APPENDIX E

SLOPE STABILITY ANALYSIS

Introduction

Mass wasting is the movement of hillslope sediment and debris due to such processes as slumps, earthflows, and soil creep. Slumps and earthflows generally develop in deeply weathered soils and tend to be deep-seated and move slowly; debris slides typically occur in shallow non-cohesive soils on steep slopes overlying less permeable bedrock (Beschta et al., 1985). Landslides are the dominant erosional processes in steep forested slopes throughout the Pacific Northwest (Swanson et al., 1987). Conditions causing landslides include: 1) zones of weakness in soil or bedrock; 2) deformation caused by soil creep; 3) drag caused by seepage pressure; and 4) removal of slope support by undercutting (Spence et al., 1996). When a landslide enters and moves down the channel network, it can scour the channel and cause extensive damage to fish habitat, riparian areas, and other public resources (i.e., public works and water quality).

Forest practices can alter both physical and biological (vegetative) slope properties that influence slope stability and the occurrence of shallow rapid landslides. Physical alterations can include slope steepening, slope-water effects, and reduction in soil strength by loss of root strength. Most physical alterations are a result of roads and skid roads. On a unit-area basis, roads have the greatest effect on slope stability of all activities on forest lands (Sidle et al., 1985).

Vegetation can also have both hydrological and mechanical effects on slope stability (Greenway, 1987). Hydrologic effects of vegetation on the hillslope include interception of precipitation by tree leaves and needles, evapotranspiration, and water routing. The primary mechanical effects of vegetation on slope stability include root reinforcement and buttressing and arching (i.e., trees at the base of a potential slide can act like piles and stabilize the slope [ODF, 1999]).

Identification and classification of unstable slopes provide a foundation for forest management and the protection of soil and water resources. Both deep-seated and shallow landslides can be initiated on naturally unstable or marginally stable slopes in riparian and upland areas by management activities such as the presence of existing and construction of new roads and timber harvest. As with stream typing, the classification or definition of unstable slopes partly guides the management prescriptions on those areas. Thus, different slope classifications and associated management prescriptions for the same terrain can result in varying levels of resource protection.

The purpose of this analysis is to discuss the differences between the alternatives in regard to unstable slopes. This includes a detailed description of how unstable slopes are addressed by the existing permanent Forest Practices Rules and the alternatives, and provides an estimate of the percentage of land that may receive some incidental protection because of RMZs. The rules and

changes within the Washington Department of Natural Resources (DNR) (institutional changes) are also evaluated.

Description of Alternatives

Alternative 1, Existing Permanent Forest Practices Rules

Under Alternative 1, unstable slopes are reviewed during the processing of forest practices applications (FPAs). Unstable areas are defined in the rules as slide prone areas; slide prone areas are determined by the DNR and are generally defined as "excessively steep or unstable soils." DNR assesses mass wasting hazards using the following criteria: (1) available soils information; or (2) evidence of geologically recent slumps or slides; or (3) where the natural slope exceeds the angle of repose for the particular soil types present; or (4) where springs or seeps may indicate unstable conditions. If movement on the unstable landform has the potential to deliver sediment to a public resource, the application would be processed as a Class IV-Special, and State Environmental Policy Act (SEPA) review and appropriate documentation would accompany any Class IV-Special application submitted to the DNR. In addition, any application for forest practices on snow avalanche slopes within areas designated by DNR as high avalanche hazard would be classified as Class IV-Special.

Class IV-Special applications are those that are considered to have some level of activity that is considered to have a potential "significant" impact on the environment. Applications to conduct forest practices on unstable slopes that have the potential to damage public resources (e.g., water quality, fisheries, bridges, water supply intakes, wetlands) require an environmental checklist to comply with SEPA, and SEPA guidelines. Forest practices in an area of resource sensitivity identified in a watershed analysis, that deviates from the prescriptions (which may include an alternate plan) in the watershed analysis, are also classified as IV-special. It may be determined that additional information or a detailed environmental statement is required before these practices may be conducted. In current rules, there is no specific SEPA guidance in the review of Class IV-Special applications for unstable slopes or landforms.

Once the application is processed as a Class IV-Special, a determination of significance, non-significance, or mitigated significance is made. DNR's threshold determination is subject to a 15-day public review period. Then the DNR has 30 days to approve, disapprove, or approve with conditions, the application. However, if an EIS has to be prepared then the Commissioner of Public Lands can allow more time for DNR to approve or disapprove the application.

Alternative 2, Forest and Fish Report

Under Alternative 2, unstable slopes would be specifically defined by slope gradient and geomorphic features. The following landforms have been identified and defined from field experience and in the scientific literature as highly susceptible to mass wasting and considered in the rules to be potentially unstable:

- convergent headwalls (especially when stacked roads are present)
- inner gorges

- bedrock hollows
- toes of deep seated landslides
- groundwater recharge areas for glacial deep-seated landslides
- outer edges of meander bends along a valley wall or high terrace in a channel migration zone.

Under Alternative 2, these landforms would be considered areas of potential mass wasting. Once a landowner submits a FPA, it would be reviewed by the DNR. The DNR then would field-verify the application or may request more information from the landowner to see if there is a potential threat of slope instability. If there is a threat of mass wasting and delivery of sediment to a public resource in a way that threatens public safety or causes adverse impacts, an expert would verify the instability and its potential for delivery to a stream. If it is decided that a slope would likely fail and deliver or threaten public safety, then the application would be processed as a Class IV-Special and the application, if not withdrawn or modified to exclude the area in question by the landowner, would go through the SEPA process. Unstable slopes that have potential to deliver to a public resource or to threaten public safety would be classified as Class IV- special.

Once classified as a Class IV- special, SEPA guidance would require that the applicant provide DNR with an analysis by a qualified expert that identifies:

1. the likelihood that the proposed forest practices would result in the failure of the identified potential unstable slopes or landforms, or contribute to further movement of a potentially unstable slope or landform;
2. the likelihood of delivery of sediment or debris to any public resources in a manner that would threaten public safety; were such slopes to fail; and
3. any possible mitigation for the identified hazard.

SEPA guidance would also provide assistance to DNR on how to review the completed proposal with its qualified expert, with a goal of keeping mass-wasting that delivers to public resources (or threatens public safety) at, or near, natural rates, and how to make the required threshold determination.

DNR would review the application with its technical experts, and make a threshold determination as to whether the proposed forest practices: (i) are likely to increase the probability of a movement that would deliver sediment and debris to public resources or in a manner that would threaten public safety, and (ii) are likely to cause significant adverse impacts. If the DNR determines the proposed forest practices are likely to have a probable significant adverse impact on the environment, a revised application would be required with technical analysis and solutions sufficient for DNR to issue a determination of non-significance or the preparation of an EIS. If an EIS is required, in addition to assessing the risk of mass-wasting that results in the delivery of sediment to public resources, the EIS process would be used to develop and implement measures that are likely to prevent a significant increase in the risk of mass-wasting that results in delivery of sediment to public resources. Tribes and other agencies would be afforded the opportunity to participate in the development of such measures.

As in Alternative 1, DNR's threshold determination would be subject to a 15-day public comment period. After completion of all required compliance with SEPA, DNR would make a determination to: (1) approve, (2) approve with conditions (restrictions) or (3) disapprove the proposed application. A proposed forest practices application would not be processed as a Class IV-Special permit as a result of unstable slopes if: (i) the permit covers forest practices to be conducted in a watershed administrative unit subject to an approved watershed analysis, (ii) it is to be conducted in accordance with an approved prescription from such watershed analysis, and (iii) the applicable watershed prescription is a specific prescription, such as a "no-harvest" prescription or a prescription that requires the retention of a certain numbers of trees (in contrast to a prescription that requires additional analysis). If the applicable watershed analysis prescription included in any application is a prescription that requires additional analysis, the procedures in the rule governing unstable slopes would apply to such application.

Non-rule based changes in slope stability:

Additional unstable landforms in certain regions of the state would be identified in the future and included in the list of potentially unstable landforms to be identified in FPAs. Moderate hazard landforms and appropriate management guidelines for forest practices on those landforms would be developed. A refined GIS screening tool for unstable slopes (currently in development) would be used and adjusted for regional variations in physiography around the state. In addition, field personnel would be trained in the identification of the potentially unstable landforms and slopes.

Alternative 3

Under Alternative 3, high-hazard unstable slopes would be defined as in Alternative 2. One more landform would be added to the geomorphic feature list; the landform is all planar slopes steeper than 80 percent slope (39°). Unlike Alternative 2, any application that has a high or moderate hazard slope will automatically be classified as a Class IV-special regardless of whether the high or moderate hazard unstable slope has the potential to deliver sediment to a public resource or threaten public safety. In addition, no forest practices would be allowed on the high hazard landform or within 50 feet of it. Moderate hazard landforms would include all slopes steeper than 50 percent (26°). Management prescriptions for moderate landforms would be developed. As in Alternative 2, additional screening tools would be developed.

Analysis Approach

To analyze the differences between the alternatives, it was necessary to broadly identify the potentially unstable slopes within the project area. The SMORPH model (Shaw and Johnson, 1995) was used, with 30 meter digital elevation models, for the sample sections of the project area to identify potential mass wasting areas. The SMORPH model identifies potentially unstable areas using a GIS algorithm that determines a hazard ranking of slope stability based upon gradient and curvature. The model identifies areas as high, moderate, and low potential for mass wasting, and only considers shallow rapid debris slides. This classification is based on management criteria used in watershed analysis for mass wasting potential (WFPB, 1997). The high hazard classification from the model includes many landforms that would be considered high hazard under Alternatives 2 and 3 including bedrock hollows, inner gorges, etc. The SMORPH model has been calibrated to landslide inventories for several basins on the west side of the state. The limitations of the

SMORPH model are described in detail in Shaw and Vaugeois (1999). The calibration criteria used in the model were applied to the appropriate sections located within those regions (see Shaw and Vaugeois, 1999). Although the SMORPH model has not been calibrated on the east side, the most restrictive calibration criteria for the west side (E. Fork Lewis River) were used as a proxy for the east side (Laura Vaugeois, pers. comm., 1999).

The information obtained from the model are used in this assessment as a comparative tool to assess prescriptions of the same potentially unstable areas. The area delineated by SMORPH is combined with the RMZ prescriptions by alternative to assess the relative effects of forest practices based upon management prescriptions. This model is only a preliminary screening tool for areas with a high and moderate failure potential. The model does not predict whether the high and moderate hazard areas have the potential to deliver sediment to public resources or threaten public safety. In addition, the model only predicts the stability in relation to shallow rapid debris slides. SMORPH is used in this analysis to identify areas that would require further field review before management activity could be occur. Only a certain proportion of the potentially unstable slopes the model predicts would be considered for forest practices by a landowner.

Results

Approximately 6 percent of the west side and 4 percent of the eastside forests are on potentially high hazard mass wasting areas (Figure 1). Approximately 12 percent of the west side and 5 percent of the east side are on moderate hazard mass wasting areas (Table 1, Figure 1). The results are a minimum of potentially unstable slopes as the model does not predict deep seated slope features.

Alternative 1

Under Alternative 1, there would be less than one percent of the high and moderate mass wasting potential area landscape on the east side and west side that is provided incidental protection with RMZs (Table 1). The rules are not specific in identifying unstable slopes, except for snow avalanche chutes, as Alternatives 2 and 3. However, unstable slopes that have the potential to impact the environment should be identified in the screening process of applications. The tools and information available to screen the applications are rudimentary which reduces the chance of further environmental review of these practices as Class IV-Special applications. Therefore, the current rules present a moderate risk of mass wasting in regard to slope stability. In addition, the current rules do not require that public safety be addressed in the application process, though the DNR has discretion to reject an application that may present a danger to the public.

Figure 1. Mass Wasting Potential of Forestlands in Washington

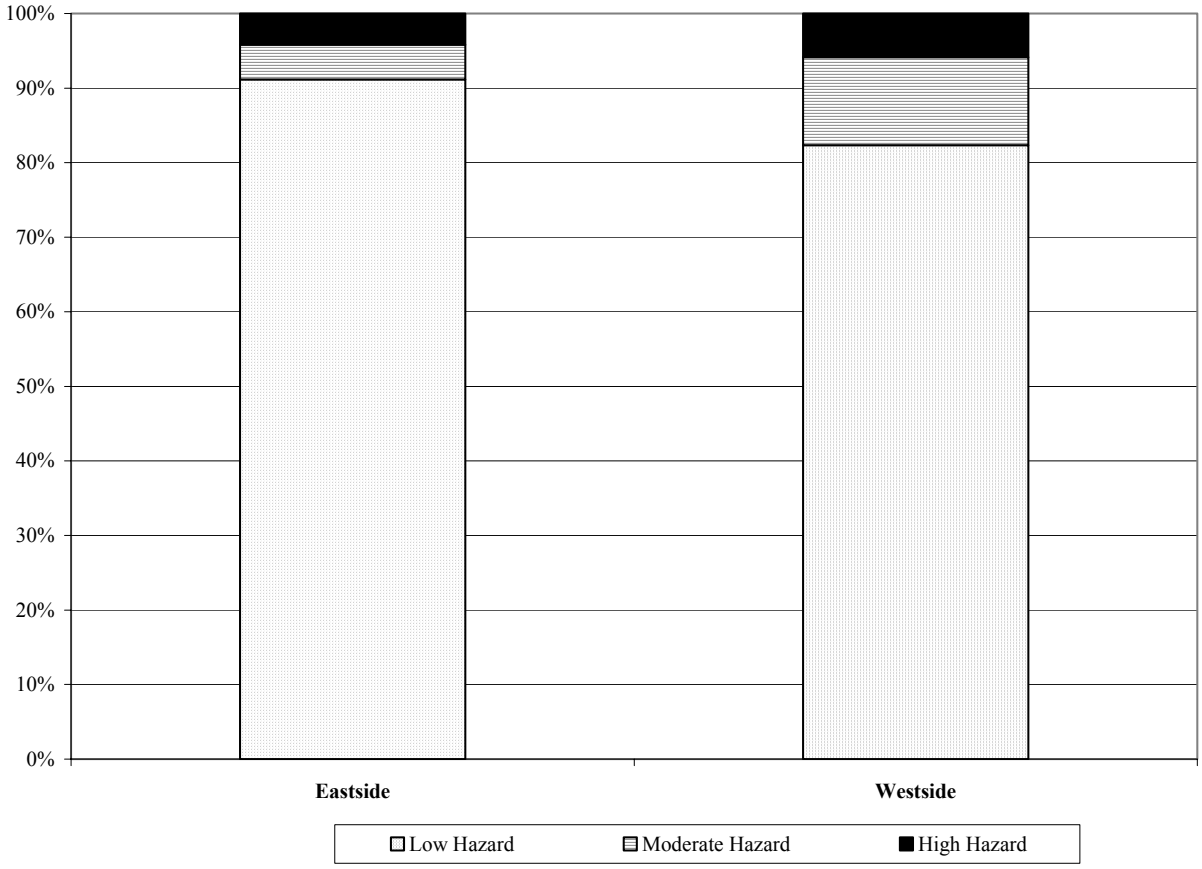

Table 1. Acres of Forested Lands in RMZs and Upland Areas for Each Hazard Class by Alternative

ALTERNATIVE 1

	Low Hazard		Moderate Hazard		High Hazard	
East Side	**RMZ**	**Upland**	**RMZ**	**Upland**	**RMZ**	**Upland**
Middle Columbia	0.9%	92.8%	0.0%	3.3%	0.0%	3.1%
Snake	2.8%	92.4%	0.0%	3.6%	0.0%	1.2%
Upper Columbia - Downstream of Grand Coulee	0.6%	83.9%	0.0%	7.4%	0.0%	8.1%
Upper Columbia - Upstream of Grand Coulee	1.7%	93.4%	0.0%	3.2%	0.1%	1.6%
GRAND TOTAL	**1.2%**	**90.0%**	**0.0%**	**4.6%**	**0.0%**	**4.2%**
West Side						
Lower Columbia	1.9%	89.6%	0.1%	4.6%	0.1%	3.8%
Olympic Coast	6.2%	82.6%	0.4%	5.1%	0.2%	5.6%
Puget Sound	4.4%	75.3%	0.6%	10.5%	0.4%	8.8%
Southwest	4.4%	72.5%	0.6%	19.1%	0.1%	3.2%
GRAND TOTAL	**4.0%**	**78.3%**	**0.5%**	**11.3%**	**0.2%**	**5.7%**

ALTERNATIVE 2[/1]

	Low Hazard		Moderate Hazard		High Hazard	
East Side	**RMZ**	**Upland**	**RMZ**	**Upland**	**RMZ**	**Upland**
Middle Columbia	3.2%	90.4%	0.2%	3.1%	0.0%	3.1%
Snake	5.6%	89.7%	0.1%	3.7%	0.0%	1.2%
Upper Columbia - Downstream of Grand Coolee	1.4%	83.1%	0.2%	7.3%	0.0%	8.1%
Upper Columbia - Upstream of Grand Coolee	3.5%	91.7%	0.1%	3.2%	0.0%	1.6%
GRAND TOTAL	**2.8%**	**88.4%**	**0.2%**	**4.6%**	**0.0%**	**4.2%**
West Side						
Lower Columbia	6.3%	85.2%	0.2%	4.5%	0.1%	4.5%
Olympic Coast	10.7%	78.2%	0.9%	5.2%	3.1%	26.3%
Puget Sound	8.2%	71.8%	1.0%	11.0%	0.9%	11.4%
Southwest	9.4%	69.2%	2.5%	19.7%	0.2%	0.9%
Grand Total	**8.4%**	**74.7%**	**1.3%**	**11.6%**	**0.5%**	**5.9%**

ALTERNATIVE 3

	Low Hazard		Moderate Hazard		High Hazard	
East Side	**RMZ**	**Upland**	**RMZ**	**Upland**	**RMZ**	**Upland**
Middle Columbia	15.9%	77.7%	0.6%	2.7%	0.4%	2.7%
Snake	25.7%	69.5%	1.1%	2.4%	0.3%	0.9%
Upper Columbia - Downstream of Grand Coolee	16.7%	67.8%	1.0%	6.4%	1.0%	7.1%
Upper Columbia - Upstream of Grand Coolee	16.1%	79.0%	0.4%	2.8%	0.2%	1.4%
Grand Total	**16.5%**	**74.7%**	**0.6%**	**4.0%**	**0.5%**	**3.7%**
West Side						
Lower Columbia	27.9%	63.5%	1.7%	3.1%	1.3%	2.5%
Olympic Coast	24.4%	64.3%	2.3%	3.2%	1.9%	3.9%
Puget Sound	17.6%	62.2%	3.1%	7.9%	2.2%	7.0%
Southwest	30.0%	47.0%	11.3%	8.5%	1.4%	1.9%
Grand Total	**24.3%**	**58.0%**	**5.2%**	**6.5%**	**1.7%**	**4.1%**

[/1] This data does not include unstable areas in Alternative 2 Type N stream RMZs.

Alternative 2

The most substantial changes in the rules between Alternative 2 and Alternative 1 is the specificity of the SEPA review process and rules that guide the identification of unstable slopes. The specific definitions of potentially unstable slopes do not preclude a more rigorous assessment of slope stability because any unstable slope that poses a threat to damage a public resource should be identified. It is anticipated that a greater but unknown number of forest practices applications would get additional review under Class IV-special. The specific SEPA guidance in the processing of Class IV- special applications would reduce the risk of mass wasting and impact on public resources and public safety because it provides a process for review and scrutiny that does not currently exist in Alternative 1. The number of landslides that would be prevented under these rules cannot be predicted.

The voluntary efforts of improved screening tools and training of field personnel would likely have the greatest effect in reducing the potential environmental effects and threats to public safety. These efforts are currently in the implementation stage within the DNR.

The RMZs under Alternative 2 will provide slightly more incidental protection of potentially unstable slopes than Alternative 1 because 2 percent of west side and less than 1 percent on the east side of the potentially high and moderate hazard areas of landscape would be in Alternative 2 RMZs (Table 1).

Alternative 3

Alternative 3 provides the greatest protection for potentially unstable slopes because it precludes any timber harvest on a high-hazard mass wasting area and requires SEPA review for all forest practices on high- and moderate-hazard slopes. In addition, a 50-foot no-harvest buffer is required on all high-hazard areas regardless of whether there is a potential to affect public resources or threaten public safety. Approximately 7 percent of the landscape on the west side and 1 percent on the east side would represent potentially high hazard and moderate unstable slopes protected by no-harvest RMZs (Table 1).

In addition, the same voluntary effects of Alternative 2, which include improved screening tools and training of field personnel, would also reduce the potential environmental effects and threats to public safety.