsop
Delezene Creek	Elizabeth Creek	Rock-Jones	WF Tilton
Deming	Lower Clearwater	Salt Creek	Willapa Headwaters
EF Humptulips	Lower Middle	Salzer Creek	Wilson Creek
Elk River	Snoqualmie	Sekiu	Wynoochee River S
Finney	Lower Naselle	SF Chehalis	
Garrard Creek	Lower Nason	SF Snoqualmie River	

9.3 Step 3 - Generate Four-Square-Mile Blocks

Who: Staff with UPSAG guidance and approval

Results: GIS layer and appropriate maps of 40 randomly selected and ordered four-square-mile blocks

Section corners that fall within state and private forest lands will be determined by intersecting the State section corner list with a current CMER Lands coverage of known state and private forest lands. A GIS-based algorithm will be used to randomly select from this section corner list within the study areas delineated in Step 2 (Figure 9-2 is provided as an example). A four-square-mile sample would be established on each of the randomly selected section corners to create the study blocks. Where overlap occurs among the samples, the first randomly selected sample will be retained and any overlapping samples will be deleted.

Each sample will also have a one-mile-wide frame (i.e., the twelve square miles surrounding the four-square-mile sample). These frames around the samples may overlap. Starting from the upper left and working toward the lower right, the overlapping frame from the adjacent buffer will be deleted and replacement acreage will be added elsewhere along the frame edge to produce the needed frame size. This process assumes primacy of the first encountered block, with adjacent study blocks being edited as needed to avoid overlap.

Before beginning the processes of assessing ownership or delineating the strata, use FPARs and watershed analysis information to verify the presence of Harvest Stratum C within the four-square-mile block or within the one-mile-wide frame.

The final four-square-mile block may not be an actual block; if Federal or residential lands lie within the four-square-mile block, they will be cut from the sample and replaced from other land within the twelve-square-mile frame by the process described in Step 6. At least 40 ordered samples (i.e., non-overlapping four-square-mile blocks) will be established the first time Step 3 is done. If too many samples are lost for various reasons (e.g., physical access, denial of landowner permission, etc), then additional samples may have to be established; this will be done from the original list of randomly selected section corners.

While Step 3 is being completed, the in-place contracts for aerial photo acquisition and field data collection will be initiated, and the necessary work to finalize the field protocol and develop the database will be started (Step 4).

9.4 Step 4 - Create Field Manual and Database

Who: UPSAG with assistance from ODF personnel and the data-collection contractor/PI

<u>Results</u>: A Field Manual with field forms (or handheld programs), a database, and the acquisition of necessary GIS layers

Appendix – Field Forms will be expanded with photos, cartoons and other types of figures, and probably additional text, to create a Field Manual that provides guidance to field personnel in the collection of all required field data. Development of the Field Manual will be started by UPSAG with assistance and input from ODF personnel and others, and will be finalized when the data-collection contractor/PI is onboard.

The data-collection contractor will create an appropriate database (i.e., either a geodatabase where the tabular database is directly linked to GIS or a stand-alone database that communicates well with GIS) and will acquire necessary GIS layers to include PLS, ownership, roads, streams, a DEM or LiDAR (as available), SLPSTAB, LHZ, relevant watershed analysis data, and the layers produced in Steps 2 and 3. The final database will require approval by UPSAG.

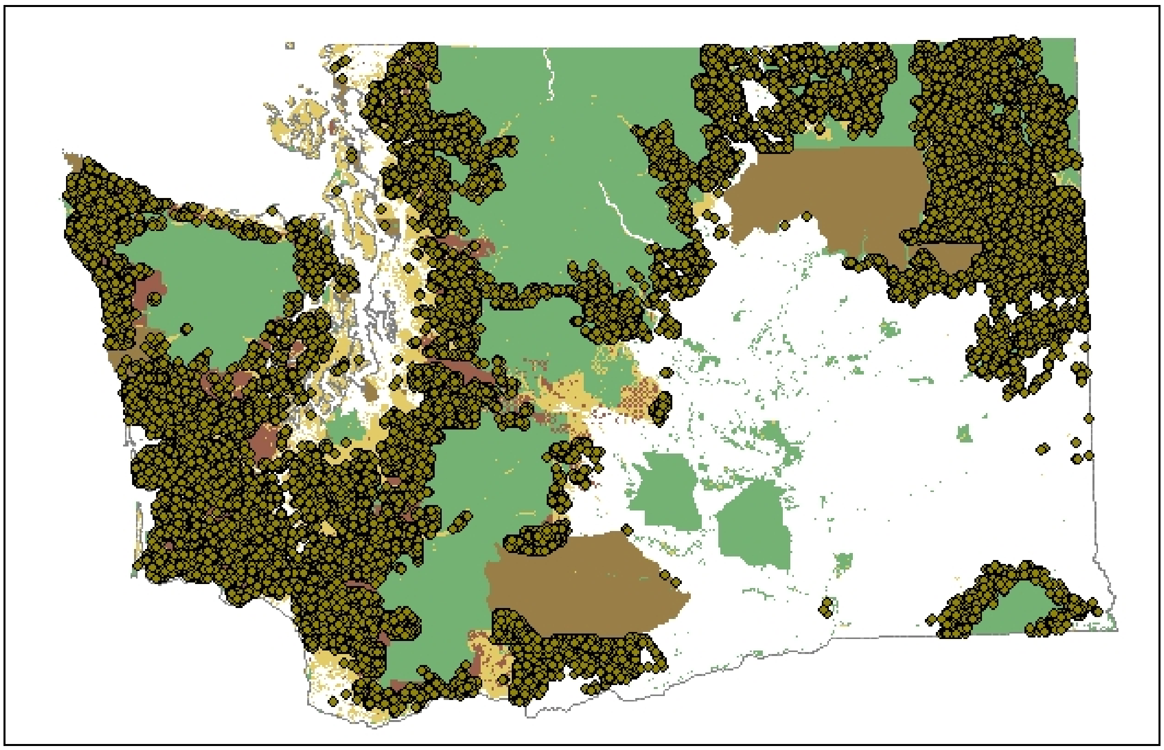


Figure 9-1. Section corners occurring on private lands. Green shading indicates federal lands brown shading indicates tribal lands, red shading (where visible) indicates HCP lands, and yellow shading (where visible) indicates other timberland owners. Each section corner is given a unique number and a random number generator can select from a range of numbers.

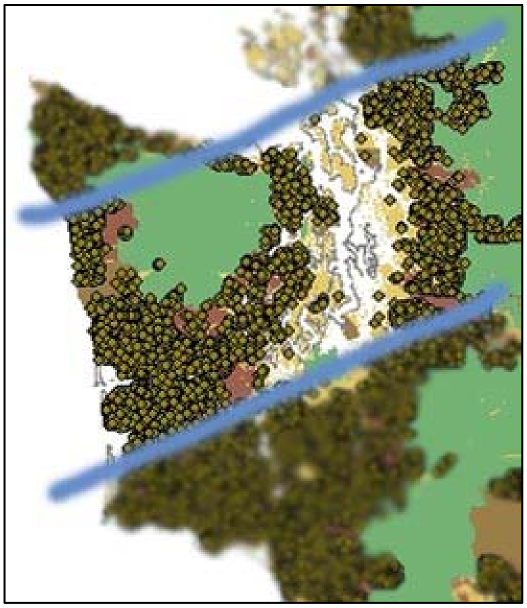


Figure 9-2. Closeup of a potential storm cell (area between blue lines) passing over western Washington. Only those section corners between the blue lines would become eligible for random selection and buffering. These will be further reduced by the actual delineation of one or more study areas that include an appropriate group of WAUs and adjacent headwater areas (refer above to Step 2).

9.5 Step 5 - Acquire Aerial Photography

Who: Staff

Results: 1:12,000, color, stereo aerial photographs for the established samples and frames

> Color aerial photographs that are approximately 1:12,000 scale and that provide the best overlapping coverage to provide full stereo coverage with minimal parallax for the identification of landslides will be acquired (specific language already exists in previous DNR contracts, but may be modified on advice from photogrammetry experts). Development of the contract will include a detailed map of areas to be flown. This will be produced by Staff using the following guidance: 1) Where clusters are closely spaced, delineate larger, contiguous areas to fly. 2) Widely scattered clusters will be flown as individual targets. 3) The potential bidders (there are only two in Washington State) will assist in making these decisions to maximize air photo coverage while minimizing total costs.

9.6 Step 6 - Design QA/QC and Participate in Training

Who: PI designs QA/QC, all people assisting with stratification attend stratification training, and all people doing field data collection attend field data collection training

Results: Approved QA/QC Plan and properly trained personnel

The PI will design a QA/QC Plan for this project. It will be modeled after the QA/QC Plan developed for the RSBM Project, and requires UPSAG approval before finalization. It will incorporate a two-day training in stratification of harvest and road types and a two-day training in the collection of field data for identified landslides and road indices. The trainings will be designed and lead by UPSAG. The QA/QC will also incorporate an interim presentation to UPSAG to finalize sample number based on preliminary statistics and to verify quality control of data collection (see Step 13 below).

9.7 Step 7 - Stratify Harvest Types

Who: The data-collection contractor/PI with assistance from landowners and oversight from Staff or UPSAG

Results: A GIS polygon layer of strata types and appropriate maps to facilitate field work

Using aerial photography, stand inventory data provided by landowners, and FPARs, delineate the five harvest strata. An overview of this process is provided in Section 3.1; implementation details are provided below. Stratification training will be provided by an UPSAG member.

9.7.1 **Definition of Strata Types**

A. **Clearcut**: Pre-FFR rules where both the unstable landform and the neighboring hillslope are clearcut (stand-age 20 years or less).

Harvest units clearcut with no deliberate buffering of unstable landforms with a current stand age of 20 years or less (stand age is defined as planted age, which may be one or two years more recent than the real age of the trees). There may be some unstable slope buffering which has occurred accidentally within riparian buffers, usually of inner gorges on Type F streams. “Pre-FFR” will not be interpreted as meaning “permitted before 2000” – harvest units permitted and/or harvested after 2000 with no deliberate buffering of unstable landforms will be categorized in this stratum. (Note: The word “clearcut” may be interpreted to mean either “clearcut” or “thinned” as it is applied to the neighboring hillslope for each of the first three strata. If the unstable landforms were avoided during the thinning operations, then the harvest unit will be classified in the Buffered Stratum. If broad areas have been thinned, including the unstable slopes, then the harvest unit will be classified in the Partial Harvest Stratum.)

B. **Partial Harvest**: Post-FFR rules or equivalent where the unstable landform is partially harvested (e.g., thinned or yarding corridors), and the neighboring hillslope is clearcut (stand-age 20 years or less).

   Harvest units clearcut with deliberate buffering but some partial cutting of unstable landforms with a current stand age of 20 years or less. Partial cutting may include thinning within unstable landforms, the cutting of yarding corridors across unstable landforms, or incomplete buffering of unstable landforms whether accidental or purposeful. Blowdown subsequent to harvest does not affect strata assignment. Yarding corridors created by flying through the upper canopy without the cutting of corridors but perhaps with the cutting of one or more danger trees will not cause a harvest unit to be stratified in this category. “Post-FFR” will not be interpreted as meaning “permitted in or after 2000” – harvest units permitted and/or harvested before 2000 with deliberate buffering on unstable landforms, such as required by watershed analysis prescriptions, will be categorized in Strata B or C. In fact, the correct identification of early “post-FFR” areas will help minimize stand age differences between Stratum A and Strata B and C.

C. **Buffered**: Post-FFR rules or equivalent where the unstable landform is in mature timber and the neighboring hillslope is clearcut (stand-age 20 years or less).

   Harvest units clearcut with deliberate buffering of unstable landforms with a current stand age of 20 years or less. Yarding corridors created by flying through the upper canopy without the cutting of corridors but perhaps with the cutting of one or more danger trees will not prevent a harvest unit from being stratified in this category.

D. **Sub-mature**: Pre-FFR rules where both the unstable landform and the neighboring hillslope are in intermediate age timber (stand-age 21-40 years).

   The stand age of the unstable landforms and the neighboring hillslope is uniform (or the trees on one or more unstable landforms are somewhat younger due to failure after the last rotation); it has been 21 to 40 years since the stand was planted.

E. **Mature**: Pre-FFR rules baseline where both the unstable landform and the neighboring hillslope are in mature timber (stand-age 41+ years).

   The stand age of the unstable landforms and the neighboring hillslope is uniform (or the trees on one or more unstable landforms are somewhat younger due to failure after the last rotation); it has been 41 or more years since the stand was planted or initiated.

The timber age classes of less than 20 years, 21-40 years, and 41+ years were used to establish the harvest strata based on evaluation of literature related both to root strength decline and recovery, and to hydrologic recovery. The first 20 years after harvest allows for significant hydrologic recovery, some limited root strength recovery after passing through the lowest point of root strength at 12-15 years (Sidle et al., 1985), and provides a sample of both pre- and post-FFR harvest units that will be approximately comparable. The 41+ year age class represents full root strength and hydrologic recovery (Sidle, 1992), and provides a “baseline” of landslide response against which the other strata can be compared. As discussed above in Section 2.2, the 41+ year age class does not represent old growth conditions and cannot be used to evaluate natural background. The 21-40 year age class is chosen because lies between the two primary age categories of interest and needs to be evaluated because of the cluster approach we are using; we have identified it as a non-critical stratum.

9.7.2 **An Explanation of Harvest Units and Boundaries**

Polygons of the five harvest strata will be coincident with one, or sometimes two or three, individual harvest units as originally engineered by the landowner. Therefore, it is important to understand why the locations of harvest unit boundaries are chosen.

Fundamentally, topography controls road and landing locations, which in turn control harvest unit boundaries. However, there is some feedback during the engineering process (e.g., a topographically isolated pocket of timber may require that additional road be built.)

Consequently, harvest unit boundaries often coincide with topographic factors such as:

- Large streams on the valley bottom;
- Small streams that flow straight down the hillslope;
- Ridgetops; and
- Edges of lakes or large Type A or B wetlands.

Other common, non-topographic boundaries include property lines which usually correspond to section, ½ section or ¼ section lines, and roads. Roads often form harvest unit boundaries because they provide an easily mapped edge. In steep ground where cable logging is the normal practice, a midslope road may form a harvest unit boundary because all downslope timber is logged to it; all upslope timber is logged to a higher road.

In summary, polygons of harvest strata will be coincident with harvest unit boundaries, and harvest unit boundaries will usually coincide with topographic features, property lines or roads.

9.7.3 **Delineate Polygons**

Polygons of hillslope strata will be delineated remotely and then field verified as field data collection occurs. Remote delineation can be improved by using stand age and harvest information (if landowners provide these data), by the evaluation of forest practices applications (e.g., FPARs on the DNR website), and by conversation with landowner representatives, local stakeholders, and local DNR forest practices personnel. All of these tools will be used so that few corrections occur as field work proceeds.

Begin the delineation of hillslope strata in the designated corner of the four-square-mile block and proceed in an approximately diagonal direction towards the opposite corner while maintaining a delineation “front” that is approximately perpendicular to the diagonal direction of delineation.

Delineate whole harvest units or stand types using the guidance provided above in the previous section. Polygons may be extended beyond the four-square-mile block to accomplish this requirement, but will not be extended beyond the one mile-wide frame around the four-square-mile block. When completed, all FFR lands within the four-square-mile block will be delineated except where only a small portion of a harvest unit or stand type lies within the block.

Where appropriate within the constraints stated in the paragraph above, a polygon will be drawn to include multiple adjacent harvest units or stands that all qualify as the same strata. Where harvest units or stand types of different strata abut at streams with riparian buffers, delineate polygons by following the stream or the approximate center of the riparian zone. This latter requirement provides a correct representation of the true edges of harvest units, and as with strata boundaries along roads it simplifies the GIS work by allowing portions of polygon boundaries to be created from existing line work.

If the entire four-square-mile block is delineated and one or more of the strata are not adequately represented, 12 additional sections in a one-mile frame will be added. A single section within the one-mile frame will be randomly selected and canvassed for the underrepresented strata. If that section fails to provide enough of the underrepresented strata to meet 5% threshold, the adjacent counter-clockwise section will be added and canvassed for the underrepresented strata. This will continue in a counter-clockwise direction until all strata are sufficiently represented or all twelve additional sections have been canvassed.

As with delineation within the four-square-mile block, it is acceptable to complete polygons by crossing back into the four mile square block for the small areas not previously delineated. It is also acceptable to delineate beyond the one-mile-wide frame, but only if the delineation is not into another four-square-mile block that is likely to become another sample site (i.e., one near the top of the random list).

In the event that sufficient acreage of each of the critical strata cannot be found within or near the four-square-mile block and its one-mile-wide frame, the results will be presented to UPSAG for consultation. A cluster may be rejected if less than 5% (of the four-square-mile block) of one of the critical strata cannot be found within the 16-square-mile cluster. Critical strata are A, C and E as listed in Section 2.2.

9.8 Step 8 - Stratify Road Types

Who: The data-collection contractor/PI with assistance from landowners and oversight from Staff

Results: A GIS road layer with attributed strata types and appropriate maps to facilitate field work

Delineate the five road strata through direct field observation while utilizing FPARs, RMAPs, and local landowner and regulator knowledge. An overview of this process is provided in Section 3.1; implementation details are provided below. Stratification training will be provided by an UPSAG member.

9.8.1 Definition of Strata Types

A. **Substandard**: Active roads not meeting FFR forest practices standards.

Active roads are those defined by the Forest Practices Rules as having been used for a forest practice at anytime since 1974. Active roads not meeting FFR forest practices standards will include drivable and non-drivable roads that display symptoms of long-term neglect including clearly inadequate drainage (e.g., few or no cross-drain culverts or waterbars) and old culverts that obviously require maintenance (e.g., blocked inlets, rusted bottoms, head-cutting through the fill from the outlet end). Often, such roads will show little evidence of topping rock (although it may be present, buried in fine sediment or organic debris), and often they will be in need of grading and/or brushing if drivable at all.

Defining Characteristics: Non-functioning culverts, few ditch relief structures, poor or no topping rock.

B. **Orphaned**: Unused for forest practices since 1974.

Orphaned roads are those defined by the Forest Practices Rules as not having been used for a forest practice at anytime since 1974. Landowners have no legal liability for these roads until such a time as they are again used for a forest practice, and no maintenance has been done since at least 1974. Usually, these roads have been un-drivable for an extended period of time as evidenced by large trees growing alongside the road and even on the road tread. Occasionally, segments of orphaned roads remain in a drivable condition because of public use. It is often difficult or impossible to absolutely validate that a road is orphaned. One imperfect but justifiable method is to use stand inventory data to show that planting was done prior to 1974 and then to assume no further forest practice use. Roads that access rock sources cannot be assumed to be orphaned because of the planting data.

Defining Characteristic: Not used since 1974.

C. **Standard**: Active roads that meet FFR forest practices standards.

Active roads that meet FFR forest practices standards are those that display evidence of long-term general maintenance (e.g., grading, topping rock, ditching) or at least evidence of modern culvert and cross-drain installations (i.e., newer pipes in good condition, adequate cross-drains to limit ditch water delivery to streams). Often, surface erosion BMPs are in evidence (e.g., silt traps, ditchouts, waterbars). In areas of rapid brush growth, un-drivable roads may otherwise fit this category, particularly with respect to the evidence of modern culvert and cross-drain installations, and will be classified in this stratum.

Defining Characteristics: Functioning culverts, adequate ditch relief structures, topping rock and shaped tread.

D. **Mitigated**: Active roads with completed instability hazard reduction efforts (drainage and/or unstable material removal).

Active roads with completed instability hazard reduction efforts display evidence that construction was originally done in a careful fashion to prevent the occurrence of landslides or that subsequent maintenance activities were done to reduce the landslide potential of the road. Evidence of care during original construction includes the avoidance of placing fill and excess ditch water into unstable landforms, or if excess ditch water was placed in an unstable landform then it was flumed down the hill to a safer location (common practice in bedrock hollows and where roads parallel inner gorges). Evidence of subsequent maintenance activities designed to reduce landslide potential includes sidecast pullback where the road is within or uphill of an unstable slope, careful rerouting of ditch water to avoid its placement within unstable landforms, and the installation of new, over-sized stream-crossing pipes. Usually, the construction or maintenance has occurred since 1992, which is approximately the advent of watershed analysis when landowners began actively working to prevent landslides.

Defining Characteristics: Pullback accomplished or no sidecast placed within unstable landforms, careful water placement, over-sized culverts.

E. **Abandoned**: (DNR-approved or equivalent).

The phrase "abandoned roads" has a very specific definition and carries legal implications within the Forest Practices Rules. It means that a segment of road has experienced a set of maintenance activities designed to best limit any future impacts from this segment, and that the DNR has agreed that these efforts are sufficient and issued a letter stating so, after which the landowner is no longer liable for any unforeseen impacts. In steep ground with landslide potential, these efforts usually include removing all pipes, adding waterbars in addition to those created by the pipe removals, and extensive sidecast pullback which may have been endhauled offsite but is often placed on the cutslope and inside tread. Sometimes, a landowner does this type of work knowing that the road will be needed for the next rotation; usually, a letter indicating abandonment is not sought. Also, in this situation, good pipes may remain in place, with waterbars dug either immediately above them or immediately downhill to preclude impacts if the pipe should plug before re-entry. Both types of "abandoned roads" as described here shall be stratified into this category because we are testing the efficacy of the maintenance regardless of actual legal standing.

Defining Characteristics: Pipes pulled or water-barred, additional non-drivable waterbars, extensive pullback.

9.8.2 An Explanation of the Realities of Road Maintenance

Forest roads can be thought of as a dendritic network of spurs from individual harvest units that route to secondary roads which access several harvest units or a few sections of land. The secondary roads may route directly to public roads, or they may route to logging mainlines. Mainline roads access sufficient timberland that log haul occurs most months as many years pass. Some harvest units lie adjacent to a larger road, and may not require any spur roads.

In general, mainline roads are well maintained and probably meet FFR Forest Practices standards. Recently-used secondary roads should meet FFR Forest Practices standards, but some may be awaiting RMAP work such as cross-drain installations. The conditions of spurs will vary widely, from new construction that clearly meets FFR standards to orphaned roads in older timber.

There are certain practical constraints on road construction and maintenance.

Firstly, all spurs into and ending in a timber stand of uniform age will stratify into the same category. An occasional exception is a set of reconstructed spurs and one or more spurs that may have been logged but were not rebuilt or used as a road during harvest and, thus, remain orphaned.

Secondly, there will never be orphaned road segments in the middle of a route from secondary to spur – from where an orphaned road begins, all roads beyond this point on the dendritic route must also be orphaned. However, this does not apply when old railroad grade has been rebuilt from both ends and routes out both directions, with an orphaned piece remaining in the middle.

Thirdly, landowners cannot casually neglect road beyond a piece that has been abandoned, so any segment of road isolated beyond an abandonment project must also be considered abandoned.

Finally, generally a FFR–standard maintenance or landslide reduction-focused maintenance will have been done along significant lengths of a road. Maintenance up to FFR standards is often done on several miles of a mainline road or an entire secondary road all at the same time. Maintenance to reduce landslide potential is often done on a secondary road and all of its spurs where they cross steep ground.

Application of these guidelines will be further facilitated by understanding that almost any segment of road will exhibit symptoms of somewhat less than perfect maintenance. (In simple terms, cost-effective maintenance is done periodically to significant lengths of road, and then small events such as cutslope collapse or pothole development are not immediately addressed. Equipment mobilization costs preclude fixing small events until they are numerous and it is appropriate to again perform periodic maintenance.) Immediately after a large storm, it is likely that many little events have occurred, and even well-maintained roads will have these small symptoms.

A general understanding of the scale of little imperfections is important in making final decisions about road strata. The difference between active roads that do and do not meet FFR standards will be the most difficult distinction. The following bullets enumerate some of the common small events that should not preclude a road segment from being stratified into the “active roads that meet FFR Forest Practices Standards” category.

a. Cutslope ravel and cutslope collapse may block short stretches of the ditchline; otherwise the ditch would be performing adequately.

b. Small, shallow potholes may have developed on the running surfaces of the road tread, despite evidence of recent grading.

c. Haul may have created shallow ruts on the running surfaces of the road tread, despite evidence of recent grading.

d. A few of the total stream-crossing culverts may be partially plugged, probably in response to the storm.

e. A few of the total flumes may have become detached from their culverts or cross-drains.

f. There may not be a proper ditchline, but the road is purposefully insloped or outsloped in such a manner as to not need ditch maintenance.

All of the guidance above provides one basic message to the individual stratifying road types: Lump significant lengths of road into a single stratum. It is our intention that entire roads and sometimes road systems be lumped into a single stratum. DO NOT split roads into small segments (e.g., short segments of pullback will not be stratified separately, but the whole road stratified as focused landslide work). **Remember when stratifying that individual landslides will be assessed for individual triggers. If a maintenance standard was imperfectly applied, that circumstance will be revealed in the details.**

9.8.3 **Attribute Road Segments**

All segments of road will be attributed by strata using a combination of remote and field efforts. Final field verification will be done by the field analyst. Delineation can be improved by stand age and harvest information and by maintenance records (if landowners can be persuaded to provide these data), by the evaluation of forest practices applications (e.g., FPARs on the DNR website) and RMAPs, and by conversation with landowner representatives, local stakeholders, and local DNR forest practices personnel. All of these tools will be utilized so that few corrections occur as field work proceeds.

Delineate spurs or spur systems and entire secondary roads as appropriate using the guidance provided above in Sections 9.6.1 and 9.6.2. Road segments may be extended beyond the four-square-mile block to accomplish this requirement, but will not be extended beyond the one mile-wide frame around the four-square-mile block – stop at the nearest road intersection or if none are close to the edge of one mile-wide frame then stop at the edge of the frame. When completed, all roads on FFR lands within the four-square-mile block will be stratified.

If the entire four-square-mile block is delineated and one or more of the strata are not adequately represented (5% of road length within the four-square-mile block), then continue delineation of the underrepresented strata into the one mile-wide frame, always starting from the randomly selected section and proceeding around the one mile-wide frame in a counter-clockwise direction. Stop when all strata are adequately represented.

If one or more of the critical strata (Strata A, C and D as listed in Section 1.5) are not adequately represented within the four-square-mile block or its one mile-wide frame (mostly likely to occur for the focused landslide reduction stratum), it is then acceptable to locate additional segments of these strata in nearby areas (provided that those areas have similar topography and underlying geology). If it is easy to do so, adding segments to the two non-critical strata in this manner would also be appropriate. This protocol represents non-random selection of road strata, but landscape variability of some of these road strata may cause non-random selection to be the only practicable method of finding sufficient length of each stratum.

Delineated road segments must be attributed by strata to a GIS road layer. If roads are found during field work that are not on the original GIS road layer, these must be digitized into that layer and attributed as a stratum. In order to be able to randomly select segments of road strata, it would be advantageous to either: 1) create a dynamically segmented GIS road layer or 2) connect all GIS-segmented roads to breaks defined by intersections.

9.9 Step 9 - Obtain Landowner Permissions

Who: Staff

Results: Landowner permissions in the form of access permits or equivalent legal documents

For each cluster, obtain permission from landowners to enter property and collect those ield data required by this study.

9.9.1 Advance Preparation

Advance preparation will help in making landowner permissions for the study as efficient as possible. The experience with the RSBM Project can inform this preparation.

Immediately after the study area is delineated:

Obtain large landowner permissions and permits;

Use existing permits for the RSBM Project which were written so that they are valid for all CMER projects when possible (the project manager will still need to obtain permission for this specific project, but paperwork and time can be reduced):

If a new permit is required, use the CMER Model Access Permit which has already been negotiated between large landowners and CMER and is appropriate for the kind of research work CMER does - requirements in this permit are consistent with DNR-CMER contract requirements;

Write a one-page project description (adapt from CMER web site);

Write a one-page landowner letter (adapt from RSMB Project).

When the study sites have been identified:

Determine parcels and landowners within selected blocks (CMER staff have parcel and landowner data for most counties). Verify current landowners with counties. Most counties now have online GIS information on parcels and sometimes landowners.

1. Send out landowner letters noting parcel ID, legal, and property description, along with project description.
2. Locate telephone numbers for landowners where possible.
3. Follow up with phone calls to obtain access permission and instructions.
4. Contact landowners again to inform them when crews will be accessing their land.
5. Send a thank you letter informing landowners when data collection is completed on their property.

9.9.2 Expected Difficulties

Obtaining landowner permission has proven to be a long and complicated process for the RSBM Project. Although this project will certainly face many of the same difficulties including determining ownership, establishing rapport and clearly communicating about the nature of the study, and follow through with the landowners, it will be somewhat simpler and more efficient than that of the RSBM Project for two reasons. Firstly, in many areas of Washington State, the higher, steeper FFR land is owned by large landowners such that many fewer permissions may be necessary. Secondly, ownership data has been collected from many counties in Washington State and is now available for future CMER studies.

9.10 Step 10 - Landslide Identification and Data Collection

Who: The data-collection contractor/PI

Results: All field data for identified landslides collected and entered into tabular and spatial databases

> Landslides will be identified and added to the inventory throughout the three basic steps of landslide identification. When it is field-determined that landslides are not “fresh” then they will be removed from the inventory. Only “fresh” landslides will receive data collection. “Fresh” landslides are defined as those that occurred in the very recent past, probably from the storm event that has triggered the implementation of this study but perhaps from a storm that occurred earlier in that winter season or even the winter season before and perhaps from a storm that occurred shortly afterwards. If vegetation is beginning to establish on the landslide, then it must be considered older than “fresh” and removed from the inventory.

Steps necessary to identify landslides:

Step 1: Conduct a landslide inventory from the newly acquired aerial photography. Map landslides and collect basic tabular data in accordance with the LHZ Protocol (http://dnr.wa.gov/forestpractices/lhzproject/phz_protocol_v2_1_final.pdf).

Step 2: Add to this inventory all landslides not already identified during Step 1 that are observed while driving or walking the roads. “Add to this inventory” means mapping and collecting basic tabular data as the LHZ Protocol requires. This step includes identifying landslides that did not initiate from the road prism; it it is observed from the road, it must be added to the inventory. (Note: Data collection along drivable roads may occur before aerial photography is acquired (see Section 4.2); the designation of Steps 1-3 assumes a temporal sequence of implementation that is not required and may not be appropriate.)

Step 3: Add to this inventory all landslides not already identified during Steps 1 and 2 that are observed while walking all of the streams in the sample area. This step includes identifying landslides that did not deliver to a stream; if it is observed from the stream, then it must be added to the inventory.

The authors of this study design recognize that the landslide inventory will not identify a population of small landslides that initiated within reprod or timber and did not deliver to a stream. This will not bias the final statistical results of the study as statistical evaluation of the macro hypotheses will include only landslides that delivered to the channel network. Data collection on landslides that did not deliver to the channel network will be done opportunistically (i.e., the landslide was observed, so it will be added to the inventory) to increase general knowledge about landslide triggers.

While walking or driving all of the roads and adding to the LHZ Protocol landslide inventory (Step 2), field data as described in Section 10 Appendix – Field Forms shall be collected for each landslide identified in Steps 1 and 2. Finally, while walking all of the streams and adding to the LHZ Protocol landslide inventory (Step 3), field data shall be collected for each landslide identified in Step 3. (Landslides identified during Steps 1 and 2 that initiate closer to a stream than to a road can undergo field data collection during Step 3 to maximize the efficiency of field work.)

9.11 Step 11 - Collect Road Indices on Subset of Road Strata

Who: The data-collection contractor/PI

Results: All field data for road indices collected and entered into tabular and spatial databases

> For each cluster, randomly order road segments by strata. Select the first 10% of the total length of each road strata to be the subset for which the road indices are collected. If 10% exceeds 1 mile, stop data collection at the end of the first mile. For data collection related to a drainage structure, collect data for all structures within the designated road length – if, for example, some of the road length draining to a structure actually lies in another stratum, count that full length of drainage as belonging to that structure anyway. In the case of lengths of sidecast pullback and lengths of potential high hazard, collect only the length within the stratum (i.e., if the pullback extends into the next stratum, do not count that length within this stratum.)
>
> Each drainage structure (i.e., all of ditchouts, waterbars, culverts, cross-drains, bridges, and rolling dips) will be identified. The data collected at each structure will be used to provide, by strata, the results described below. Actual data to be collected is detailed in the Appendix – Field Forms.

Index 1: The average of pipe diameter divided by bankfull width. It is our expectation that the mitigated road stratum will have a value greater than 1 because of over-sized pipes, that the standard road stratum will have a value of approximately 1, and that substandard and orphaned road strata will have values less than 1 because of under-sized pipes. The abandoned road stratum will not produce a value because pipes will not be present.

Index 2: The average of the total number of structures divided by the number of stream crossings. This value will be greater than 1 for all road strata, but is likely to be significantly higher for the mitigated, standard and abandoned road strata where cross-drains or abundant waterbars are the norm. This value might not be much greater than one for the substandard and orphaned road strata where most structures accommodate a stream crossing.

Index 3: The average of the length of road and/or ditch draining to each structure. This value will be much smaller for mitigated, standard and abandoned road strata, but will also be sensitive to channel density and may help explain unusual results of Index 2 (i.e., areas of very high channel density may have a low value for Index 2 but also a low value for Index 3, supporting a positive interpretation). Also, average road gradient for each drainage length will be collected as this datum may help us improve BMP recommendations.

Index 4: The total length of sidecast pullback divided by the length of road crossing potentially high hazard landforms. This value will be significant for the mitigated and abandoned road strata, may have a small value for the standard road stratum because of limited sidecast pullback as stream crossing fills were replaced, and will be zero of the substandard and orphaned road strata. It is the coauthors' intention that the length of road crossing potentially high hazard landforms be determined remotely by some simple means such as visual interpretation from the SLPSTAB layer.

9.12 Step 12 - Statistical Analysis

Who: PI

Results: Statistical analyses as described in Section 3.3 to evaluate the macro hypotheses and appropriate covariates and such analysis and presentation as is appropriate to describe the micro hypotheses (see Appendix – Linkages)

9.13 Step 13 - Reporting

Who: PI

Results: Quarterly written reports to Project Manager on status, cost, implementation issues, and statistic findings as those data become available; an interim presentation to UPSAG after data has been collected for 6 clusters and preliminary analyses have been performed (part of QA/QC because of a the need to finalize the sample size); final summary report presenting results of statistical analyses delivered to Project Manager and UPSAG for review and approval (final report may require up to 3 electronic drafts before finalization and will be of very professional quality which may require a technical editor subcontractor); final reporting includes submission of all data, maps, field notes, and all final analyses and processes

10 APPENDIX – FIELD FORMS

Presented in this appendix are lists of data to be field collected at individual landslides and the data to be field collected for road indices. Data in the Primary Table will be collected at each landslide, and then data for one of Hillslope (Non-Road) Table, Midslope Road Table, or Stream Crossing Road Table will be collected as appropriate. Road indices data will be collected along the entire road network of selected sample areas; these data are listed in the Road Indices Table. Also presented are preliminary descriptions of what exactly is to be measured or estimated, and brief explanations of how the data will be used.

With the assistance of Oregon Department of Forestry (ODF) personnel who participated in the evaluation of the 1996 storm (Robison et al., 1999), UPSAG and the contractor hired to implement this study design will finalize the exact list of data to be collected, develop field forms or handheld programs, write a field protocol manual, and design an appropriate database. This work will be completed before the start of field data collection, but may occur simultaneous to efforts described in Sections 9.1 to 9.7. Actual field experience will likely lead to subsequent changes to the field data collection methods; these must be approved by UPSAG.

Primary Table

Field Measurements

GPS Location

Azimuth _____ of 360^o

Gradient at failure site (%)

Slope Form– Horizontal (Choose one)
Divergent
Convergent
Straight

Slope Form – Vertical (Choose one)
Convex
Concave
Planar

Rule-Identified Landform? (Choose one)
Bedrock Hollow
Inner Gorge
Toe of Deep-Seated Landslide
Meanderbend Curve
Null)

Mapped / Observed Geology Choose one)
Glacial
Sedimentary
Metapmorphic
Igneous

Exact Stand Age

Understory Plant Characteristics

Landslide Information

Initial process

Evolved process (if different)

Height
Width
Depth
Estimated Volume

Delivery to Typed Waters? (Y/N)

Damage Category (Choose one; see description)

Very low
Low
Moderate
High

Event Location (Check one; see appropriate sheet)

Hillslope (Non-Road)
Road Mid-Slope
Road Stream Crossing

Primary Table Instructions

GPS Location

Record the GPS location of each landslide.

Azimuth ______ of 360°

Using a compass, measure aspect of the hillslope at the site of the landslide initiation by standing facing the hillslope and approximating the perpendicular from the trend of the hillslope.

This measurement will be evaluated to see if aspect exerts control on landslide rates or sizes at either the landscape scale or the local scale (i.e., structural controls).

Gradient at Failure Site (%)

Using a clinometer, measure the hillslope (or fillslope if the failure initiated from a road) **adjacent** to the landslide initiation. The length of the measurement will be at least 20 feet.

As in previous studies, this measurement will be evaluated to see how gradient influences landslide rates or sizes.

Slope Form – Horizontal

From the perspective of the horizontal plane, is the hillslope curved outward (divergent), curved inward (convergent), or not curved (straight)? Refer to the Landslide Hazard Zonation Protocol for descriptions of slope form.

Slope Form – Vertical

From the perspective of the vertical plane, is the hillslope curved outward (convex), curved inward (concave), or not curved (planar). Refer to the Landslide Hazard Zonation Protocol for descriptions of slope form.

Slope form data will be evaluated to see how slope form influences landslide rates, sizes or delivery.

Landform

If the landslide initiated within a rule-identified landform as described in Chapter 16 of the Board Manual, then circle the landform type. Otherwise, circle the “null” choice.

This datum will be evaluated to compare rates of landsliding in different landforms and may help validate the rule-identified landforms.

Mapped / Observed Geology

Compare local geology as observed in the landslide scar or nearby roadcut with geology map. Confirm identification or reclassify into one of the broad categories provided.

(**Glacial –** till, lacustrine, glacial outwash; **Sedimentary –** sandstone, siltstone, conglomerate; **Metamorphic –** slate, phyllite, schist, gneiss; **Igneous –** basalt (fine-grained extrusive), granitics (coarse-grained intrusive), pyroclastics)

Data will be used to compare landslide rates between different geologic units, and if significant differences are found, these data may be used as covariates when comparing differences among strata. Field verification of the geologic unit at the site of the landslide is important because most geologic mapping is done at scales of 1:24,000 to 1:100,000.

Exact Stand Age

Determine the planting age of trees for the harvest statum which the landslide lies within or is adjacent to. If the landslide initiated within a buffer of older timber, the age of that older timber is collected elsewhere; this value is the planting age of the associated harvest unit, and it may be younger than the age of trees right at the landslide initiation. Stand ages may be provided by the landowners or by conducting select increment borings; for firs, the nodes can be counted.

Data will be used to validate strata delineation and may be used to refine our evaluation of the strata comparisons.

Understory Plant Characteristics

Evaluate the hillslope adjacent to the landslide initiation site to determine if wet-site plant species such as horsetail, slough sedge, water parsley, skunk cabbage, bull rush or devil's club are present. Are there any present? (Yes/No)

This datum provides basic information about annual soil moisture, which will be evaluated for its potential relationship to landslide rates.

Initial Process

Determine the initial type of failure, right at the initiation site. Refer to the Landslide Hazard Zonation Protocol for descriptions of the failure types.

Evolved Process

If different than the initial failure process, identify the evolved type as the landslide continued downhill. It is common that a debris slide or even a rock slide can evolve into a debris flow if it reaches confined topography. Refer to the Landslide Hazard Zonation Protocol for descriptions of the failure types.

These data are standard information to collect for landslides. It adds to the larger pool of landslide data collected around the world, and will be used in this study to broadly characterize the landslide population.

Landslide Height

Measure or estimate the hillslope length of the initial failure mass.

Landslide Width

Measure or estimate the horizontal width of the initial failure mass.

Landslide Depth

Measure or estimate average depth of the failure site approximately perpendicular to the hillslope length measurement.

These measurements will allow us to crudely calculate initial failure volumes as length X width X depth. While careful measurements will be collected where possible, personal safety must always come first and eyeball estimates will be accepted. For certain oddly shaped landslides, such as a road stream-crossing fill, there are better ways to estimate volume, and other methods are encouraged where appropriate.

Estimated Volume

This value is length X width X depth except where another estimation method is used. If another method is used, provide an explanation of the method. (Likely other methods are volume estimates of small triangular-shaped debris slides or trapezoid-shaped stream-crossing fills.)

Strata will be evaluated by both landslide density (the total number of landslide initiations) and by landslide volumes. While the former conveys information about landslide response, the latter more directly addresses whether FFR is effective at reducing impacts to fish and water quality.

Delivery to Typed Water

This simple yes or no question will be answered yes whenever any quantity of the landslide routed into a stream channel, and answered no only when no delivery to channelized water occurred. (Please note that intermittent streams that do not connect to the extended channel network are NOT defined as typed water, and answer no where an intermittent stream does not connect.)

Landslides without delivery will not be included in the final evaluation of the strata, but may provide useful information to the qualitative assessment of prescriptions.

Sediment Delivery Categories:

Very Low – either no delivery occurred, or estimated delivery was less than 10 cubic yards (1 dump truck).

Low – delivery was greater than 10 cubic yards and less than 200 cubic yards and the landslide stopped in Type Np water or in the very upper end of potential Type F water.

Moderate **–** landslide flowed through more than 200’ of Type F water or delivered more than 200 cubic yards to the channel network.

High – landslide delivery exceeds 10,000 cubic yards or triggers a dam break flood through Type F water.

Event Location

Pick one of the three basic locations: Road Midslope, Road Stream-Crossing, and Hillslope (Non-Road). Choose the Road Stream-Crossing Form when the failure site occurred within the prism of a stream-crossing fill, even if only the outer edge of the fill failed. Choose the Road Midslope Form when the failure site included some portion of a road prism and was not contained within a stream-crossing fill (some fillslope failures may include but extend well beyond a shallow stream crossing – these will be evaluated on the Road Midslope Form.) Choose the Hillslope (Non-Road) Form when no portion of the initial failure site was within a road prism (if drainage from a road caused a hillslope failure, this will be identified on the Hillslope (Non-Road) Form.) Proceed to the appropriate form to continue data collection.

Recording this datum guides field personnel to the next appropriate form, and will assist in the categorization of data between the two basic groups of strata and between the micro hypotheses of each.

Hillslope (Non-Road) Table

Tree Composition
Primary
Secondary

Size (est. QDBH)

Density (Choose one)
None
Sparse
> 75 trees/acre
>150 trees/acre

Exact Stand Age at Landslide Initiation

Buffered? (Y/N/NA)

If "Yes" or "NA", estimate blowdown (Choose one)
<10%
10-25%
26-50%
51-75%
76-100%

If "Yes" or "NA", did LWD deliver? (Y/N)
If "No", make detailed landform comment:

Potential Triggers (Choose all that apply)
Yarding Corridor (Y/N)
Silvicultural Treatment (Choose one)
PCT
CT
Pruning
Spraying
Mech. Brushing
Concentration of water from upslope road (Y/N)
Yarding scar water concentration (Y/N)
No obvious triggers (Y/N)
Comments

Hillslope (Non-Road) Table Instructions

Tree Composition:

Identify the primary and secondary species in the stand adjacent to the failure. If the failure occurred on the edge of two different type stands, look upslope and downslope to try to judge in which stand the failure occurred. Failure debris can also be used to identify the stand in question.

Average Tree Size:

If the stand which the failure occurred in is uniform, provide an average diameter at breast height (DBH) for the primary species.

Density:

In the stand where the failure occurred, identify the density as no trees, sparse (less than 75 trees/acre), greater than 75 trees/acre or greater than 150 trees per acre.

Exact Stand Age at Landslide Initiation:

From landowner records, increment borings, or other estimation methods, note the stand age at the site of the landslide initiation. If the landslide initiated within a buffer, then this age is older than the stand age collected in the Primary Table.

Tree species, size, density and age may be useful for determining root reinforcement around the failure site.

Buffered:

Select "Yes" if the failure initiated in a buffer and "No" if the failure initiated in the unit.

This datum is needed in conjunction with landform identification to answer several of the harvest micro hypotheses.

Blowdown:

If the failure occurred in a stand that is 40+ years or in a buffer, estimate the percentage of blowdown in the immediately adjacent stand. Assign blowdown categories of < 10%, 10-25%, 26-50%, 51-75%, 76-100%.

It is useful to know whether blowdown may have reduced rooting strength prior to failure.

LWD Delivery:

If the failure occurred in a stand that is 40+ years old or in a buffer, indicate whether or not any LWD was delivered to the stream network (yes/no).

The delivery of wood (in addition to sediment) helps clarify the total aquatic effect of the landslide, and validates buffer effectiveness.

Landform:

If the failure occurred within a harvest unit (stand <41 years old and no buffer), make a detailed landform comment (e.g., micro bedrock hollow with no delivery mechanism).

Noting the associated landform will allow determination of the proportion of landslides occurring in rule-identified or other landforms.

<u>Potential Triggers</u>

Yarding Corridor:

Indicate if the failure occurred in a yarding corridor (yes/no).

Silvicultural Treatment:

Select the following category which best describes the most recent silvicultural treatment: pre-commercial thin, commercial thin, pruning, spraying, mechanical brushing. If these categories are not obvious on the ground, the Project Manager will make this determination from the most recent Forest Practice Application associated with the unit.

Water Diversion From an Upslope Road:

Indicate whether or not there was a concentration of water from the upslope road to the failure site (yes/no).

Yarding Scar:

Indicate whether or not there was a yarding scar water concentration at the failure site.

No Obvious Trigger:

Indicate whether or not there is an obvious trigger (yes/no).

Information on the landslide triggers listed above will help determine why failure occurred, a major goal of the project.

Comments:

Provide comments on the site. If a trigger was identified that isn't highlighted by the categories above, identify and describe.

Midslope Road Table

Failure Location (Choose one)
Cutslope
Fillslope

Natural Ground Gradient (%)

Road Geometry (Choose one)
Crowned
Insloped
Outsloped

Tread Condition (Choose one)
Adequately graded
Potholes
Rutted

Ditch Condition (Choose all that apply)
Continuous and flowing
Continuous Adequate and ponded
Discontinuous
Silt traps in ditchline
NA (Outsloped)
Comment (as needed)

Sidecast Volume (Choose one)
None
Very Low
Low
Moderate
High

Drainage (Choose all that apply)
Cross-drain to failure site
Ditchout to failure site
Waterbar to failure site
Silt trap/pond/berm in fillslope
Pirated water from channel to site
Outsloped road water concentrated to failure site

Upslope road distance draining to site (ft)

Comments:

Midslope Road Table Instructions

Failure Location

Choose where the initial failure occurred: cutslope, fillslope or downslope of the road. Sometimes, this is difficult to determine because there may have been a secondary failure in response to the first one. The common example of this is a cutslope failure either causing a fillslope failure, or occurring after much of the road tread has failed. If it is obvious that two failures have occurred, collect data separately for each and note in the comments field that they are related. In all other cases, choose the highest point of the failure to determine the failure location.

Cutslope is the area excavated (generally a slope steeper than the natural gradient) during road construction uphill of the road bed. Fillslope is the material deposited to construct the road bed and supporting the roadbed downhill (generally a steeper slope than the natural gradient).

Location data will indicate the frequency of landslides in each of the categories and will help link to slide trigger.

Natural Ground Gradient

With a clinometer, measure the slope of the natural hillslope below the bottom of the fillslope.

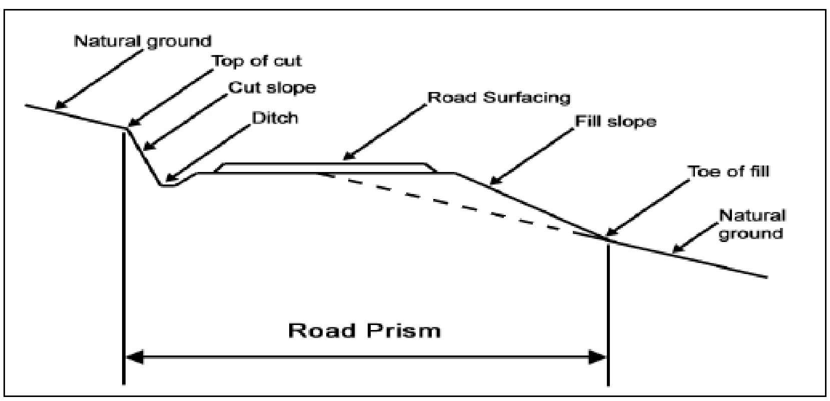


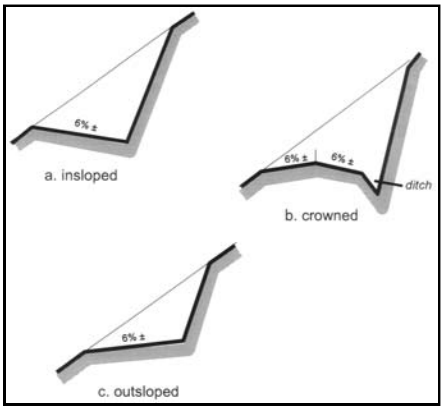
Figure 10-1. Road prism geometry.

Measuring Road Prism Characteristics (From Washington State Forest Practices Board Roads manual)

This measurement will be evaluated to see how natural gradient influences landslide rates and sizes on midslope roads.

Road Geometry

Select whether the road bed is crowned, insloped towards the ditch or outsloped towards the fillslope.



This datum by strata will determine if road geometry and/or general maintenance practices influence landslide rates and sizes.

Figure 10-2. Road surfacing geometry.

Tread Condition

Select whether the condition of the tread is adequately graded, potholed, or rutted. Adequately graded roads have smooth surfaces and drain water from the tread surface to either the fillslope, the ditch, or both. Potholed roads that have depressions deeper than two inches and greater than two feet across which collect water during the wet season. Rutted roads have developed wheel ruts. “Rutted” often means that the wheel ruts are deeper than two inches, but the directing of water down the road instead of off the road treads will be the big consideration in making this choice.

This datum links closely with Road Geometry, and when evaluated by strata will help provide information on which conditions of road are susceptible to landslides.

Ditch Condition

Choose one of the following to describe the condition of the ditch that drains into the slide location: continuous and flowing (adequate), continuous and ponded (adequate), discontinuous, or outsloped (no ditch). Provide comments if the ditch is not described in the categorized above.

This datum will help link ditch conditions to landslide location and size.

Sidecast Volume

Categorize the volume of sidecast material into the following groups: none, very low, low, moderate, or high. Evaluate the category of material from the graphics below:

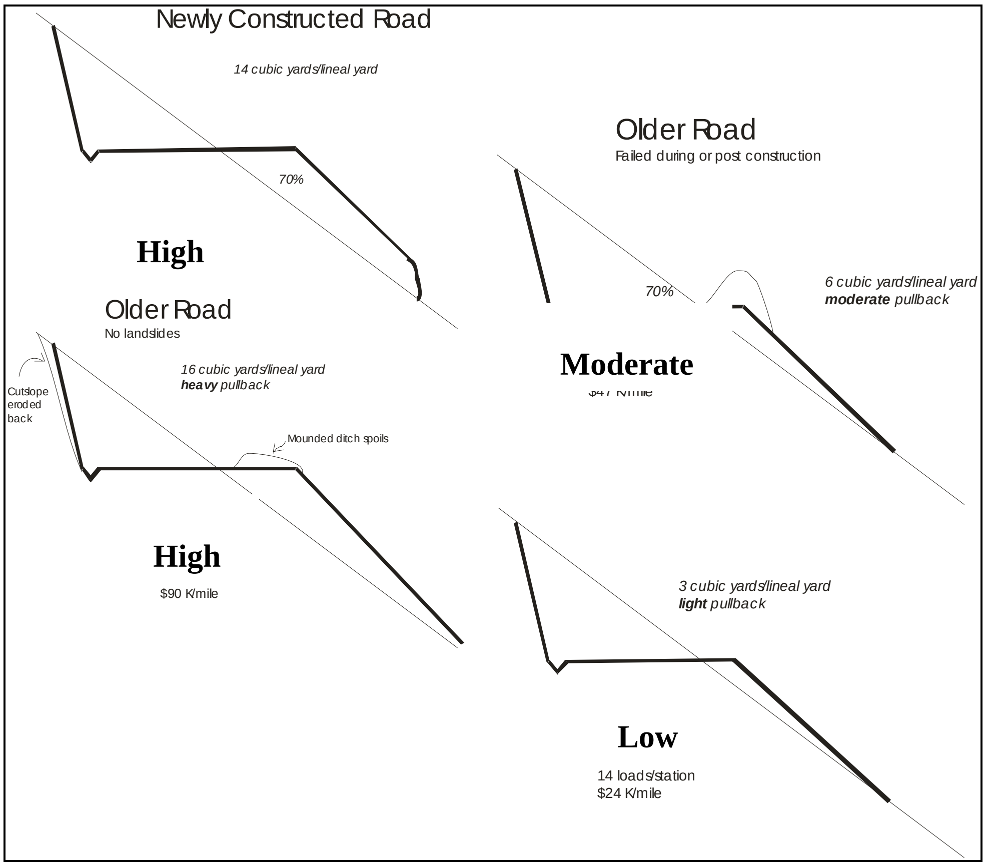


Figure 10-3. Sidecast volumes

This datum, coupled with Hillslope Shape, will help to evaluate how sidecast volume affects location and size of landslides from midslope roads.

Drainage

Evaluate the drainage and choose all descriptions that apply directly to the failure site: cross drain, ditchout, waterbar, silt trap/pond/berm in fillslope, pirated water from channel to site, outsloped road water concentrated to site.

Estimate upslope road distance draining to site.

Drainage data will help to evaluate which drainage features affect failure locations and size.

Comments:

Provide comments on the site. If a trigger was identified that isn't highlighted by the categories above, identify and describe.

Road - Stream Crossing Table

Upstream Bankfull width (ft):

Stream Gradient Downstream (%):

Pirated water to site? (Y/N)

Sediment Load (Choose one)

Low
Moderate
High

Pipe Gradient (%)
Pipe Material (Choose one)

Metal
Concrete
Plastic
Wood

Pipe Condition (Choose one)

New
Okay (may be rust-colored))
Rust - flaking
Hole(s)
Blocked

Pipe Size (based on information above; Choose one)

Generous
Adequate
Inadequate

Original fill design

… *Flume(Y/N/U)*
Compacted (Y/N/U)
Total fill depth at outlet (ft):

Failure Description (Choose one)

Overflowed and eroded (washout)
Debris flow initiation of fill prism
Ponded & fillslope collapsed
Fillslope collapsed without ponding

Comments:

Road – Stream Crossing Table Instructions

Upstream Bankfull Width (feet)

Measure or approximate the bankfull width of the stream upstream of the road. Do this at a point upstream that is clearly beyond the influence of the fill (e.g., many undersized or shallow pipes cause sediment accumulation for a short distance upstream – this area of sediment accumulation does not represent true bankfull width). A detailed explanation of bankfull width measurements is provided in the Forest Practices Board Manual, Section 2. Many people underestimate bankfull width when visually estimating it, so it is best to actually measure it either at all crossings or at least at some crossings.

These data will be compared with pipe diameters to determine if pipe size was generous, adequate or inadequate. This in turn will help establish triggering mechanisms at road stream crossings.

Stream Gradient Downstream (%)

Downstream of the lowest extent of the original fill prism, measure stream gradient. Stream gradient is difficult to measure accurately; it is usually best to stand exactly at the elevation of a water surface, hang a flag at eye level on an adjacent twig, walk at least 30 feet up or downstream from this flag and align the clinometer on the flag to take an accurate measurement. If the stream is dry, it is appropriate to use bankfull elevation (approximated as the edge of vegetation in small streams) to make this measurement.

This datum will help establish empirically 1) the lowermost stream gradients where road stream crossings begin to fail as debris flows (as opposed to the occurrences of lost stream crossings that washed out by fluvial actions), and 2) the range of stream gradients where road stream crossings commonly fail by debris flow. These data may help us refine stream-crossing BMPs

Pirated Water to Site

Pirated water means that a stream is flowing down a significant length of ditchline (>20') before it reaches a road stream crossing. The pirated stream MUST originate from a channel with defined bed and banks above the cutslope. Cutslope seeps without a proper channel above the cutslope will not be considered pirated water. Pirated water may occur by deliberate engineering (i.e., the water was purposefully directed down a segment of ditchline to a lower road stream crossing to avoid installing an additional stream crossing structure) or by poor maintenance or accident (i.e., a road stream crossing structure has plugged or a cutslope collapse has redirected water).

The addition of pirated water to lower road stream crossings is a common trigger that this study will quantify with respect to other triggers.

Sediment Load

Estimate sediment load, which may include the fluvial transport of woody debris, by looking for the following characteristics upstream of the zone of influence of the road stream crossing.

A stream with a **low sediment load** is usually narrow and deep. Gravel bars or accumulations are rare. Some streams with low sediment load are flowing on bedrock or a smooth surface of the local soil or glacial material. If gravel is present in the stream bottom, it is often somewhat cemented by fine sediment just below the surface and algae may be present.

A stream with a **moderate sediment load** will have modest accumulations of gravel such that the wetted thalweg during the summer months or during dry spells during the winter is covering approximately 30-70% of the area within bankfull width. Gravel deposits are uncemented, providing evidence that they are being transported downstream. The channel is single threaded for most of its length.

A stream with a **high sediment load** will have large gravel accumulations with respect to the wetted thalweg during dry spells. The channel will be multi-threaded along much of its length, and bankfull width will be difficult to estimate because of the variability along a channel segment.

These data may inform the adequacy of pipe sizing, and may improve future pipe sizing by making landowners and regulators aware of the influence of sediment load on the probability of failure.

Pipe Gradient (%)

Measure or estimate the gradient of the pipe lay if it is possible to determine. Following the stream gradient procedure by using either the bottom of the pipe or the top of the pipe for elevation and hanging a flag at eye level at one end to shoot on from the other end may be preferable. If the stream crossing structure is a bridge, the datum is null.

These data will help establish relationships between each of sediment load, pipe diameter, bankfull width, and stream gradient in understanding triggering mechanisms of road stream crossing landslides.

Pipe Material

Indicate if the stream crossing structure is formed of metal (steel alloy, galvanized steel, aluminum, aluminized, etc.), concrete (concrete slab bridge or concrete pipe), plastic, or wood (log stinger bridges, wooden box "culverts" built from logs, wood plank culverts). When assessing bridges, choose the predominant material.

This datum allows us to some opportunity to date the installation of the structure. Not sure how this will indicate age.

Pipe Condition

The five pipe conditions are listed in order of best to worst (New, Okay, Rusty, Holes, and Blocked). “New” means a recent installation, usually less than 2 years. “Okay” means older than new, functioning properly, and while rust discoloration may have occurred in the bottom of the pipe, flaking of large rust chips is not occurring. Some “Okay” pipes are 25-30 years of age. “Rusty” means that large rust chips are lifting off the bottom of the pipe. “Holes” means that there are holes eaten through the bottom of the pipe; if the pipe is very rusty and holes in the pipe bottom can be enlarged with a stick, then designate “holes”. “Blocked” means that the pipe inlet is partially or completed blocked in such a way as to restrict flow and/or pond water. Do not use “Rusty” to describe bridges, but the other 4 can be applied. “Holes” with respect to bridges means that holes have developed in the surface of the bridge. Any other pipe conditions that appear to have contributed to the problem will be noted in the comments.

As with Pipe Material, this datum allows us some opportunity to date the installation, and some ability to assess if a general lack of maintenance contributed to the failure of the crossing.

Pipe

First, measure the diameter of the pipe or the length of the bridge. Second, using this datum and each of Upstream Bankfull Width, Pirated Water to Site, Sediment Load, and Pipe Gradient, Material and Condition, decide if the pipe size was “Generous”, “Adequate” or “Inadequate.” Clearly, this latter is a value statement; empirical knowledge of the local area will assist in this determination which is critical to understanding different triggering mechanisms which can range from 1) pipe obviously too small, 2) pipe of adequate size but no maintenance in 20 years has lead to a blockage, and 3) pipe of adequate size and maintenance appropriate but the unpredicted happened such as tree recently fell over and blocked the pipe.

These data will used to better clarify triggering mechanisms and may contribute to better information about pipe sizing.

Original Fill Design

Was a flume present – Yes, No or Unknown. Is there evidence remaining at the landslide site to suggest that the pipe was flumed? Please circle “No” if there is no evidence and it is unlikely that the flume was transported and deposited (i.e., the initial landslide volume was too small to transport the flume). Please circle “Unknown” if the initial landslide volume was large enough to transport a flume and the deposit is large enough to have completely buried it.

Was the fill compacted – Yes, No or Unknown. This is difficult to assess, but if a fill is formed of hauled ballast (looks different than the immediately adjacent colluvium) and does not contain large woody pieces, then it can be characterized as a high quality fill that was probably compacted. If the fill is obviously local material, especially if that local material was inappropriate to use as fill (e.g., soil or glacial till), and if the fill contained large woody pieces, then it can be characterized as a low quality fill that was probably not compacted. In general, really old crossings on railroad grades were compacted because the weight of trains required structurally sound fills.

Total Fill Depth at Outlet (feet). Measure the vertical distance from the bottom of the original fill, which may be several feet below the pipe if the pipe was installed at a gradient less than that of the channel, to the top of the road. This can be done in steps with a clinometer and a staff marked at eye level, working up the slope in increments of your eye height. If measuring this datum is too dangerous, visually estimate it.

The presence of a flume or evidence of compaction, however indirect, provide information about the care with which a fill was built, and help us understand if modern BMPs are limiting landslide occurrences. Total fill depth may reveal a range of depths susceptible to debris flow initiation, and may be related to stream gradient in our efforts to improve our understanding of stream-crossing failures.

Failure Description:

There are four basic road stream crossing failure types. 1) **Overflowed and eroded** (washout) - The pipe has plugged, water was ponded and then overflowed the fill, and the fill was eroded by predominately fluvial processes. This situation, while a version of "mass wasting", is not really a landslide. Downstream impacts will be limited to new gravel accumulations. 2) **Debris flow initiation of fill prism** - The pipe plugged, water was ponded, and the entire fill prism catastrophically failed as a debris flow initiation. Downstream impacts, including areas well above bankfull will be freshly scoured. 3) **Ponded and outlet fill edge collapsed –** The pipe plugged, water was ponded, and the outlet or downstream edge of the fill collapsed, leaving some of the road prism intact. 4) **Outlet fill edge collapsed without ponding –** The outlet or downstream edge of the fill collapsed, leaving some of the road prism intact and there is no evidence that the pipe plugged and water was ponded.

This datum will be used in conjunction with stream gradient to establish empirically 1) the lowermost stream gradients where road stream crossings begin to fail as debris flows (as opposed to the occurrences of lost stream crossings that washed out by fluvial actions), and 2) the range of stream gradients where road stream crossings commonly fail by debris flow. We may also better understand conditions that lead to outlet fill edge failures which are common but not well understood.

Comments:

Provide comments on the site. If a trigger was identified that isn't highlighted by the categories above, identify and describe.

Road Indices Table

For Each Structure:

Road Stratum (Choose one)

Substandard
Orphaned
Standard
Mitigated
Abandoned

Stream Crossing? (Y/N)

Length of Road/Ditch Drainage (ft)

Average Road Gradient for Drainage Length (%)

For Each Stream-Crossing Structure:

Structure Diameter (in)

Bankfull Stream Width (in)

Structure Gradient (%)

Natural Stream Gradient (%)

For Each Road Segment:

Length of Sidecast Pullback or No Original Sidecast (ft)

Length of Potential High Hazard (ft)

Road Indices Table Instructions

Road Stratum:

As stratified by this project, choose the road stratum within which this structure lies.

Stream Crossing:

Answer yes if one of the following two statements is true: 1) There is a natural channel with bed and banks ABOVE the cutslope of the road; 2) There is a natural channel with bed and banks ABOVE the cutslope somewhere up the road and it is being pirated down the ditch to this pipe. Answer no if neither of these two statements is true, even if there is significant groundwater interception in the cutslope and a natural channel below the road.

Length of Road/Ditch Drainage:

Measure the length of road contributing water to this structure by string box or pacing (after pace has been calibrated and tested). This is usually the length of ditch flowing towards the structure, but in the case of strongly insloped or outsloped roads there may not be a ditchline. In the case of strongly outsloped roads, estimate the length of road that contributes to the OUTLET of the structure (this is often less than 50').

Average Road Gradient for Drainage Length (%):

Measure by clinometer an average gradient for the length of road draining to the structure. If drainage comes from two directions with different gradients, then approximately normalize two measurements. For example, if one direction is 300' of road at 6% and one direction is 100' of road at 12%, then the normalized gradient is 7.5%, and will be rounded up to 8%. Road gradient is hard to measure, especially along segments of low gradient road. Tying a ribbon at eye level to shoot on is a simple solution – tying a ribbon to the vehicle antennae at eye level will be very useful.

Structure Diameter:

If the structure is a pipe, measure the diameter with a tape measure. If the pipe is accidently skewed, such as an old pipe that is collapsing, measure the longest and shortest diameters and determine the original size. Old and modern pipe sizes include 6”, 8”, 12”, 15”, 18”, 24”, 30”, 36”, 42”, 48”, 54” and thereafter in full foot increments. If the structure is a waterbar with a stream flowing through it, measure the width of the bottom of the waterbar. If the structure is a bridge, measure or estimate the span length underneath the bridge as it is the opening available for high flow in which we are interested. REPORT ALL RESULTS IN INCHES, INCLUDING LARGE VALUES FOR BRIDGES.

Bankfull Stream Width:

Using methods described in the Forest Practices Board Manual, measure bankfull width of the stream either far enough upstream of the structure to avoid any influence from the structure or far enough downstream to be on natural ground below the original road fill.

Structure Gradient:

Measure the gradient of the structure if the structure is a pipe or a waterbar; it is not possible or useful to provide this answer for a bridge. If the structure inlet or outlet cannot be approached, or if it is not possible to see through the structure, then estimate the structure gradient by drawing a diagram of the fill prism.

Stream Gradient:

Measure with a clinometer the natural stream gradient above the influence of the structure inlet and below the road fill; if these values are different, then average them. As with road gradient, hanging a flag at eye level is useful, especially for small, meandering streams, for low-gradient streams and for brushy situations.

Length of Sidecast Pullback or No Original Sidecast:

By road segment as stratified, tally the lengths of road that have experienced sidecast pullback or where the material from the cutslope was not sidecast over the edge. Include new stream crossing fills where the outlet edge of the fill is smooth and <80%. Search carefully through brush and small alder trees, as the visual evidence of sidecast pullback can be obscured by dense vegetation. Some landowners may have maps and data that facilitate identifying these lengths, and FPARs may be helpful for new road construction and recent reconstruction of older roads, but field measurement must still occur.

Length of Potential High Hazard:

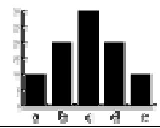
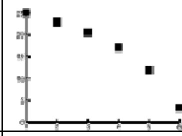
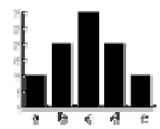
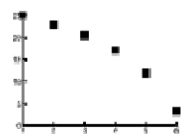
By road segment as stratified, tally the lengths of road that lie within or immediately upslope from potentially high hazard areas. The actual method by which this occurs will be developed by the contractor with UPSAG approval. Our vision is that visual interpretation of the red pixels on SLPSTAB maps, either on the desk or on the computer screen, could be used for this purpose.

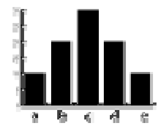
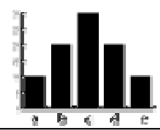
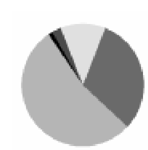
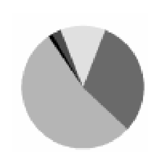
11 APPENDIX – LINKAGES

Linking Hypotheses to Data Collection

The table presented on the following pages illustrates the linkages between this study's macro and micro hypotheses and the data collected to evaluate these hypotheses. In the far right-hand column, pictographs or a few words serve to indicate how data might be displayed or evaluated. These linkages are not exhaustive or exclusive, but serve to illustrate how the study is structured, and how the data collected will inform the study results.

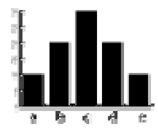
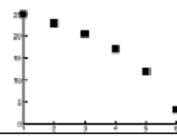
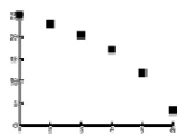
* Indicates General Presentation of Basic Scientific Data – not related to hypotheses

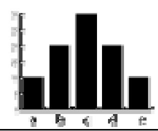
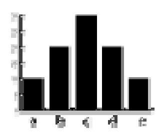
Primary Table		
Hypotheses	**Data**	**Presentation**
*	Azimuth	
*	Gradient	
* **H3:** Landslides occur in landforms that were not rule-identified (e.g., glacial terrace faces or weakly concave hillslopes). **R1:** Landslides will occur on planar slopes with no or insufficient pullback.	Slope Form – Horizontal and Vertical	  *# of H3 by form; # of road failures by form (by strata?)*

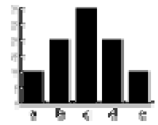
* **H1:** Landslides that originate in post-FFR-harvested unstable landforms do not deliver to protected resources. **H2:** Delivering landslides occur on rule-identified unstable slopes that were harvested.	Rule-Identified Landform	 *# of H1 by landform* *# of H2 by landform (links to Effectiveness of Landform Identification Project)*
*; May be used to calibrate landscape of hillslope and road strata	Observed Geology	
Macro – Hillslope	Stand Age Estimate	*Validates hillslope stratification*
*	Understory Plant Characteristics	*Maybe plot by landform – could be big differences between landforms and could provide relative instability information*
*; Macro – Road and Hillslope	Initial Process	 *Histogram by Strata*
*; Macro – Road and Hillslope	Evolved Process	 *Histogram by Strata*
*, Macro – Road and Hillslope	Landslide Length/Width/Depth/Volume	*Ranges* *Areas and/or Volume by Delivery* *Area and/or Volume by Strata*
Macro – Road and Hillslope **H1:** Landslides that originate in post-FFR-harvested	Delivery to Typed Water	*Widely used to separate delivery/non-delivery throughout the data evaluation*

unstable landforms do not deliver to protected resources. **H7:** Landslide delivery will be inversely proportional to buffer/riparian stand density. **H8:** Landslides that route through standing timber will deliver large woody debris.		
Macro – Road and Hillslope	Damage Categories/Channel Impacts	*Used to evaluate relative hazard between different populations of landslides (e.g., road versus hillslope)* *May show differences between strata or triggers that help prioritize BMPs*
Macro – Road and Hillslope **R1:** Landslides will occur on planar slopes with no or insufficient pullback. **R2:** Small stream-crossing pipes will be associated with landslides.	Event Location	*Initial division of data into 2 macros and specific road micros*

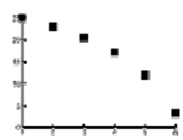
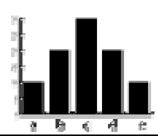
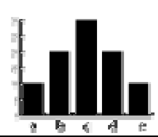
Hillslope Table

Hypotheses	**Data**	***Presentation***
H7: Landslide delivery will be inversely proportional to buffer/riparian stand density.	Tree Composition	 *May be used in conjunction with Understory Plant Characteristics*
H7: Landslide delivery will be inversely proportional to buffer/riparian stand density.	Average Tree Size	
H7: Landslide delivery will be inversely proportional to buffer/riparian stand density.	Density	

H1: Landslides that originate in post-FFR-harvested unstable landforms do not deliver to protected resources. **H2:** Delivering landslides occur on rule-identified unstable slopes that were harvested. **H3:** Landslides occur in landforms that were not rule-identified (e.g., glacial terrace faces or weakly concave hillslopes). **H5:** Landslides will occur in association with buffer blowdown.	Buffered	*Necessary screen for several micro-hypotheses*
H5: Landslides will occur in association with buffer blowdown.	Blowdown	
H8: Landslides that route through standing timber will deliver large woody debris.	LWD Delivery	 *# of Landslides by LWD Delivery w/ and w/out buffers*
H2: Delivering landslides occur on rule-identified unstable slopes that were harvested. **H3:** Landslides occur in landforms that were not rule-identified (e.g., glacial terrace faces or weakly concave hillslopes).	Describe Landform	*Descriptive information*
Macro – Hillslope	Silvicultural Treatment	*Identifies potential triggering mechanism and validates partial harvest hillslope stratum*

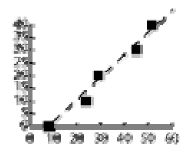
H6: Harvest upslope of unstable landforms will increase landsliding. **H9:** Focused water from upslope roads will be associated with hillslope landslides.	Concentration of Water	 *# of Landslides by Type of Water Concentration*
Macro – Hillslope **H10**: Landslides will occur along yarding corridors.	Yarding Corridor	*Identifies potential triggering mechanism and validates partial harvest hillslope stratum*
H4: Triggering mechanisms may not be identifiable for all landslides. **R5:** Landslides will occur when roads are inadvertently located on unstable slopes.	No Obvious Trigger	*Verifies two micro-hypotheses, and may be used in conjunction with Rule-Identified Landform and Describe Landform to identify the subset of truly natural landslides*

Mid-slope Road Table

Hypotheses	**Data**	**Presentation**
*	Failure Location	
* **R1:** Landslides will occur on planar slopes with no or insufficient pullback.	Natural Ground Gradient	 *Relations between %, fill volume and delivery will be evaluated*
R4: Poor tread maintenance or inappropriate road geometry will be associated with landslides.	Road Geometry	
R4: Poor tread maintenance or inappropriate road geometry will be associated with landslides.	Tread Condition	
R3: Inadequate water control measures will be associated with landslides.	Ditch Condition	*# of landslides related to inadequate ditch condition*

R1: Landslides will occur on planar slopes with no or insufficient pullback.	Sidecast Volume	*Relationships between %, fill volumes and delivery will be evaluated*
R1: Landslides will occur on planar slopes with no or insufficient pullback. **R2:** Small stream-crossing pipes will be associated with landslides. **R4:** Poor tread maintenance or inappropriate road geometry will be associated with landslides.	Drainage	 *Evaluated to determine #'s of landslides associated with different types of focused water*

Road-Stream Crossing Table

Hypotheses	**Data**	***Presentation***
R2: Small stream-crossing pipes will be associated with landslides.	Upstream Bankfull Width	*Used as part of the measurable data to assess triggering mechanisms*
	Stream Gradient Downstream	 *Also used to determine critical stream gradient where crossings blow out at debris flows – not a hypothesis*
R3: Inadequate water control measures will be associated with landslides.	Pirated Water to Site	*Used as part of the measurable data to assess triggering mechanisms*
R2: Small stream-crossing pipes will be associated with landslides. **R3:** Inadequate water control measures will be associated with landslides.	Sediment Load	*Used with other data to see predictive patterns which may enhance BMP implementation*
R2: Small stream-crossing pipes will be associated with landslides. **R3:** Inadequate water control measures will be associated with landslides.	Pipe Gradient	*Used as part of the measurable data to assess triggering mechanisms*
R2: Small stream-crossing pipes will be associated with landslides. **R3:** Inadequate water control measures will be associated with landslides.	Pipe Material	*Used as part of the measurable data to assess triggering mechanisms* *Tells us something about pipe age*

R2: Small stream-crossing pipes will be associated with landslides. **R3:** Inadequate water control measures will be associated with landslides.	Pipe Condition	*Used as part of the measurable data to assess triggering mechanisms* *Tells us something about pipe age*
R2: Small stream-crossing pipes will be associated with landslides.	Pipe Size	*Used as part of the measurable data to assess triggering mechanisms*
	Original Fill Design	*Evaluated to understand if quality fill design is a meaningful BMP*
	Failure Description	*Used with other data to see predictive patterns which may enhance BMP implementation*

12 APPENDIX – SAMPLE SIZE ANALYSIS

Important decisions about a statistical population are often made on the basis of relatively small samples. Properly designed experiments must ensure that statistical power is reasonably high to allow reasonable detection of departures from the null hypothesis. Power varies with the statistical test, sample size, effect size, and effect variance. Where effect size and variance can be estimated prior to a study, the relationship between power and sample size can be estimated for a given statistical test.

In this study, we used a bootstrap analysis of data collected after the 1996 storms in Oregon to synthesize a large landslide dataset to calculate power as a function of sample size for a one-way ANOVA. The data were provided by Dr. Dan Miller who has used them to develop spatially distributed estimates of shallow, translational landslide density (Miller and Burnett, in press). Provided datasets included: 1) a 10-m grid forest-cover classification based on 25-m grid Landsat Thematic Mapper satellite imagery from 1996; 2) an air-photo-based landslide inventory collected by the Siuslaw National Forest (SNF) (Bush et al., 1997) showing landslide initiation points and landslide size (area); 3) a polygon coverage showing the spatial extent of the SNF air-photo-analysis; 4) a vector road dataset based on US Geological Survey 1:24,000-scale DLG data; and 5) a field-based landslide inventory collected by the Oregon Department of Forestry including landslide sizes (Robison et al., 1999). The datasets were broken up into two regions representing Siuslaw North and Siuslaw South. Siuslaw North is 524 square miles and had 287 identified slides. Siuslaw South was 1113 square miles and had 1041 identified slides.

The 10 forest-cover classes of Ohmann and Gregory (2002) were regrouped by Miller and Burnett (in press) into three broad classes: 1) Open (<10 yrs age) and recently clear-cut harvested areas, or very-small-diameter (< 10 cm dbh) conifer and hardwood/conifer forests; 2) Mixed (10–80 yrs) hardwood forests, and small- and medium-diameter (10 – 50 cm dbh) conifer and hardwood/conifer forests; and 3) Large (>80 yrs) and very-large-diameter (>50 cm dbh) conifer and hardwood/conifer forests. Reclassified forest-cover data were resampled into a 10 m grid using a nearest-neighbor algorithm. To separate road and forest related landslides, a 100 m wide buffer placed around each road segment. Landslides that initiated from within the road buffer were assumed to be road-related and excluded.

Miller and Burnett (in press) noted a bias in landslide detectability among air-photo analysis classes as a function of landslide size. Landslides above 1000 m^2 in area were detected in all classes, but landslides less than 1000 m^2 were not detected in the large class. Landslides less than about 300 m^2 were only detected in field based surveys (Figure 12-1).

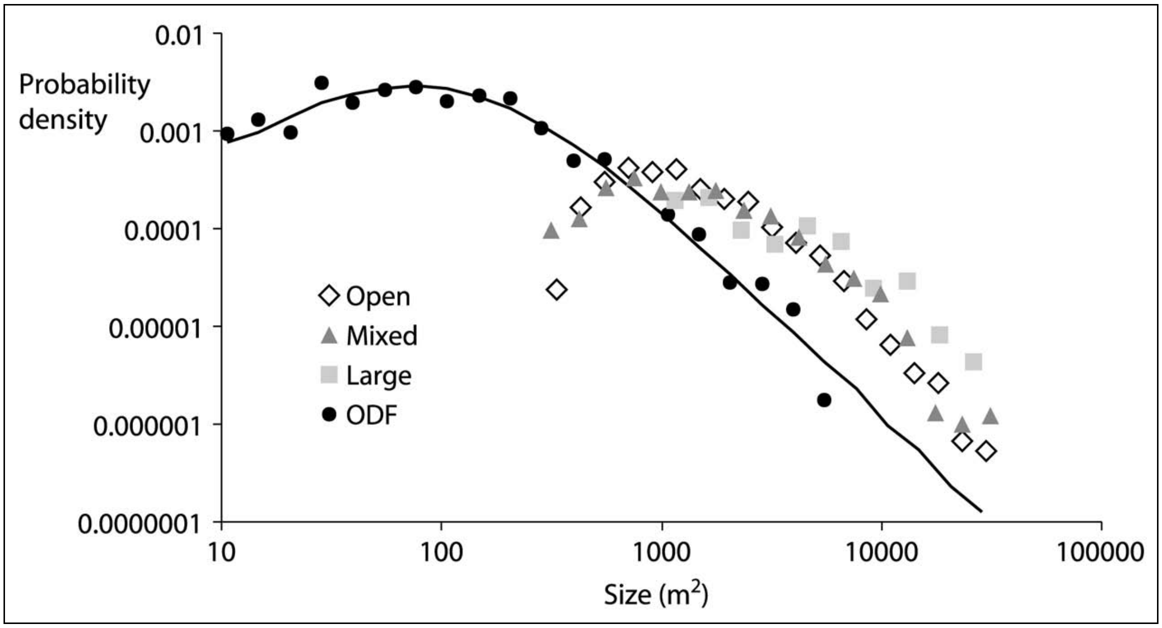


Figure 12-1: Landslide size distributions, given in probability density for each forest-cover class in the Siuslaw inventory and for all landslides in the Oregon Department of Forestry field inventory (Miller and Burnett, in press).

Given that this potential bias causes differences in landslide detectability, we excluded landslides smaller than 1000 m^2 from our analysis

For the bootstrap analysis with replacement, 5000 four-square-mile polygons were randomly placed in Siuslaw North and Siuslaw South. Each four-square-mile polygon fell entirely within the extent of the corresponding Siuslaw air-photo-analysis polygon. For each randomly placed polygon, Hawths Tools, an ArcGIS extension (Beyer, 2004), was used to determine the area of each forest type in the polygon and the number of landslides in each forest type.

In Siuslaw North, approximately 38% of the four-square-mile polygons had no landslides at all. In Siuslaw South, 32% had no slides. Polygons without slides were removed from the analysis because the sampling protocol requires that each sample cluster contain at least one slide. The remaining data were log-transformed to normalize the data for the power analysis [log(slides+1/area)] (Figure 12-2).

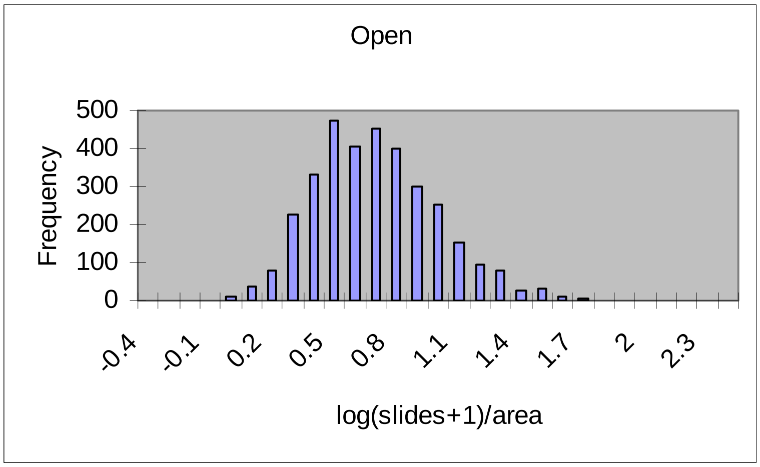


Figure 12-2: Example of log-transformed landslide density.

In this study, the financial and institutional implications of falsely detecting or not-detecting a difference in landslide rates are equally great. As such, we chose to balance alpha and power in our analysis (Table 12-1). The power analysis showed that Siuslaw North required 14 clusters to resolve significant differences between forest type at alpha = 0.01, and 28 were required to get power >= 0.9. For Siuslaw South, 8 clusters were required to resolve significant differences at alpha=0.1 and 13 were required for power >=0.9. When the data for Siuslaw North and South were combined, 15 clusters were required for significant results and 22 were required for power >=0.9.

Table 12-1: Power analysis for log-transformed landslide density using a one-way ANOVA with both Siuslaw North and South combined.

Sample Size	Alpha	Power
21	0.05	0.8
22	0.1	0.9
21	0.2	0.95