TFW Effectiveness Monitoring and Evaluation Program

Monitoring Effectiveness

of

Forest Practices and Management Systems

Mass Wasting

Study Design Guidelines, Procedures, and Methods

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Acknowledgements

This document was prepared for the TFW Monitoring Advisory Group, formerly known as the TFW Monitoring Steering Committee. This group is a subcommittee under the Cooperative Monitoring Committee of the Washington Timber/Fish/Wildlife Program. Dave Schuett-Hames of Northwest Indian Fisheries Commission was the committee's representative providing both technical review and administrative guidance in preparation of this document. Nancy Sturhan, Washington Department of Natural Resources and Kevin Lautz, Washington Department of Fish and Wildlife were the committee's technical representatives for this project. Others providing technical input and advice were: Carl Davis, Wenatchee National Forest; Tom Robison, Wenatchee National Forest; Jim Ward, Weyerhaeuser; Bill Shelmerdine, Olympic National Forest; Gary Ketcheson, Mt. Baker-Snoqualmie National Forest, Dr. Walter Megahan, NCASI; and Dr. Julie Dieu, Rayonier. Charles Chesney, Washington Department of Natural Resources and Jeff Light, Plum Creek Timber provided technical review of these documents. Bill Shelmerdine and Jim Ward provided technical review of the Key to Diagnosing Causes in Appendix B. Level One methods and procedures described in the document were field tested. Field trials would not have been possible without the assistance of Kate Sullivan, Warren Sorenson, Jim Ward, and Mike Kennedy of Weyerhaeuser Company and Jeff Light and Dave Lorence of Plum Creek Timber Company.

Matt Brunengo and Eric Schuster of Washington Department of Natural Resources greatly assisted in the development of Geology Groups of Washington in Appendix B. Appreciation is also extended to the numerous field geologists around the state who kindly assisted in classifying lithologic units into these broad categories based on their local familiarity.

Author’s Note to Users:

This draft, Version 1.1, is the first approximation of the TFW framework developed to assist monitoring evaluations of forest practice effectiveness in controlling the affects from mass wasting. The guidelines within should be used with the understanding that this draft is the first of its kind and requires more extensive review and testing before complete adoption as the TFW framework.

Not all members of the TFW Monitoring Steering Committee are in complete agreement or support of the entire approach. But as in all endeavors of this magnitude, this first draft supports TFW Effectiveness Monitoring Program goals toward implementation. It provides a written format that can be reviewed, discussed, tested, critiqued and revised.

Users of Version 1.1 should bear in mind that they are using a framework model that may change and that they have an important role in participating in modifications and refinements. Your comments and feedback on how to improve this framework model are essential in moving these guidelines to the next level, full implementation.

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Part II: Monitoring Procedures and Methods

Introduction

The TFW Effectiveness Monitoring and Evaluation Program Plan (TFW,1997), hereafter called "The TFW Monitoring Program Plan", describes the goals and strategy for a comprehensive monitoring program for forest practices. The primary users of the program and its supporting documents, such as this one, are TFW cooperators and the CMER Monitoring Steering Committee.

Three goals are outlined by the TFW Monitoring Program Plan to guide the effectiveness monitoring program and individual monitoring efforts contributing to the program:

1. To evaluate the effectiveness of individual forest practices and restoration measures in achieving aquatic resource protection or restoration objectives on a site scale.

2. To evaluate the effectiveness of forest management systems in achieving aquatic resource protection goals on a watershed scale.

3. To document regional and statewide trends in aquatic resources and watershed conditions.

The TFW Monitoring Program Plan identifies the need for study design guidelines that outline important considerations in developing or reviewing monitoring plans and the need to develop standard methods that provide consistency in evaluation of effectiveness of forest practices. A component of the TFW Monitoring Program is to provide a mechanism for sharing results of individual monitoring projects and aggregating observations from several monitoring efforts to increase certainty in findings. A consistent approach to study design and data collection serves this corporate approach to data management.

The purpose of this document is to provide the framework, under the TFW Monitoring Program Plan, for evaluating the control of fine and coarse sediment delivered to the aquatic resource from mass wasting. This document provides guidance for preparation of monitoring plans, procedures for conducting evaluations, and methods of evaluation.

There are two other important sources of sediment influenced by forest practices, surface erosion and streambank erosion. Channel scour of 1st Order channels from mass wasting is covered in this document. Subsidence of banks from hydraulic energy is not. A framework for evaluating management-related surface erosion is provided in a similar document, *Monitoring Effectiveness of Forest Practices and Management Systems – Surface Erosion* and can be obtained through the TFW Monitoring Steering Committee.

The document is organized into two parts: Part I discusses considerations in designing a monitoring project and Part II outlines the procedure and methods necessary to conduct a TFW monitoring project.

Part 1: Study Design Guidelines

1.0 General Considerations for Monitoring

Who benefits from monitoring? The TFW Monitoring Program Plan outlines the need to develop an "adaptive management" mechanism whereby TFW cooperators are informed as to how well forest practices and respective management systems are performing and to identify when adjustments are needed to improve effectiveness. A consistent, mindful approach to monitoring and a "corporate" sense toward monitoring will support such an "adaptive management" mechanism.

Monitoring efforts may take various forms: TFW cooperators choosing to focus on issues important to them locally or to meet regulatory requirements; CMER or a group of cooperators may choose to focus on regional issues. Although individual efforts may appear to be unique, there are common threads that will contribute to the overall adaptive management theme. Monitoring cooperators are encouraged to consider the relative contribution to adaptive management, regionally or locally, when developing their monitoring plans.

More recent watershed analysis (Washington Forest Practices Board, 1997) may have watershed monitoring plans or outline recommendations that can help identify specific issues to evaluate within the watershed. Those designing monitoring projects will need to decide whether site scale or watershed scale monitoring best address issues identified from whatever the source.

1.1 Considerations in Evaluating Mass Wasting Processes

If mass wasting were not a natural, dynamic process, monitoring the effectiveness of management actions would be much easier. Monitoring would be simply looking for presence or absence of mass failure events associated with a given practice or management system. Mass wasting is a natural watershed process influenced by several independent and variable factors.

Mass wasting processes vary over time and space being influenced by climate and various physical and biological site factors that also vary temporally and spatially. Forest management can increase the rate, extent, and frequency of landslides in a watershed which elevates the amount and duration of sediment load transported by the stream system.

A stable slope could be viewed as one that all factors are "in balance" with one another. Natural disturbances such as earthquakes, extremes in weather and/or management actions can influence slope stability by altering this balance. Imbalance causes adjustment. These adjustments result in debris slides, torrents, deep-seated failure, rock fall, and others. Sometimes mass wasting triggers are clearly attributed to forest practices and in other situations the question is more whether forest practices accelerated the timing of an event that would have occurred naturally in due time. On a watershed scale both are significant management influences.

The key to a successful monitoring effort, one that yields improved understanding of management influences, is to structure the evaluation within the context of this very dynamic setting. Those developing study designs should use the following understandings to guide their approach to monitoring.

- **Mass wasting varies by time and space relative to a given landscape setting.** Landscape setting typically can be defined by geology, geomorphology, and climate. The rate, extent, and frequency of mass wasting events are useful parameters to characterize the variation of mass wasting from place to place and within a setting. Rate measures the number of events or amount of sediment yielded, extent is the area encompassed by events, and frequency is the number of events per time or sediment yielded over time. All three parameters can be altered by management practices. Stratifying monitoring observations within this context is critical to understanding if reduction or acceleration of mass wasting has occurred in the watershed.

- **Time lags between activities and response can lead to false interpretation**. For example, it appears that root strength is at its lowest approximately 3-7 years following clearcut harvest and recovery occurs within a reforested stand of 16 to 35 years (Ziemer, 1981; Burroughs and Thomas, 1977). Deep seated failures are influenced not by magnitude and occurrence of an individual storm but by seasonal and annual water balance. Hence, response time for deep seated failures may be months to years following the activity or a heavy precipitation event.

- **Storm event expression and recurrence intervals which induce mass wasting vary statewide.** A significant storm causing mass wasting may occur every two years in the coastal region and every 25 years or longer in the Blue Mountains. Monitoring timeframes and recommendations should be placed within a local climate context relative to the regional recurrence intervals and storm expression.

- **Not all forest practices are implemented as prescribed for various reasons.** Prescriptions are altered when site conditions are not represented by the prescription. Prescriptions may not be interpreted correctly or they may be unclear. Only activities that are implemented as prescribed, and that have prescriptions that address the trigger influencing the site should be a part of the effectiveness monitoring data set. An evaluation of whether practices are implemented correctly is also a useful form of monitoring. It provides feedback on management systems' ability to provide clear and implementable prescriptions and whether operations are conducted in a manner that produces practices that are compliant with management system direction.

- **Current forest practices are focused on preventing mass wasting by commonly avoiding high hazard areas. This will reduce available number of monitoring observations of individual practices developed to address hazard within most watersheds. The limited number of monitoring sites will require aggregation of data sets to fully evaluate effectiveness of individual practices.** Avoiding placing practices on high hazard terrain in itself is a practice. Watershed scale monitoring will need to identify the difference between a management decision to avoid a sensitive area and when there has just been no activity taking place. The extent of prescriptions designed to address hazardous terrain may monitoring sites where new practices can be evaluated, either at the watershed or site scale. At the watershed scale because the extent of forest practices have varied over time, it is important to report findings relative to the extent of the practice or extent of hazard in the watershed. This is called normalizing of results.

1.2 Site scale versus Watershed scale monitoring

Two scales of evaluation are identified by the TFW Monitoring Program Plan. They provide for different emphasis in evaluating the overall effectiveness of forest practices. They are:

- Individual practice effectiveness evaluated on a site scale
- Multiple practice and management system effectiveness evaluated on a watershed scale

Site scale monitoring is an intensive look at individual forest practices to evaluated how well they prevent mass wasting and sediment delivery to channels. One or a series of related practices and restoration measures are evaluated for effectiveness in controlling mass wasting or sediment delivery, or both. Practices are evaluated over varying site conditions. Triggering mechanisms are clearly diagnosed for practices that are not effective so that adjustments to practices are recommended. Practices that are evaluated may be state-approved “Best Management Practices” as defined by standard rules or Class IV special condition by the Forest Practice Act or approved prescriptions from Watershed Analysis, Habitat Conservation Plans or Landscape Plans, and restoration measures.

Watershed scale monitoring provides a big picture view of the effectiveness of all forest practices in reducing mass wasting to avoid management-related impacts to the aquatic ecosystem. It provides a means to evaluate performance of management systems such as, watershed analysis, habitat conservation plans, standard forest practice rules and landscape plans (under development). Analysis of monitoring results covers the entire watershed inclusive of all landowners and management systems. Monitoring results may be used to demonstrate trends toward meeting aquatic resource goals, improve hazard identification, and, if needed, to adjust management system direction or operation in a watershed.

Guidelines for developing study designs for site scale monitoring of individual practices and restoration measures are covered in Section 2.0 and monitoring procedures are covered in Section 4.0. Study design guidelines for watershed scale monitoring o multiple practices and management systems is covered in Section 3.0. Watershed scale monitoring procedures are covered in Section 5.0.

1.3 Monitoring Approaches

Observing the point of initiation for a mass wasting event and tracing run out features to a delivery point, or source/delivery is the most direct means for evaluating whether management-related mass wasting or sediment delivery is being prevented. Qualitative evaluations use visual observation and are quick and cost effective, allowing for a larger number of observations. Rate, extent, and frequency are defined in the number of events. Quantitative approaches use a numerical index that reflects increases in sediment yield over background. Landslide dimensions are measured or estimated and a sediment yield is calculated.

Neither approach provides an understanding of the direct impact to the aquatic resource. If sediment delivery is completely prevented, the conclusion is clear, the aquatic resource is unaffected by management practices. If some sediment delivery is occurring, the conclusion is not so clear.

In order to assess the degree of impact to the aquatic resource, one needs to assess “how much is too much sediment?” Trends in habitat conditions compared to sediment source/delivery monitoring may provide an indication of this. Monitoring change in channel morphology and streamed characteristics provides an indication of habitat condition and can be compared with species viability. If monitoring is conducted over several geomorphic and lithologic settings, an understanding of differences in response to sediment input may be determined. If so, sediment thresholds or desired conditions could be established.

Linking individual forest practices with channel response has proven difficult. Certainty in cause and effect links are confounded by flux in sediment supply and routing, both temporally and spatially (MacDonald, 1991; Bunte and MacDonald, 1998; Benda, 1995 and others). Site selection for channel response monitoring will need to be mindful of the varying sediment transport rate and timing from the numerous tributaries to a mainstem. The closer the monitoring sites are to the sediment source the higher probability that relationships can be observed.

A network of channel response observations located throughout the watershed integrated with a watershed scale evaluation of sediment input (all sources) may provide a better insight to routing mechanisms and sediment flux than monitoring channel response or hillslope practices separately. This approach builds a body of observations of source area and delivery to compare with changes observed in the channel. Because of unknown routing mechanisms, temporarily and spatially, commitment toward numerous monitoring sites and long term monitoring is necessary. And, at best, conclusions may only be in terms of trend for the period of monitoring and may not reflect the long-term dynamic of aquatic habitat.

When monitoring channel response or relative effect to the aquatic resources at the watershed scale, study designs should consider including procedures for monitoring all sources of fine and coarse sediment. Guidelines covering surface erosion processes are provided in a companion document, *Monitoring Effectiveness of Forest Practices and Management Systems – Surface Erosion.* In future versions, the two documents may be combined. Channel erosion when evident should also be included.

2.0 Site Scale Evaluation - Individual Practices

Covered in this section is guidance in study design development for site scale evaluation of individual practices and restoration measures. Discussed are elements important to developing a monitoring plan: 1) monitoring goals and objectives, 2) project scoping, 3) developing monitoring questions and hypotheses, 3) a discussion and approach for evaluating effectiveness, 4) considerations for study design, and 5) considerations in analysis and reporting results.

The TFW approach is to evaluate effectiveness through direct evidence that mass wasting was initiated by a forest practice and whether the event delivered sediment to a stream channel. If a practice or restoration measure is ineffective either in prevention of mass wasting or delivery, the practice and site conditions are further evaluated to diagnose the cause. This diagnosis is used to develop recommendations to improve effectiveness.

2.1 Goals and Objectives

To meet TFW goals and objectives for site scale monitoring, the following goal and objectives are identified to guide evaluation of individual practices or restoration measures in controlling the effects from mass wasting.

Goal:

Support the TFW monitoring plan by evaluating the effectiveness of practices or restoration measures in protecting the aquatic resource from increased delivery of fine and coarse sediment. And, to support adaptive management by conducting monitoring projects that contribute defensible findings of effectiveness and recommendations for improved effectiveness.

Objectives:

1. To evaluate effectiveness of practices or restoration measures in prevention of management-related mass wasting and in prevention of delivery of fine and coarse sediment to the stream system.

2. To evaluate site conditions that influence effectiveness of practices or restoration measures in prevention or reduction of mass wasting and/or delivery of fine and coarse sediment to the stream system.

3. Diagnose causes contributing to ineffective or partially effective practices through observing indicators of triggering mechanisms. Provide recommendations for adjustments in practices or restoration measures to improve effectiveness in prevention or reduction of mass wasting and/or delivery of fine and coarse sediment to the stream network.

There are several assumptions that help support this goal and these objectives.

Assumptions:

Delivery of fine and coarse sediment associated with management practices suggests an acceleration over natural background rates. Adverse affects to the aquatic resource are suspected when rate, frequency, and extent of mass wasting is accelerated over background rates. Measuring practice performance in preventing mass wasting and delivery of sediment from practices and restoration measures provides an indicator of effectiveness in protecting the aquatic resource.

The complex nature of sediment routing makes it difficult to determine the relative effect of an individual practice on aquatic resources. Monitoring effects on aquatic resource is best served at the watershed scale. Observing points of landslide initiation, tracking delivery to the stream network, and diagnosing triggering mechanisms from an individual practice is the most clear means of evaluation at the site scale.

Diagnosing the cause of a mass wasting event leads to understanding how the practice may be improved. Improving the effectiveness of individual practices in prevention of mass wasting is expected to provide for maintenance or recovery of the aquatic resource.

2.2 Problem Statement

The first step in developing a monitoring plan is to obtain a clear understanding of the reason for monitoring and to record them in a problem statement. In many cases, the purpose and scope of an individual monitoring effort will be specific to the issues present in a particular watershed. In other cases, the purpose and scope may be derived from regional issues covering several watersheds.

Issues that direct monitoring of individual practices are identified by several means. During watershed analysis, a practice may be prescribed that has been untested in a particular site condition. A widely used practice or restoration measure may require a demonstration of effectiveness over a variety of site conditions. During a 5-year watershed review, a practice may be identified as potentially ineffective and needs further evaluation at the site scale. A review of a practice category (e.g., road abandonment) may provide information on the relative performance of the practices or restoration measures within the category.

A problem statement is one of the first components presented in a monitoring plan. It summarizes the issues and clarifies the purpose and scope of the monitoring project. It provides focus to the monitoring plan and helps communicate the context for the project to others.

The problem statement may identify priorities for the monitoring project. It defines the type of practice or practices and site condition or site conditions to examine. One should be able to develop monitoring questions and test hypotheses directly from the problem statement.

Below, is an example of a problem statement:

> *Roads have been identified as the primary source of mass wasting in XYZ watershed. The priority for road maintenance in the next few years is removal of unstable sidecast from every road constructed on slopes over 55%. This practice is very expensive and the landowner, Pumpkin Timber Company, would like assurance that the practice is effective and to only apply the practice where it will prevent mass wasting or delivery. An inventory of road related landslides across different slope morphology, geology, and slope position has been conducted on roads were sidecast has failed to identify site conditions most likely to deliver from unstable sidecast. Road maintenance has removed sidecast based on site conditions criteria developed from the inventory. Effectiveness in sidecast removal will be evaluated across all site conditions in the watershed.*

The issue in this problem statement is that the practice is expensive and appears to need extensive application. The purpose of the monitoring project is to evaluate effectiveness in site selection and effectiveness of the practice under all site condition situations in the watershed. The scope is to evaluate all site conditions existing on lands owned by the Pumpkin Timber Company in the XYZ watershed.

2.3 Monitoring Questions and Hypotheses

The next step in developing a monitoring plan is to develop monitoring questions and from these questions, hypotheses. Monitoring questions are developed from the purpose and scope of the problem statement. Hypotheses direct the study design and selection of monitoring methods.

A general framework of questions and hypotheses is provided to guide development of project-specific questions and hypotheses for individual project plans. Table 1 outlines examples taken from a few representative Watershed Analysis Prescriptions. These examples illustrate a format and structure to follow when constructing project specific questions and hypotheses. A monitoring plan may have a series of questions and hypotheses or just one, depending on the project scope.

The prescriptions from Watershed Analysis, geotechnical reports or the Forest Practice Rules special condition will provide important background for monitoring questions. They identify what practices are to be applied in areas sensitive to mass wasting. Watershed analysis identifies triggering mechanisms and specific site conditions that can help in formulating detailed monitoring questions. The “rule call” defines a target condition to evaluate practice effectiveness. Similar information may be obtained from local land managers or state forest practice foresters for practices guided by Standard Forest Practice Rules.

In some cases, a series of practices define a prescription. In other cases, one practice defines a prescription. The choice to include all practices within a prescription or to combine site variables into one monitoring question is an important one. Monitoring questions guide all aspects of study design, i.e., whether one practice or a series of practices are to be evaluated, what parameters are to be measured, the intensity and duration of measurement, and stratification of site factors.

The more practices and site variables included in the monitoring question the more complex the study design becomes. The more variation that is combined the higher risk that there will be less certainty in the relative influence of individual practices or variables.

The following list provides examples of the four possible monitoring situations:

- **One practice, one site condition**. This scenario focuses on the fewest variables and therefore, is the simplest of cases. This approach may be used to evaluate a specific practice applied to a defined site condition. An example of this scenario is monitoring clearcut harvest of 0 Order channels on slope gradients greater than 70% in convergent headwall areas and on the same bedrock formation.

- **One practice type, multiple types of site conditions**. This scenario determines the effectiveness of a practice in different site conditions. An example of this scenario is clearcut harvest of 0 order channels on slope gradients greater than 70% comparing different sizes of convergent headwalls and single parallel channels on the same or several bedrock formations.

- **Multiple practice types, one type of site condition.** This scenario describes a prescription that requires several treatments to be effective. An example is retention of a wind buffer area adjacent to partial cut leave areas on unstable slopes that are prone to tree topple from the wind.

- **Multiple practice types, multiple site conditions.** This is the most complex scenario to monitor. An example is in minimizing accelerated movement of a deep seated landslide. Multiple practices might be: 1) retain vegetation along toe of deep seated movement and encourage stream to direct flow away from the toe directing stream flow; 2) Construct roads with sawdust fill. Site conditions are evaluated in different climatic regimes.

As an addition reference, Table 2 provides a list of triggering mechanisms and common practices summarized from various watershed analysis prescriptions and from Forest Practices Rules. This summary may be helpful when selecting individual practices for evaluation, in structuring a study design around triggering mechanisms or in associating triggering mechanisms with individual practices when writing monitoring questions and hypotheses.

Table 1. TFW monitoring question framework and monitoring question/hypotheses examples – site scale mass wasting.

	TFW Monitoring Question Framework	Project Level Monitoring Question Example	Project Level Test Hypotheses Example
1A	Are timber harvest practices effective in preventing management-induced mass wasting? When a landslide occurs, is delivery to stream channels prevented?	*Are partial cut leave areas in the drainage heads of 0 and 1st Order channels effective in maintaining slope stability or preventing delivery of landslides when they occur?*	*Effectiveness of partial cut leave areas in the drainage heads of 0 and 1st Order channels will depend upon loss of root strength from windthrow and root strength and use of soil water by species, age and composition.*
1B	Are there factors that influence effectiveness?	*Are these practices effective on a variety of soil types, landforms, and climate regimes?*	*These practices are effective on all soil types and climate regimes.*
2A	Are road design and construction practices effective at preventing management-induced mass wasting? When a landslide occurs, is delivery to stream channels prevented or minimized?	*Is the spacing rule for relief culverts effective in slopes prone to shallow rapid landslides?*	*Effectiveness of the standard spacing rule will vary depending the specific conditions at each location and the degree of slope instability at the location.*
2B	Are there factors that influence effectiveness?	*Does effectiveness vary by slope position or bedrock type?*	*Effectiveness will vary by slope position with upper slope positions being more effective than mid or lower. Effectiveness will vary by bedrock type but also by site specific bedrock structure variation within a type.*
3A	Are road maintenance practices effective at preventing mass wasting? When a landslide occurs, is delivery to stream channels prevented?	*Is removal of sidecast from road prisms in concave positions but not on convex positions on all slopes greater than 55% effective in preventing mass wasting or delivery of landslide sediment to the stream channel?*	*Removing sidecast based upon slope morphology will be effective most of the time. Exceptions are expected where road drainage is divert to remaining sidecast independent of slope morphology.*
3B	Are there factors that influence effectiveness?	*Will effectiveness vary with climatic regime, slope position, and landform(landtype)?*	*Effectiveness will be lower in climatic regimes with high storm intensity, on mid and lower slope positions, and in highly dissected landforms or landforms with very shallow soils.*
4A	Are road management objectives (e.g. inactive, active, abandoned, limiting haul) effective in preventing mass wasting? When a landslide occurs, is delivery to stream channels prevented or minimized?	*Will stabilizing mid-slope roads with a long history of mass wasting and placing into abandoned status in lieu of continued active management status be effective in preventing mass wasting or delivery of landslide sediment to the stream channel?*	*Effectiveness will depend upon the effectiveness of each individual practice implemented in abandonment which are sidecast pullback, sidecast disposal, stream crossing restoration, etc.*

Table 1. TFW monitoring question framework and monitoring question/hypotheses examples – site scale mass wasting.

	TFW Monitoring Question Framework	Project Level Monitoring Question Example	Project Level Test Hypotheses Example
4B	Are there factors that influence effectiveness?	*Will effectiveness vary depending on soil parent material, bedrock type and landform.*	*Effectiveness will vary by landform although effectiveness will be more related to pre-existing condition of the road being abandoned.*
5A	Are restoration effective in minimizing delivery of the effects of mass wasting to stream channels?	*Will reconstruction of stream crossings to reduce dam/diversion potential be effective in preventing mass wasting and delivery to stream channels?*	*Changing stream crossing road grades to prevent stream diversion outside of channel will be effective in preventing mass wasting under these conditions.*
5B	Are their factors that influence effectiveness?	*Are there differences in slope position that influence practice effectiveness?*	*Effectiveness of this practice will not vary with site conditions factors.*

Table 2. Categories of management activities to address triggering mechanisms

ACTIVITY CATEGORY	TRIGGERING MECHANISM	COMMON PRESCRIPTION AND/OR STANDARD RULE
Timber Management -Harvest Layout -Type of Harvest -Yarding System -Site Preparation	Loss of root strength	"No cut" in hazard areas "Partial cut" in hazard areas
	Surface runoff	"Leave areas" in steep, convergent drainages Drainage prevented onto landings Complete avoidance of hydrological sensitive area
	Increase soil pore pressure	"No cut" in hazard areas "Partial cut" in hazard areas Complete avoidance of hydrologic influence zone
	Surcharging (Increasing surface load e.g, sidecast)	Landings compacted with no organic fill Avoid landings on hazard areas Directional fell to avoid slash accumulation in drainages
Road Management -Layout -Design/Construct -Maintenance -Abandonment	Interception and concentration of drainage	Minimum relief culvert distance and size Minimize "stacking" of roads Locate roads away from springs and seeps Avoid mid-slope roads on steep slopes Locate drains away from hazard areas
	Exceeding natural angle of repose for slope or soils	Avoid roads in inner gorges or other known unstable areas Limit cutslope angle
	Unstable sidecast	Full bench and end/haul on steep slopes No organic fill in road prism Remove unstable sidecast and dispose in a stable location Prevent drainage onto sidecast
	Drainage system failure	Upgrade culvert size and gradient in stream crossings "Dip crossings" Minimum/maximum road gradient Minimize stream crossings with road location Bridges in lieu of culverts Remove temporary roads prior to next storm season Road grading to keep surface drainage functional Replace damaged/worn culverts Add relief culverts Keep drainage structures functional on "inactive" roads
Restoration -Erosion Control -Road decommissioning	Drainage system failure	Restore stream crossings to natural channel condition Disperse road drainage with persistent waterbars when decommissioning roads
	Interception/Concentration of runoff – roads	Rip road surface when decommissioning roads Outslope road surface and disperse drainage with frequent persistent waterbars Reconstruct original slope contour and revegetate upon road decommissioning
	Surface runoff - harvest unit	Add energy dissipaters Revegetate Control and disperse runoff source (if from roads above)
	Increase pore pressure	Revegetate Restrict further vegetation removal with area influencing hydrology to the unstable area
	Unstable sidecast	Remove unstable sidecast and dispose in a stable location

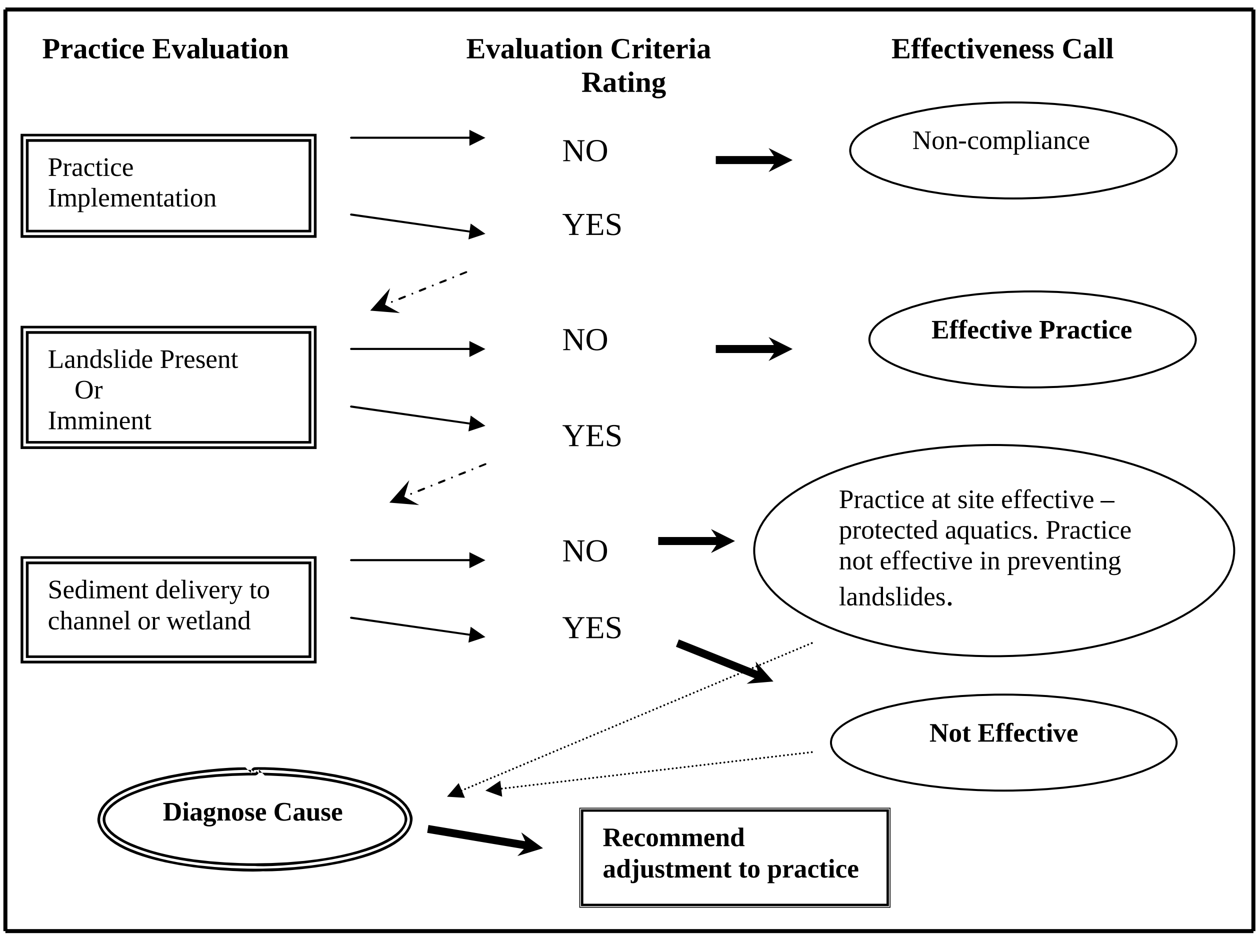
2.4 Evaluating Effectiveness and Diagnosing Cause

Effective practices either prevent mass wasting from occurring or if mass wasting does occur, sediment is not delivered to the stream network. The primary focus for the evaluation is prevention of mass wasting. Unlike surface erosion where chronic erosion from roads is often a fact of the practice and controlling delivery becomes a primary management strategy, generally for mass wasting processes, practices are designed to prevent mass wasting not to control delivery. Determining an "acceptable level" of mass wasting relative to natural background is difficult for the reasons mentioned in Section 1.1 and is best addressed at the watershed scale.

Delivery must be a component of evaluation because of the need to evaluate relative effect to aquatic condition. The measure of effectiveness is focused on the ability to predict when delivery will occur rather than the application of a practice to control delivery. Practices that control delivery are limited, often temporary, and usually very expensive.

The second component of the effectiveness evaluation is to diagnose the cause of ineffective practices. From understanding the relationship between the triggers and the practice, recommendations for refinement or change of the practice are made. The flow diagram in Figure 1 illustrates the process for effectiveness evaluations.

Figure 1. Effectiveness evaluation flow chart



The first step is to evaluate practice compliance with the management guidance for the site, i.e., Watershed analysis prescription, Habitat Conservation Plan, or Forest Practices Standard Rules or Special Conditions. Practices not implemented according to the guidance are considered not in compliance with the design and hence, not representative of the practice. Sites with non-compliant practices are identified and reported as a part of the analysis but they are removed from the pool of candidate monitoring sites.

Next, the compliant practice sites are evaluated for whether a mass wasting event is associated with the practice. If there is no landslide and no features at the site indicating a landslide may occur in the near future, the practice is evaluated as effective. If there is a landslide associated with the practice but there is no delivery to a stream channel or wetland, the practice is not effective in preventing landslides but effective at the particular site in protecting the aquatic resource. This is a very important distinction. This practice should be viewed as suspect in being effective universally. Site conditions are further evaluated to fully understand the factors that led to prevention of delivery. In this case, diagnosis of both triggering mechanisms of the landslide and factors preventing delivery is conducted. A recommendation to adjust the practice is made. Also, a recommendation outlining what conditions the existing practice could be used with a high degree of confidence that delivery would not occur.

If a landslide associated with the practice delivered to a stream channel or wetland, the practice is obviously not effective. The cause of ineffectiveness is diagnosed and recommendations for improvement in the practice are made.

The evaluation of individual practices has four probable outcomes. These outcomes are:

Outcome One: Effective - no landslides associated with the practice

Outcome Two: Effective in protecting aquatic resource/ineffective in preventing mass wasting - a landslide associated with the practice but no delivery

Outcome Three: Not effective – landslide associated with practice delivers to a channel

Outcome Four: Indeterminate – unable to discern whether landslide is related to practice

Outcome One should pass through one additional screen. If mass wasting has not occurred, the evaluation looks for indicators of triggers for future landslides and asks "Using what I know about triggering mechanisms, their lag times and effects of climatic regimes, does this practice appear to have avoided or controlled the expected triggers for this site?" "Has enough time passed to be a true test of the practice?" If the answer is yes to both questions, Outcome One practices can be rated effective.

Outcome Two effectiveness may be circumstantial and these practices should not be included in Outcome One. Effectiveness may be related more to local site factors, such as slope gradient or slope morphology, than to the actual practice. Site factors then become part of the prescription and the relationship to effectiveness between the two must be clearly identified. A practical example is taken from setting priorities for road maintenance or restoration. Selection priorities for removing unstable sidecast may be based on whether it is predicted to deliver to a stream channel if it fails. There is risk in making the wrong prediction but if delivery predictions are correct, the practice is effective. One would want to avoid making the judgement that selective removal of unstable sidecast is effective everywhere because the ability to predict delivery is variable by site and human factors. Hence, Outcome Two requires a further diagnostic step to evaluate mass wasting triggers and what prevented delivery.

Outcome Three goes directly to the diagnostic step to evaluate why mass wasting occurred.

In Outcome Four several situations may result in a very low confidence interpretation or indeterminate conclusion. These are, as follows:

- Several practices interact with triggering mechanisms and it is unclear whether the practice being evaluated contributed to the landslide.
- The extent of the landslide obliterates diagnostic features and the practice to the extent that an analysis of the interactions between triggers and the practice can not be made.
- Survey methods did not allow for confidence in the conclusions

Upon evaluating the entire set of monitoring sites, a trend should appear for the practice being evaluated. Effectiveness of the practice is reported in the percent of sites resulting in one of the four outcomes along with the number of sites observed. If results are variable, the diagnosis for each monitoring site is reviewed for site characteristics that can be attributed to the difference in practice performance. If more than one practice or site condition has been evaluated, this analysis is conducted for each situation.

Diagnosing Causes of Management Related Mass Failure

Diagnosing the cause of the failure leads to better understanding of the interactions of the practice with site factors and to defensible recommendations for improvements. One of the benefits of conducting effectiveness evaluations that track the pathway of sediment from source to delivery point is that throughout the survey there is an opportunity to observe the contributing causes of failure or success of a practice. Essential to diagnosis is the ability to observe signs left by triggering mechanisms and to recognize primary and secondary factors contributing to mass wasting or delivery. It is also important to collect enough site condition information so influences of site factors can been evaluated.

Questions to have in mind when diagnosing causes for failure in a practice effectiveness are:

- What triggers are associated with this kind of practice, site, or landslide type? Do you see indications of them at the site?

- What site conditions led to sediment being delivered or not delivered?

- What features of the practice addressed the triggering mechanisms? What triggering mechanisms were not addressed by the practice?
- How does the failure of this practice compare to a worse case scenario?

A field key for diagnosing triggering mechanisms for shallow rapid and deep seated landslides is provided in Appendix B. This key outlines the more common indicators for triggers and lists practices that address these triggers in certain site conditions. Another reference is Table 2 where triggering mechanisms and practices commonly used to address them are listed for each forest management category.

Evaluations within the context of "design life" of the practice

A dilemma exists in evaluating effectiveness of a practice that has an administratively established "design life". Design life is most commonly used in designing road drainage structures. Culverts are placed and sized for a certain storm recurrence. Design life was established in the past to obtain the greatest benefit compared to cost for road management. Past design life criteria may or may not be compatible with monitoring effectiveness goals of protection of the aquatic resource. It is important to understand the difference between compliance with design established administratively to meet aquatic resource goals and effectiveness in meeting aquatic resource goals. The best approach for recognizing this difference is to report effectiveness within the context of "design life", storm recurrence, and effects to the aquatic ecosystem.

An analogy can be made to harvest as well. Although "design life" is not a common aspect of design of harvest units, the degree of effectiveness is related to the storm recurrence. Some practices may fail under a 50-year storm event while others fail under a 500-year storm event. It would not be appropriate to ignore the difference. The best approach here is to compare rate of landslides with a reference condition under the same storm interval.

2.5 Design Elements of Monitoring

This section covers design elements of a monitoring project. Elements carefully outlined in the monitoring plan should be: 1) the use of stratified sampling and identification of situational categories: 2) site selection; 3) the sampling schedule; 4) level of certainty and sample size; 5) monitoring methods and; 6) data analysis and reporting results.

2.5.1 Stratification

A monitoring program that characterized every known variable would be a complex and costly venture. The challenge for an efficient but effective monitoring program is to identify logical groups or "situations" that best represent the range of variation needed to address the monitoring questions of the project. Analysis sensitivity can be enhanced by reducing the amount of variability or by grouping known variability into sample sets of predicted outcomes. These are called "situational categories".

The TFW Monitoring Program Plan suggests that a statewide system for stratifying monitoring situations would facilitate data management, aggregation of data sets to increase certainty in results through larger sample sizes, and extrapolation of findings, regionally. The discussion on stratification for site scale monitoring is presented here to meet this expectation.

Presented is a hierarchical approach to stratification. This provides flexibility for statewide and local study design needs and allows for extrapolation of results to similar situations. The problem statement in a monitoring plan may identify the need to evaluate the effectiveness of road maintenance practices over site conditions representative for the state. Another problem statement may identify the need to evaluate a certain road maintenance practice (e.g., sidecast pullback on 150 miles of road) in a particular watershed. Both of these monitoring projects are greatly assisted by stratification. The first example identifies multiple practices and multiple site conditions, the second example identifies a single practice under several site conditions. The regional stratification system provides a framework for both.

Site characterization often is confused with stratification. Groupings for stratification are purposefully broad. These groups are used to categorize similar basic attributes and to make useful distinctions for cataloguing observations and for site selection. They delineate situations of similar conditions and distinguish meaningful differences. They can be used to describe site conditions in general, but some site conditions may vary within a strata. Site characterization is an important companion to stratification. The purpose for site characterization is to collect data specific to the site being evaluated in order to understand how specific site conditions influence effectiveness. Site conditions are used in diagnosing causes of failure in effectiveness. Both site characterization and stratification are used in developing recommendations for improvement. Stratification is used to compile monitoring results and to extrapolate to similar landscapes.

In identifying situational categories, monitoring plans should follow the framework for site conditions and practice types presented in the following discussion. The framework has been designed to be sufficiently broad to allow for all possible situations. Consistently identified situational categories will provide the foundation for the TFW regional database.

2.5.1.1 Regional Stratification of Site Conditions

{Note: This approach is under further evaluation and review. Users are encouraged to use this framework with this understanding. Comments should be submitted to the TFW Monitoring Steering Committee}.

Climatic regime is the first layer and is defined at the largest scale (e.g., 1:350,000 – 1:500,000. Soil parent material group is the next layer and is defined at an intermediate scale using geologic resource mapping (e.g., 1:100,000 – 1:250,000). The third layer is Landtype which is delineated at the watershed scale (e.g., 1:24,000) and is defined by a combination of landform and soil parent material groups.

Climate

Physiographic Regions of Washington summarized in Pentec (1991) provides a division of the state that represents a surrogate for climatic regimes. It is based on a composite of Fiksdal and Brunengo (1980), Gallant (1986), and McDonald and Ritland (1979). These climatic regimes represent areas of similar storm recurrence, intensity, and duration. An additional climatic regime has been added to the original map, Olympic Rainshadow. Figure 2 is the map from Pentec (1991) with the new addition.

Figure 2. Physiographic regions of Washington

Monitoring plans should identify which physiographic regions are pertinent to the project. Selecting monitoring sites in different physiographic regions should assure evaluation of varying site conditions if that is one of the objectives of the monitoring project. To serve local or regional interests, subcategories may be identified further. These subcategories would be identified within these regions to assure consistency with the statewide stratification layer. An example of a subcategory may be a change in precipitation amount or type possibly indicated by a different composition of tree species (e.g., subalpine fir plant associations versus ponderosa pine plant associations).

Soil Parent Material/Geology Group Types

Lithology and surficial deposits play a major role in determining physical properties that influence mass wasting. The statewide framework identifies groups of bedrock or surficial deposit types that have basic differences in weathering properties, soil parent material properties, rock hardness, bedrock strata, and structural complexity. These groups are identified in Appendix A.

There are other aspects associated with geology that are as important to mass wasting processes but can not be included in such a broad stratification system. Aspects not covered in the statewide categories are: local structural differences within the same Lithologic Unit; local differences in density or texture of glacial till; separation of slight differences in one Lithologic Unit over another within the same bedrock hardness and origin; and fault altered zones. Some of these aspects are further stratified by the next layer, Landtypes. Others will be identified during site characterization. Another option is to create subcategories for local use when stratification will greatly enhance the study design.

Careful consideration should be made before adding subcategories to whether the addition describes a inclusion of small extent or a large area. Stratifying inclusions will serve to devote precious resources in evaluating a small and potentially, less significant situation. Many subcategories may be handled through site characterization. An example were subcategories might be useful is where a complex sedimentary bedrock group includes vastly different bedrock properties. By definition this group is broadly defined because the complexity is too intricate to be mapped at the scale of most geologic resource maps. The differences in bedrock type within the unit may be very relevant to findings. There are two choices: identify subcategories during site selection once the project area is selected or document the variability through site characterization.

Results for subcategories as well as regional categories should be reported to accommodate regional consistency goals while not masking potentially important findings in the subcategory. The monitoring plan should describe situational categories within the context of both statewide stratification and any additional subcategories.

Landtypes (provisional)

Landtypes provide a third layer of stratification combining landform features and parent material/geology groups to identify situations of predicted differences in mass wasting or sediment delivery potential. Linked to geomorphic process, landtypes broadly stratify differences in stream density, slope gradient, slope complexity (shape and length), efficiency in routing sediment, and hydrologic regimes (e.g., rapid runoff response to storms). Landtypes also stratify landscapes having different types, rates, extent, and frequency of mass wasting. Landtypes are the stratification layer were extrapolation of results will most likely be made. They also are essential in establishing reference landscapes for comparing the degree of mass wasting as natural background with management-related mass wasting.

At this point, landtype mapping is not available. Landtype concepts can be used to direct selection of candidate project areas. Once project areas are identified, landtypes are delineated and used in the site selection process. Appendix A provides instruction on development of landtype concepts.

Monitoring plans should outline what landtypes will direct site selection and the procedure used to identify landtypes.

2.5.1.2 Local Stratification of Site Factors

Slope morphology and slope position

The statewide stratification categories provide useful stratification for project level monitoring. Subcategories may be designed when pertinent to study design objectives. The slope morphology categories in Table 3 provides a convention for stratification. At the site characterization level, slope shape should be described both in the horizontal and vertical axis and slope gradient described as an absolute not a range.

Table 3. Stratification or site characterization of slope morphology

Slope shape		Slope gradient	
Complex	Convex	0-30%	65-75%
Concave	Planar	31-50%	75%+
		51-65%	

Slope position may be a possible local category but again it could be handled under site characterization as well. If used as stratification it should be kept simple. The categories upper, mid, and lower are suggested.

Land Unit

Landtypes delineate landforms averaging between 10 to 500 acres in size. Landunits are subdivisions of landtypes and are created when a unique landform/geology feature smaller than a landtype warrants more detailed stratification. Two examples are: inner gorge landforms and convergent headwalls. Both of these landforms are recognized in the Landtype legend but they occur at different scales across the landscape. Inner gorge landforms and convergent headwalls are very significant to mass wasting processes no matter at what scale. A land unit stratification layer delineates inner gorges and convergent drainage heads smaller than 10 acres. Another example of a land unit stratification layer is a computer generated map identifying areas of sensitivity based upon slope morphology.

2.5.1.3 Stratification Categories of Practice Types

There are numerous variations of forest practice types and restoration measures. The list in Table 2 is testimony to the wide range of practices. For consistency, categories have been developed for the TFW framework. Table 4 outlines activity categories and practice categories for cataloguing individual practices and restoration measures. These categories can also be used in study designs to stratify multiple practices to be evaluated at the site scale.

If the individual practice to be evaluated does not fit within a practice category, use the activity category to catalogue the practice and list the practice. Monitoring plans and reports should provide both categories and a detailed description of the specific treatment, practice or restoration measurements being evaluated.

Table 4. Practice type activity and practice categories.

Activity Category	Practice Categories	
Road Design/Construction	Location Drainage	Road prism Stream crossings
Road Maintenance Practices	Drainage Disposal of maintenance spoils	Sidecast Removal
Harvest	Clearcut Clearcut with no-cut leave area Clearcut with partial cut leave area	Partial cut No cut Plantation improvement thin
Restoration/ Mitigation	Revegetation Bioengineering Road obliteration	Stream crossing Disposal Sites

Road management/use levels may produce different results in mass wasting usually related to decisions about scheduling maintenance or drainage function. Stratifying studies of road maintenance practices by the following categories is recommended.

Table 5. Road management/use level categories

♦ Active	♦ Abandoned
♦ Inactive	

2.5.2 Site Selection

Candidate sites for monitoring are identified base on situational categories. For the earlier problem statement example in Section 2.2, below is a possible scenario for identifying candidate sites using the TFW stratification approach.

Example:

> *All roads with completed sidecast removal and all roads identified where sidecast removal was not necessary define the practice portion of the situation category. The activity category is road maintenance. The project area is XYZ watershed located in the Eastern Cascades physiographic region. Landtypes delineate both geology groups and landforms needed to stratify site conditions. From the local inventory the following site factors were used to identify delivery hazard: slope position, slope morphology, and slope gradient. Landtypes stratify general slope morphology and slope gradient adequately to meet project objectives. More precise data will be collected during monitoring. Slope position (i.e. upper, mid, and lower) is used to further stratify road location. Candidate roads and landtypes are overlayed. There are 10 landtypes in the watershed with five landtypes having slope gradients and slope morphology identified in the inventory as high hazard. We decide to focus on the landtypes stratifying high hazard site conditions. No high hazard situations coincide with upper slope positions in this watershed. So our situational categories are comprised of five landtypes, two slope positions and two subcategories of candidate roads i.e. no removal and removal. There are 30 candidate locations to select from for monitoring.*

Most statistical texts will suggest selection should be random from the entire population. Random selection from all possible sites is not a problem if precise location is not important or the variables are known or the number of variables are few. This is not the case in natural systems (MacDonald, 1991). In the example, the number of variables has been reduced to represent site conditions that occur more frequently and site situations where ineffectiveness is predicted. This greatly increases efficiency in focusing on a few important variables but maintains a range of representative variables for the study, at a reasonable expenditure of cost and time.

Assuring the candidate sites are in locations that are representative of the situation to be tested greatly increases efficiency of the evaluation. To reduce the likelihood of spending time

evaluating a site that is not representative, the next step screens candidate sites for the final pool of candidate sites. This screening is a combination of an office exercise and field reconnaissance.
Candidate sites are screened using the following criteria:

- Practice at candidate site was not implemented according to the prescription and is not representative of the practice.
- Evaluation requires a reference or control site. Candidate site lacks a representative control site that is isolated from practice effects or other non-representative variability.
- Interaction with other practices can not be adequately separated at the candidate site.
- Operations or completion of the candidate site do not allow for evaluation of effectiveness at the optimum time.
- Field reconnaissance verifies candidate site is not representative of site conditions or practice being tested (e.g., slope gradient, soil type).

Candidate sites that pass this screen become the pool from which the final selection of sites is made.

Monitoring plans should outline the process and what criteria will be used in site selection. Monitoring reports need to summarize the process and the criteria that was used for site selection and discuss the level of confidence in the sites evaluated in representing the issues outlined in the problem statement.

2.5.3 Frequency and Timing of Sampling

The triggering mechanisms associated with management-related mass wasting present an interesting challenge to monitoring efficiency and effectiveness. Lag times for increases in pore water pressure and loss of root strength may be years after the management activity. Identification of triggers for mass wasting works best when indicators are "fresh". Sampling immediately after storm events assures that signs left by runoff, spring activity, or impoundment at stream crossings will not be altered by subsequent storms. Table 6 outlines the optimum timing for monitoring mass wasting processes. The information in this table was adapted from Table 5.1 in Pentec (1991) adding emphasis to monitoring after landslide-causing storm events.

Table 6. Time scale for sampling mass wasting processes

Management Activity	Erosion Processes		
	Shallow Rapid Landslides	**Debris Torrents**	**Deep Seated Failures**
Harvest unit design	5-15 years after harvest Immediately after a landslide-causing storm event 5 years after broadcast burning	Immediately after a landslide-causing storm event	Beginning of photo record and/or instrumentation to stand hydrologic maturity
Road design/construction and maintenance	5 to 7 years after construction Up to 20 years for sidecast and landings with buried wood debris Immediately after a landslide-causing storm event	5 to 7 years after construction Up to 20 years for sidecast and landings with buried wood debris Immediately after a landslide-causing storm event	Beginning of photo record and/or instrumentation until stand reaches hydrologic maturity
Restoration	1-5 years after treatment Immediately after the first landslide-causing storm event	Immediately after a landslide-causing storm event	Beginning of photo record and/or instrumentation until stand reaches hydrologic maturity

If confidence in the initial monitoring observation for shallow-rapid and debris torrent landslides is high, a one-time observation per site should be adequate. Lag time in soil hydrology and complexity of triggering mechanisms of deep seated failures require progressive observation over several years. Timing and frequency of monitoring for deep seated failures should be determined on a site-specific basis and determined based on past rate and extent of movement.

2.5.4 Sample size

MacDonald (1991) states “the ability to detect a difference between two populations is a logarithmic function of sample size rather than a linear function. This means that increasing the sample size may make a substantial difference if there are very few samples (e.g., less than five or ten), but the benefits of increasing the sample size beyond about thirty or forty generally are very small."

For all but the simplest of sampling designs, time and resources will limit the ability to achieve a high level of statistical significance through large sample sizes. In other cases, stratifying carefully to assure that the array of practice types and site conditions are compared appropriately will limit the available candidate pool. The best approach is to have confidence in the sites undergoing evaluation by conducting the screening scheme suggested in Section 2.4 and to observe the maximum number of sites within resource constraints. Trend data collected from quality test sites is far better than collection of data with a high amount of background noise. The accumulation of observations made in a consistent manner over time will provide the level of evidence and with it, certainty in practice performance.

2.5.5 Methods

Procedures are covered in Part II, *Procedures and Methods* of this document. This section provides an overview of the methods and a few considerations in selection of methods. Monitoring plans should outline specific methods to be used in the project.

Careful pre-field screening to qualify sites to be monitored will save time by avoiding to collect data on situations not representative or anticipated. Pre-qualification steps should include assuring practices are in identified hazard areas and that practice implementation complies with the prescription or the Forest Practice application.

Site conditions should be characterized at each monitoring location. Specific details on prescriptions are recorded and variations at the site (within compliance) are described. As for consistently applied stratification, consistently recorded site characterization between monitoring projects allows for upward aggregation of data sets and extrapolation.

Monitoring projects evaluating a series of multiple practices within an activity category or practice category must evaluate effectiveness by the individual treatment or prescription. This allows for separation of the relative influence each treatment has on effectiveness. There are numerous treatments or prescriptions involved in road related effectiveness. Monitoring a segment of road for its effectiveness without identifying the specific treatments and how they controlled triggering mechanisms will bring ambiguous results.

Presence, absence *or potential* of management-related mass failure and mass failure type are evaluated. There are two approaches to the evaluation. Level One – qualitative and Level Two – quantitative. Level One evaluates effectiveness simply based upon a yes or no answer to "was there a landslide and was there delivery? Level Two measures the size of the landslide scar to obtain volume of sediment and estimated the percent of coarse and fine material transported to the stream or wetland system. This method is time intensive but an essential step if results may be carried over into a watershed scale sediment budget that can be integrated with channel response monitoring. A less time intensive approach under Level Two is to estimate landslide size and volume using a calibration factor from a small sample of measured sites. Landslide sizes would be noted generally as small, medium or large and then converted to volume estimates.

Both Levels produce a summary of the percentage of monitoring sites that were effective and those that were not. Both levels diagnose all sites with landslides.

2.6 Analysis and Reporting Results

Monitoring plans outline how the analysis will be conducted and generally what kind of information will be provided in the monitoring report.

The analysis should include the evaluation of monitoring data from each site and interpetation of how these results demonstrate effectiveness for the practice. Individual site observations are summarized by situational categories. Context is discussed in regards to storm recurrence and design life criteria. If there is more than one site condition evaluated, observations are analyzed for each condition and effectiveness is compared. Any differences in effectiveness related to site characteristics and not stratification are noted. Tabular summaries are organized by TFW stratification categories to facilitate data entry into TFW's corporate database

Monitoring reports should include:

- A brief review of the monitoring plan's purpose and methods
- A description of the site selection process
- A discussion of how and why methods may have been altered from the plan
- A review of the results relative to the monitoring questions/hypotheses
- A tabular summary of observations and a discussion of results
- A section on adaptive management discussing effectiveness of practices and recommended improvements
- An appendix with raw data.

A copy of the monitoring report, data, and maps showing monitoring site locations should be archived with the TFW Monitoring Program's information system. A system for permanent data storage locally is also recommended.

3.0 Watershed Scale Evaluation - Multiple Practices and Management Systems

Covered in this section is guidance in study design development for watershed scale evaluation of multiple practices and management systems. Discussed are elements important to developing a monitoring plan: 1) monitoring goals and objectives; 2) project scoping; 3) developing monitoring questions and hypotheses; 4) a discussion and approach for evaluating effectiveness; 5) considerations for study design; and 6) considerations in analysis and reporting results.

These guidelines are useful to those evaluating progress toward meeting management goals to reduce effects from mass wasting, such as for the TFW 5-year review, for comparing of different management systems' effectiveness in reducing delivery of sediment to stream channels, for providing feedback for improvement of management systems (adaptive management), for screening for practices that may need further evaluation at the site scale, and for accumulating evidence of effectiveness in protecting aquatic resources.

The focus of this section, primarily, is on the evaluation of controlling the acceleration of delivery of fine and coarse sediment to the aquatic system from management-related mass wasting. It is recognized that controlling sediment delivery from mass wasting is only one of the components in evaluating effectiveness in protecting the aquatic resource at the watershed scale.

Effectiveness evaluations should include other possible sediment sources, such as, surface erosion and streambank erosion. The TFW framework for monitoring surface erosion is available from the TFW Monitoring Steering Committee, *Effectiveness Monitoring of Forest Practices and Management Systems – Surface Erosion.* A TFW framework for monitoring bank erosion has not been developed to date. Also, management-induced sources should be compared with natural sources to understand the relative influence management-related sediment may be having on the aquatic resource.

Integrating evaluations of input sources with an evaluation of changes in the aquatic environment over time provides an opportunity to evaluate response. This document discusses considerations for integrating channel response evaluations with input source evaluations. Procedures and methods for evaluating channel response are not included in this document but are available from other sources. References for these sources are located in Section 3.5.

If resources are limited, monitoring plans should place a priority on source/delivery monitoring over channel response. Monitoring input processes provides the best means to link increases of sediment delivery to a source and allows for analysis of practice effectiveness that can lead to recommendations for improvement. If both types of monitoring are planned, study design elements should be developed jointly.

Watershed scale, for the purposes of this document, is considered either at the Watershed Administrative Unit (WAU) level or some aggregation of Watershed Administrative Units. Management systems currently in place and considered in this guide are Washington's Forest Practices Rules, Watershed Analysis, and Habitat Conservation Plans. Other management systems that may be considered in the evaluation are county regulations, USDA Forest Service Forest Plans, and other jurisdictional regulations operating in the watershed.

3.1 Goals and Objectives

To meet TFW program goals and objective for watershed scale monitoring, the following goal and objectives are identified to guide evaluation of management systems and multiple practices in a watershed.

Goal:

To support the TFW monitoring strategy by evaluating, at the watershed scale, the effectiveness of management systems in providing protection from delivery of fine and coarse sediment and by supporting adaptive management through recommendations to improve effectiveness.

Objectives:

1. To document and evaluate direct effects or changes in mass wasting processes, on a watershed scale, in response to multiple forest practices.

2. To evaluate if management systems are effective in recognizing mass wasting and sediment delivery hazard which prevents potential impacts to the aquatic resource.

3. To evaluate if management systems are effective in preventing adverse changes or encouraging recovery of impaired aquatic condition over time.

There are several assumptions that help support this goal and these objectives.

Assumptions:

Delivery of sediment from mass wasting associated with management practices constitutes an accelerated influx of sediment over natural background rates. Adverse affects to the aquatic resource are suspected when rate, extent, or frequency of mass wasting is accelerated over background rates.

Watershed scale evaluations of accelerated mass wasting delivered to stream channels provide an indication of the potential effect to the aquatic resource. The degree to which management systems direct forest practices or restoration measures in preventing mass wasting and its delivery of sediment to stream channels is a measure of effectiveness of the management system.

Changes in channel diagnostic features (e.g., width, depth, bank erosion, pool frequency, particle size) and sediment load (i.e., amount and particle size distribution) over time related to observed changes in sediment supply and stream discharge may be useful in determining influences of management systems relative to influences from natural processes.

3.2 Problem Statement

The first step in developing a monitoring plan is to obtain a clear understanding of the reason for monitoring and to record them in a problem statement. A problem statement summarizes the issues and clarifies the purpose and scope of the monitoring project. It provides focus for the monitoring plan and helps communicate the context for the project to others. The problem statement may identify priorities for the monitoring project. It states the objective for the evaluation.

Issues that direct monitoring at the watershed scale are identified by several means. Regional interests in a particular element of a management system such as maintenance plans or abandonment programs may direct a cooperative evaluation over several watersheds and landowners. Five-year watershed reviews of watersheds with a completed watershed analysis may focus a higher intensity of monitoring on a category of practices needing review as determined by the analysis. If relative sediment sources and hazard are not known, a five-year review would evaluate all practices at the same intensity. A study may be designed to address a statewide interest to compare performance of several management systems. And, interest in evaluating trends in watershed aquatic resource condition may direct a long-term study to monitor both input sources and channel response in several “benchmark” watersheds.

Depending on the purpose of the evaluation, the scope of the monitoring project may be limited to certain practice types. Since the relative effect of all input sources is important to understanding the cumulative effect of multiple practices on aquatic resources, a high level of certainty is needed to exclude practice types as input sources from the evaluation. All practices and all management systems in the watershed must be a part of the analysis to determine effectiveness in protecting the aquatic resource. But monitoring can be conducted at different levels of intensity depending on certainty. For example, if a watershed analysis has demonstrated that mass wasting is the primary source of management-related sediment in the watershed, the field evaluation may be limited to reconnaissance validation of watershed analysis findings and field evaluation of those practices determined to potentially place watershed condition at risk. On the other hand, a long-term benchmark study requires a high level of certainty over time and space of all sediment input sources, natural and management-related, to determine relationships with changes observed in a network of channel response monitoring reaches.

Below, is an example of a problem statement:

Example:

The Crystal Clear Waters Watershed has been managed under a watershed analysis for five years. During this time, landowners have used the findings from watershed analysis to prioritize road drainage upgrades and road abandonment. Harvest prescriptions have been implemented to retain root strength on steep, concave landforms (i.e. drainage heads, convergent headwalls) prone to shallow rapid landslides after clearcut harvest. The road maintenance plan has identified roads to be abandoned or upgraded (i.e. sidecast removal, drainage function upgrade) using a hazard/risk model developed from watershed analysis. During the five-year review we will evaluate watershed analysis recommendations and the hazard/risk model for road maintenance are serving to protect the watershed from sediment produced by management-related mass wasting.

The issue that directs this monitoring project is the need to conduct a 5-year review. The purpose is to provide an evaluation of watershed conditions relative to 5-year review standards by reviewing performance of multiple practices under the direction of the management system, watershed analysis. The scope of the monitoring project is all practices of all landowners guided by watershed analysis with an emphasis on road maintenance plans, hazard identification, and harvest prescriptions on steep slopes prone to mass wasting.

3.3 Monitoring Questions and Hypotheses

Once the problem statement is developed, the next step is to develop monitoring questions and from these questions, test hypotheses. Monitoring questions are developed from the purpose and scope of the problem statement. Hypotheses state what is expected from the findings of the evaluation. The study design is developed to prove or disprove the hypotheses.

A general framework of questions and hypotheses is provided in Table 7 to guide development of project-specific questions and hypotheses. Most watershed scale evaluations will have questions and test hypotheses similar to the example. Project specific questions may address specific emphasis in the evaluation, but should meet the intent of the TFW framework.

One study design approach is to identify generically all the potential issues for a watershed and evaluate them all. In some cases, particularly in watersheds where little is known about mass wasting processes and effects, this approach is warranted. In most watersheds, issues unique to the watershed are known and monitoring design can be streamlined to focus on those unique issues. For those watersheds where Watershed Analysis or other basin-wide investigations have been conducted, general issues have been examined. Reading module reports and the Casual Mechanism Reports will help identify unique issues and help determine the focus in study design. Where watershed analysis has not been conducted, the SEPA checklist and Forest Practice Applications may provide some insight to unique issues in the watershed. Using the local experience of forest practice foresters and cooperators will also be helpful in focusing on the important issues.

It is important to maintain an element of objectivity in designing the study and when reviewing background documents. One of the TFW framework monitoring objectives is to evaluate whether the issues have been identified correctly by the management system and the issues identified are used to guide management activities appropriately. The reader should review documentation with this in mind and structure monitoring observations to evaluate how well the analysis assumptions and recommendations measure up over time.

Depending on the level and certainty needed for the monitoring project, a wise choice may be to evaluate all issues but spend more effort on those issues that are of greatest concern. For example, some watershed analyses conducted in western Washington indicate that the relative contribution of sediment delivered to streams is, in this order, highest to lowest: landslides from roads or harvest, road construction, amount of road traffic, surface erosion from landslide scars, and hillslope erosion from harvest. A monitoring design could be stratified based on relative potential for sediment input. Of course, the relative rate and type of erosion must be evaluated for each project area to consider this kind of prioritization.

Monitoring only a sub-sample of the highest sediment producing sources is not advised for benchmark studies integrating channel response evaluations. The complexity in input and routing of sediment, spatially and temporally, warrants a thorough understanding of all input sources, both management-related and natural.

Table 7. TFW monitoring questions framework and examples of project level monitoring questions/hypotheses – watershed scale

	TFW Monitoring Question Framework	**Project-level Monitoring Question Example**	**Project-level Hypotheses Example**
1	What effects or changes in surface erosion delivered to stream channels are observed in response to multiple practices and management systems within the watershed?	*Over the last 5 years in implementing watershed analysis recommendations, has mass wasting delivered from roads and harvest practices been reduced to within approximated natural levels? In Springwater subwatershed, are turbidity levels maintained within Drinking Water Standards of 2 NTU at the municipal water supply intake?*	*Because the watershed has not received a significant storm event since implementing WA recommendations, it is expected that no mass wasting delivery has occurred associated with new practices compliant with WA recommendations. No mass wasting events will contribute to elevated turbidity levels in Springwater subwatershed.*
2	Are management systems effective in recognizing surface erosion and sediment delivery hazard? What is effective or not effective about hazard identification?	*Has mass wasting/delivery potential been identified in a manner that provides for prevention of mass wasting and/or delivery from road management activities and harvest activities? What is effective or not effective about hazard identification?*	*The mass wasting hazard map, A-2 and map unit descriptions are effective in identifying moderate and high hazard for general areas. The hazard/risk model used to prioritize work for the road maintenance plan has been effective in providing site specific guidance to road drainage upgrades and removal of unstable sidecast and locating roads for abandonment.*
3	Are management systems controlling fine sediment input to a level that is preventing adverse change or is encouraging recovery of an impaired aquatic condition?	*Has the deposition of fine sediment in pools and width/depth ratios changed over time in the selected response reaches? What relationship is suggested between management related sediment input, routing of stored sediment, and inputs from natural processes and the observed change in in-channel sediment or other diagnostic features?*	*Fine sediment levels in pools will decline over time as accelerated input of fine sediment from management decline. Channel depth/width ratios will change as coarse sediment is remove and stream depth increases. A lag response is expected as stored sediment is routed through the stream network.*

3.4 Effectiveness Evaluation

Effectiveness defined in the TFW Monitoring Program Plan (1997) is as follows:

> *"When aquatic resources conditions are in the desirable range, an effective practice or management system will prevent significant impacts to fish habitat, water quality or water quantity or changes in the watershed input processes that affect these conditions. When aquatic resource conditions are less than desirable, an effective practice prevents impacts and allows, or encourage natural recovery processes."*

Evaluation of management system effectiveness in controlling affects from management-related mass wasting can be defined as follows:

- Fine and coarse sediment delivery from management-related mass wasting is prevented or controlled within natural background – rate, extent, and frequency.
- Levels of sediment in stream channels are within the natural range of variability for the aquatic system or levels of sediment in stream channels are decreasing allowing for recovery of an impaired aquatic system.

TFW Monitoring Program Plan objectives and the TFW framework monitoring questions provide a structure for evaluating the various elements of management systems that influence effectiveness.

TFW Framework Monitoring Question One

This question directs us to assess the effect or change in mass wasting processes and sediment delivery in response to multiple practices in a watershed. The evaluation for effectiveness follows a similar pathway as for site scale evaluations. Situations, representative of the various practice types and site conditions, are evaluated for effectiveness. Because the situations are representative of the full range of practice categories and site conditions in the watershed, results from sample sites can be extrapolated to reflect conditions in the watershed. As in the Figure 1 illustration of the site scale effectiveness evaluation pathway, for watershed scale, situations representative of multiple practices are evaluated for preventing mass wasting and if not, preventing delivery of fine and coarse sediment to a channel. Causes for ineffective and partially effective practices are diagnosed and improvements recommended.

There is a choice of two evaluation levels. A Level One monitoring evaluation results in a summary of percentage of activity categories and within them, practice types that are effective or not effective. The rate, extent, and frequency of management-related mass wasting in compared over time and with an estimate of natural background rate, extent, and frequency stratified by different site condition situations. There is a qualitative assessment of representative practices stratified by different site conditions. Level Two results in a numerical index of sediment input relative to a natural background using a stochastic approach to illustrate rate and frequency. Extent is compared using stratification by different site conditions situations similar to Level One. Trend or change is an indicator of the relative effectiveness of management systems over time and can be used to compare with channel response monitoring and results from Monitoring Question Three.

Summarizing the effectiveness evaluation for either level too broadly may be misleading and risks oversimplification of findings. Observations are best described and analyzed in "raw" form. For example, report percentages by practice types or activity categories within situational categories that have been rated effective and those that have not. The numerical index in Level Two is reported as a percentage of the natural background index. The relative change of either the percentage of effective practices or percent sediment input over background suggests a trend in protection provided to the aquatic resource. The primary focus of the evaluation should be on the relative change or improvement by multiple practices categories directed by management systems, reporting effective practice types and management direction, and diagnosing management system direction that is not effective.

When channel response information is not available and the evaluation is compelled to draw conclusions about the relative protection of the aquatic resource, a standard approach to risk rating provides consistency in interpreting results. Table 8 outlines a risk rating matrix that has been empirically derived from the watershed analysis approach (WFPB, 1997) to interpreting results. This matrix should be used to guide the development of conclusions and not to make conclusions about relative effectiveness in protecting the aquatic resource.

Table 8. Rating effectiveness in protecting the aquatic resource from fine and coarse sediment input (provisional).

Relative Risk to Aquatic Resource	**Level One** (Averaged percent of situational categories effective in preventing fine sediment delivery)*	**Level Two**
Low risk of effects	>90% Number of landslides/sq mi are < 20% over reference condition by landtype.	<50% increase in rate; no increase in extent or frequency over background index
Moderate risk of effects	75-89% Number of landslides/sq mi are 21-40% over reference condition by landtype	50-100% increase in rate, < 20% increase in extent, and < 40% increase in frequency over background index
High risk of effects	<75% Number of landslides/sq mi is greater than 40% over reference condition by landtype.	>100% increase in rate or >20% increase in extent or >40% increase in frequency over background index

The remaining percentage of ineffective practices are evaluated for risk. If sediment input or potential for input is high, there may be justification to change the "relative risk" call to the next higher level. Rationale for this change should be explained.

TFW Framework Monitoring Question Two

This question directs the evaluation of how effective management systems are in recognizing mass wasting and sediment delivery hazard.

There are four evaluation criteria for this question:

- Hazard and triggering mechanisms are consistently identified throughout the watershed.
- Triggering mechanisms are correctly identified.
- There is a direct correlation with practice design and type with hazard and triggering mechanisms identified.
- Timing and design of practices is responsive to the level of hazard and risk to the aquatic resource.

Management systems must demonstrate all of the items listed below to be considered effective at recognizing hazard:

- Success in all four criteria elements with an adaptive management program that identifies and improves upon each of the four areas as needed or success in at least 90% of the land area in the watershed.
- A plan for addressing all high and moderate risk areas.
- Reasonable progress in mitigating high and moderate risk situations.

TFW Framework Monitoring Question Three

This question directs us to assess effectiveness in preventing adverse change or encouraging recovery of aquatic conditions. This question asks for validation that conditions of the aquatic resource are being protected. All sediment sources should be included in this evaluation. In fact, synthesis with other monitoring elements such as, large wood recruitment and fish passage will contribute to understanding the entire watershed scale picture.

There are two approaches to addressing this question with regards to effects from sediment input. The first approach is to infer protection of the aquatic resource using the evaluation of

Monitoring Question One and rating guidelines in Table 8. The second approach is to integrate the evaluation of sediment input with an evaluation of diagnostic features in selected channel response reaches.

The evaluation criteria element is trend or change in condition. The ideal context to compare change is "natural range of variability" for the aquatic system. In most cases, natural range of variability will need to be approximated. Reference sites having similar geomorphic characteristics as response reaches are rare. A decision pathway in Appendix C displays the elements and techniques in establishing a reference condition. It shows what elements are need to establish a reference site or when modeling of reference condition is warranted.

In some cases, confidence in reference condition is so low that trends in channel response may need to be compared from the first day when the monitoring site was established. In all cases, what ever reference approach is used, the approach must be qualified as to certainty in its relation to a natural range of variability, over time and spatially, relative to routing and deposition mechanisms in the watershed.

The following scenarios are offered to guide effectiveness evaluations:

Scenario One:
Decreasing trend in sediment input from forest practices/Relative risk to aquatic resources is low (Table 8)/High residual amount of elevated sediment in streambed – EFFECTIVE (high potential for recovery or channel has a naturally high incidence of armoring)

Scenario Two:
Increasing trend or no change in sediment input from forest practices/Relative risk to aquatic resources is moderate or high (Table 8)/ High amount of fine sediment streambed and channel depth is decreasing/width increasing . – INEFFECTIVE

Scenario Three:
Increasing trend in sediment input from forest practices/No adverse indices in channel response – INEFFECTIVE (high risk of adverse change)

Scenario Four:
Decreasing trend in sediment input from forest practices/No adverse indices in channel response – EFFECTIVE

Scenario Five:
Trend in fine sediment yield from forest practices is insignificant compared to background rate/Relative risk to aquatic resource is low (Table 8) – EFFECTIVE

Examples of modeling reference condition

Below are two examples of modeling reference condition for rate and frequency of sediment input. These are simplistic examples. Another example is illustrated in Benda (1995). Part II, *Procedures and Methods* describes a procedure for arriving at a reference condition for extent using subwatershed stratification.

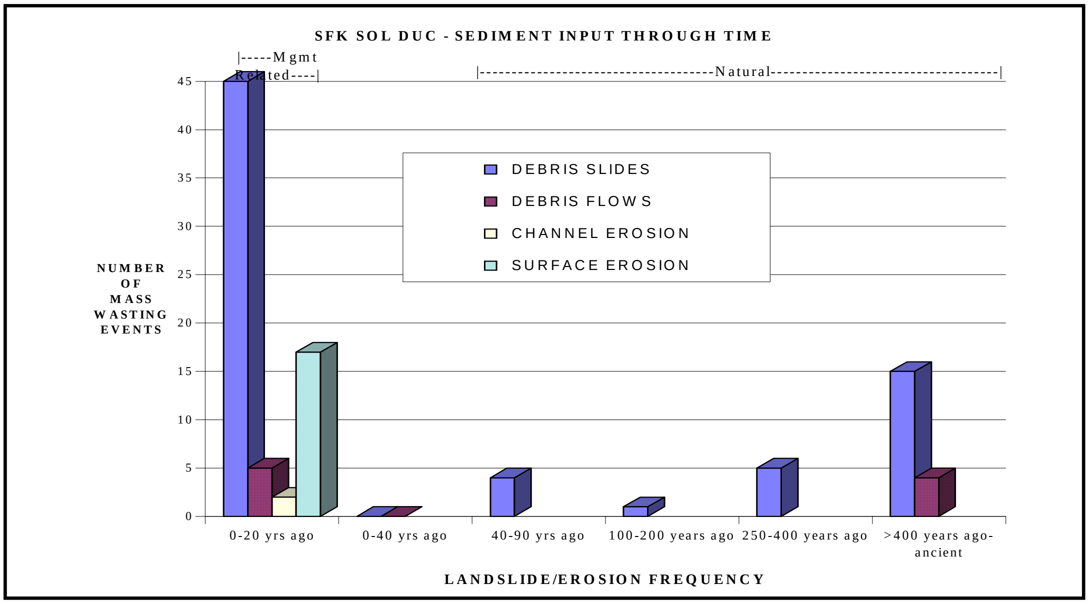


Figure 3. Example of a Level One approach to modeling a reference condition for mass wasting rate and frequency taken from the Sol duc Watershed Analysis (USDA, 1995).

In this example of using a Level One approach, the number of landslides were tallied for each subwatershed in the WAU. The subwatersheds were relatively similar in size and represented a unique array of situations that could be correlated to diagnostic features in subwatershed channels. A historical chronosequence of photography beginning with the year 1939 up through the present was used to inventory both natural and management-related shallow rapid landslides. Older landslides greater than 100 years were approximated using geomorphic features and stand age. What is not shown on this graph but was used to interpret relative effects of multiple practices are eras of different intensity of road building and harvest versus history of wildfire.

An approach using Level two is below. A stochastic model, R1/R4 Sediment Yield Model (1991) was used to model input of sediment from mass wasting and surface erosion through time. Sediment input (rate and frequency) from forest practices was calibrated using historic and field observations in the watershed. Wildfire history, landtype mapping using geomorphic process as mapping differentia, mass wasting inventory using historical chronosequence of aerial photography, and history of road building and harvest were data sources. Landtypes and the mass wasting inventory was used to calibrate the natural background rate, frequency and extent of sediment input. Landslides dated 100-500 years old were approximated using geomorphic features and stand age. Older events were generalized using wildfire history.

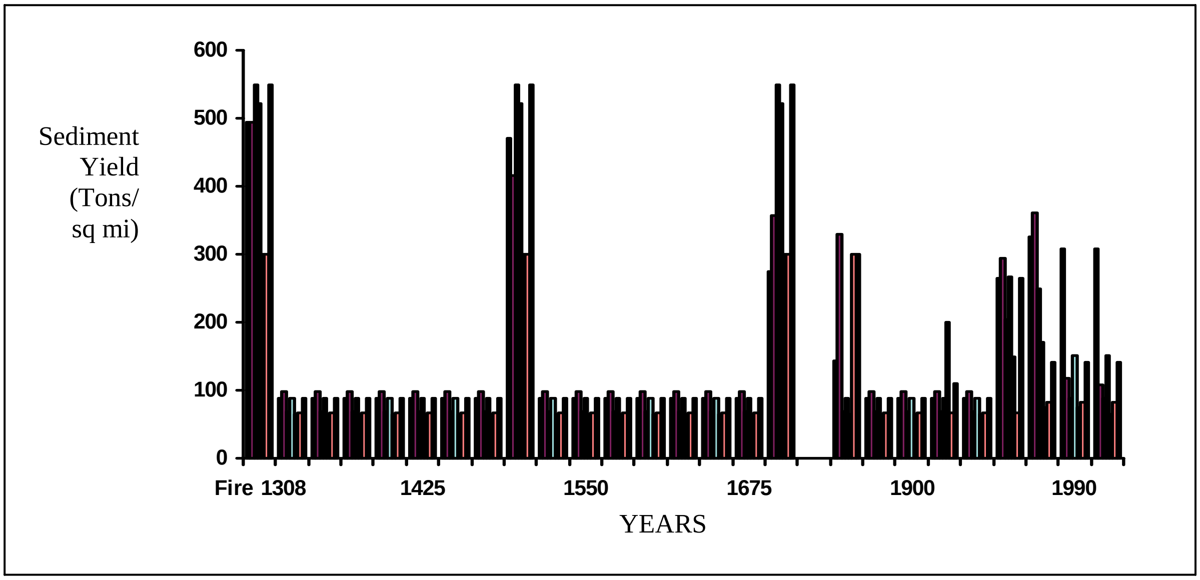


Figure 4. Example of a Level Two approach to modeling a reference condition for mass wasting and surface erosion rate and frequency taken from the Big Quilcene watershed analysis (WDNR and USDA, 1995).

This graph illustrates the change in rate and frequency starting with the first forest management entry of minor road building in the 1930's as represented by the first elevated yield after 1990. The cluster of elevated yields after the 1930 spike represents mainline road construction in the 1950's and full scale development in the watershed in through the 1970's. After 1980, low amounts of new road construction and harvest on low hazard landtypes results in the model showing a reduction in sediment input until wood debris in sidecast roads began to decay and fail during significant storm events. The graph shows periods where the management era rate approached natural background rate between wildfire periods. An analogy to monitoring change in effectiveness is when management systems began to removed sidecast and reducing other sediment hazards from roads, the model shows a trend moving toward a more natural range in variability in rate and in time, hopefully, frequency.

The entire WAU was modeled in this example. Providing a reference condition for each subwatershed will provide a better understanding of sediment flux that can be compared with channel response by subwatershed. (This reduces dilution of the analysis by decreasing routing distance between source and response which minimizes the degree of variability in input and routing mechanisms).

3.5 Design Elements of Monitoring

This section covers design elements of a monitoring project. Each one of these following elements should be carefully outlined in the monitoring plan: 1) the use of stratified sampling and the identification of situational categories; 2) site selection; 3) the sampling schedule; 4) level of certainty needed and sample size; 5) monitoring methods; and 6) data analysis and reporting procedures.

3.5.1 Stratification

Stratification is a useful tool in monitoring of uncontrolled settings such as in the natural resource environment. Efficiency is improved by organizing variables into distinct sample sets. Sensitivity of the analysis can be enhanced by reducing the amount of variability or by grouping known variability into sample sets of predicted outcomes. These are called "situational categories".

The TFW Monitoring Program Plan suggests that a statewide system for stratifying monitoring situations would facilitate data management, aggregation of data sets to increase certainty in results through larger sample sizes, and extrapolation of findings, regionally. The discussion on stratification for mass wasting monitoring at the watershed scale is presented here to meet this expectation.

Presented is a hierarchical approach to stratification. This provides flexibility for statewide and local study design needs and allows for extrapolation of results to similar situations. There are similarities between stratification for site situation categories for the site scale and watershed scale so that cross references can easily be made between monitoring scales for the same practice type.

Situational categories are determined by identifying site conditions important to mass wasting and delivery processes and the practices directed by management systems that influence mass wasting processes. Outlined in this section are the categories for site conditions and activity types for the TFW statewide framework. Several examples are provided demonstrating how further local level stratification may serve to stratify sampling further and enhance efficiency within the TFW framework.

Site characterization is an important component of monitoring and a companion to stratification. At the watershed scale, individual practices and site conditions may be grouped to categorize major differences. Minor differences are documented through site characterization. For further details on the difference between site characterization and stratification, see Section 2.5.1.

3.5.1.1 Regional Stratification Categories of Site Conditions

The same site condition categories used in stratifying individual practices and restoration measures at the site scale are used for watershed scale monitoring. There are three categories.

Table 9. TFW stratification categories for site conditions.

- Climate (Physiographic Region)
- Landtypes– a combination of Soil Parent Material Groups and Landforms
- Watershed analysis unit (WAU)

These categories are outlined further in Section 2.5.1.2 and in Appendix A. For watershed scale monitoring, landtyping becomes a useful tool in organizing a large area into a manageable number of strata to evaluate multiple practices and management systems over varying site conditions. Site conditions important to evaluating mass wasting and delivery mechanisms represented by Landtypes are: lithology, slope gradient, soil depth, slope morphology, sediment delivery efficiency, and slope hydrology. Landtypes also provide a tool to analyze basic differences in geomorphic processes that are essential in the site selection of channel response monitoring sites. Geomorphic processes and rate potentially interpreted by Landtypes are: mass wasting, surface erosion, snow avalanche, natural sediment delivery, sediment routing characteristics, and hydrologic regime. Landtypes become the basis for extrapolating monitoring results beyond a watershed.

3.5.1.2 Local Stratification of Site Conditions

Geology subcategories

In general, statewide categories should be sufficient for watershed scale stratification. Sub-categories may be developed within the statewide framework when useful to separate significantly different site conditions not separated by the broader statewide framework. An example where subcategories may be useful is when distinctly different mass wasting rates or frequency are observed for different lithologic units that are combined in the TFW Geology Group categories. Any most cases, site characterization will be adequate to describe the more subtle differences in site conditions or those not easily delineated at 1:24,000 scale. Examples better identified through site characterization are structural differences within the same lithologic unit or fault zone alteration.

Slope Morphology

Slope morphology, that is gradient and shape may be an optional stratification to landtyping although these categories do not provide the geomorphic process stratification necessary to establish reference condition or for easy extrapolation of results. If these categories are needed, it is best to tier them within the Landtype framework.

See Section 2.5.1.2, Table 3 for slope morphology categories. All monitoring situations should have slope gradient and slope shape described as a site characterization element in addition to the situation category.

Subwatersheds

Stratifying situations by subwatershed allows for a higher certainty in conclusions when attempting to connect hillslope monitoring with channel response monitoring. Some subwatersheds may support different aquatic species dependent on the specific environment produced by a unique array of geomorphic process. Stratifying watershed scale observations by subwatershed is mandatory for a more specific analysis that may be compared with trend data on species or their habitat.

A combination of subwatershed, Landtypes, and reach morphology is recommended for monitoring site selection of channel response reaches. Sediment flux, hydrologic regimes, and general channel morphology can be compared between tributaries using Landtypes which aids in stratifying subwatersheds by similar and unique characteristics in the watershed. Developing a network of channel observations representative of the differences between tributaries may help make connections between flux in sediment input, routing, and deposition.

3.5.1.3 Stratification Categories of Management Systems and Multiple Practices

Forest practices are directed by a variety of sources or “management systems” in a watershed. There are numerous variations on forest practice types and restoration measures directed by management systems. Management systems are continually changing and improving and it should be anticipated that several eras of management systems will be influencing mass wasting processes in the watershed. Watershed scale evaluations provide an overview of effectiveness of all practices. Multiple practices are stratified into logical groups that represent all practice situations but retain enough detail that problem practices can be identified and the cause for ineffectiveness can be diagnosed.

The following categories are sufficiently broad to cover most practice and management system situations occurring in a watershed.

Table 10. TFW stratification categories for management systems.

- Forest Practices Rules: standard and conditioned
- Watershed Analysis
- Landscape Plans (proposed management system)
- Habitat Conservation Plan
- National Forest Management Plans or other
- Total Daily Maximum Load (TMDL) Plans

In addition, for TFW Framework Monitoring Question Two, the specific mass wasting/ delivery hazard identification approach used by management systems becomes a local stratification. Activities directed by management systems and observations of mass wasting are evaluated using this strata to determine effectiveness in recognizing hazard.

There may be overlapping management systems, where a previous, no longer existing management system has left "legacy" practices. To meet TFW Monitoring Program goals, all practices including legacy practices are evaluated under current management systems recognized in the watershed. The expectation is effectiveness monitoring should include the evaluation of management system's actions in mitigating fine sediment input from legacy practices as well.

Table 11. TFW stratification categories for multiple practices.

- Road Design/Construction
- Road Management/Use
    - Active
    - Inactive
    - Abandoned
- Harvest
- Restoration/Mitigation
- Road Maintenance

Sometimes patterns of practice types or design can be identified with "management era" of activity or location of activity. These patterns can be used to further stratify situations at the local project level. For example, often road construction and road design practices can be grouped into "management era" categories. Below is a example of "management era's" and road design features common to several watersheds the Olympic Peninsula Physiographic Region. An example in using location of activity might be road location (e.g., valley bottom roads, toeslope roads, midslope roads, and ridgetop roads).

Example:

Pre-60's: Roads with cut/fill designs, few cross drains, reconstruction of old railroad grades, unconsolidated fill with buried debris.

60-70's: Roads on steep slope gradients constructed with sliver fill and sidecast. Infrequent cross drains. Locations on steep, mid-slope positions. Often with grades less than 6 percent.

80 –90's: Roads on steep slope gradients constructed with full bench construction. More frequent cross drains. Steeper road gradients than previous eras.

90's+: Increased road maintenance and road drainage upgrades. Restoration measures, such as abandonment of roads. Includes older roads that have been upgraded to current standards.

3.5.2 Site Selection and Sample Size

The discussion for site selection and sample size is divided into two parts: sediment source/delivery monitoring and channel response monitoring.

Sediment Source/Delivery Monitoring

After situational categories are identified, sample size is determined based upon the level of certainty needed, the number of replications of the situational category in the watershed and the land area within the watershed of each situational category. The higher the number of replications of a situational category, the more certainty needed in the evaluation, and the larger the area represented by a category, the more extensive the observations should be.

Five year reviews:

All new activities within the last five years are evaluated for implementation compliance.

For watersheds that have completed analysis, issues described in the analysis can be used to determine the relative need for certainty, thus, sample size. Situations where mass wasting was identified as an issue in the analysis should receive a higher number of observations than situations where mass wasting was not identified.

For watersheds without a complete watershed analysis or other watershed scale assessment that determines relative influence of management sources of mass wasting, all multiple practice categories should be examined to meet the same level of certainty. A preliminary reconnaissance may be helpful in eliminating practice categories and site conditions where mass wasting potential is low. Using mass wasting hazard identification tools may be helpful in identifying site conditions prone to mass wasting. Mass wasting hazard should not be used exclusively or biased sampling may occur. Practices should be eliminated based upon watershed analysis or field examination. An example to illustrate this point can be made using unstable road sidecast. Mass wasting of unstable sidecast occurs both on slopes that are naturally prone to shallow rapid landslides and slopes that have steep gradients but lack other natural triggers that cause slopes to be prone to shallow rapid landslides. If the sampling design was based solely on where high hazard for shallow rapid landslides was expected, the data set would be biased and exclude important observations regarding causative factors solely related to management.

Below, identification of situational categories and candidate sites is illustrated using the earlier problem statement example in Section 3.2.

Example:

Landtypes are stratified for the Crystal Clear Waters Watershed. It is noted that the watershed falls within the East Cascade physiographic region. Twelve landtypes have been identified representing the array of site conditions in the watershed. Two landtypes delineate areas with a potential high hazard for shallow rapid landslides. One landtype is associated with convergent slope hydrology where interaction of natural and management-related triggers have caused culvert failures and sidecast failures in the past. Another landtype delineates areas with ancient deep seated landslides. Watershed analysis is the current management system and multiple practice activity categories identified are: all subcategories of Road Management; Road Maintenance, Restoration, and Harvest. The situational categories are the union between activity categories and all 12 landtypes. The map of landtypes is overlain by the map of locations of activity categories in the watershed. There are 72 possible combinations. Results from watershed analysis and quick field reconnaissance to validate WA findings, it is determined that 25 situations of landtype and different practice categories have any likelihood of mass wasting.

Candidate sites are selected replicating situational categories needing a high level of certainty in results and land area represented in the watershed. It was decided that a high level of certainty was needed for practices conducted on the three landtypes with known triggering mechanisms for mass wasting. All candidate sites within these situations will be evaluated. The landtype with the largest land area happened to have a very low likelihood of mass wasting for any practice type, so replications were planned only to assure observations included any unanticipated variability within the stratification categories for that situation. The same strategy was used for the remaining landtypes that replications were planed to assure observations included any unanticipated variability within the stratification categories. Replication and selection of candidate sites were based on having adequate sampling in two subwatersheds were channel response monitoring was also taking place.

Evaluation of hazard recognition, TFW Framework Monitoring Question Two, requires that all activities be identified so management decisions on location and design can be compared to identified hazard. A stratified sample based upon issues identified in the watershed analysis may bias the evaluation of hazard recognition. In the event that the watershed analysis or other management system misinterpreted hazard or misidentified hazard, the evaluation should be independent of the previous analysis. All practices within the 5-year review period should be included in the sample set and not stratified by issues described in the previous watershed analysis.

Channel Response Monitoring

The watershed is stratified by subwatersheds. Unique subwatersheds are identified by the distribution of Landtypes. The ideal in site selection for channel response monitoring is to establish a network of monitoring sites that may illustrate routing behavior and response over time. The more isolation of hillslope processes and other hydrologic variables, the clearer the evaluation of response may be. A network of sites is established by identifying a response monitoring area in every subwatershed that has unique conditions in site variation and management situations. In addition, two or three sites should be established in the mainstem channel representing a “mid” and “lower” mainstem position.

Low gradient reaches, less than 4 percent gradient, are candidates for selection. The reality in site selection is the challenge in finding low gradient reaches in some subwatersheds. “Step-pool” response sites may be as useful in the upper watershed network as “pool-riffle” or “pool-dune” reaches are to monitoring in mainstem channels.

3.5.3 Frequency and Timing of Sampling

Sediment Source/Delivery Monitoring

The five-year review time interval may be too short of an interval to evaluate multiple practice effectiveness in preventing mass wasting. Because lag times for triggering mechanisms can be longer than 5 years, (e.g., loss of root strength after harvest may take five to ten years, increase pore water pressure in deep seated landslides may take the accumulations of several wet year cycles), an evaluation five years after practices are implemented may not be conclusive. The benefit of a five-year review is that it provides a chronosequencing of observations that can lead to conclusions of multiple practice performance at the ten-year or fifteen-year review. Also, project planning can take one to several years which means a sample site may have been in place for only 2-3 years of the five years being assessed. Nevertheless, the state of condition of a watershed can be addressed for all management systems i.e., legacy practices from past management systems and new practices of current management systems. At the five-year review, conclusions should be limited to addressing Monitoring Question One and Monitoring Question Two and within the context of lag times for mass wasting processes. Effectiveness evaluations and adaptive management recommendations concerning mass wasting should be reserved for the ten-year and fifteen-year reviews.

To assist the five-year review, supplemental implementation monitoring during implementation or within the first year of a new practice will facilitate evaluations of acute sediment delivery connected with construction. It also provides documentation at the five-year that can be summarized for reporting of implementation compliance. If there has been very little activity since the last five-year review, it may be practical to carry the few records of implementation monitoring forward to the next cycle where more extensive activity can be evaluated.

Monitoring during or immediately after a severe storm event may improve certainty in visual observation methods. It is also advised that evaluations be conducted soon after the season's wet period, (e.g., snow melt or rain season and prior to ditch clean-out and road grading). The opportunity to see diagnostic features of triggering mechanisms diminishes with time and the degree of management activity that has taken place since the mass wasting event.

Lag times for mass wasting response differs for each practice category as illustrated in Table 6 in Part I, Section 2.5.3. This table may be useful in placing monitoring observation into context and judging whether enough time has past to test the practices to support a conclusion of effectiveness.

Channel Response Monitoring

In general, every five years is an appropriate monitoring time interval with the addition or adjustment of timing to capture channel alteration by significant storm events. A long term commitment to channel response monitoring is needed to evaluate change. A minimum of 15 years and more is a minimum with some indication that 25-30 years may be a suitable timeframe for streams west of the Cascade divide (Robison, 1996; Robison, 1998; Benda, 1995). The timeframe may also be dependent on watershed size. A shorter timeframe may be adequate for smaller watersheds with fewer variables than for larger watersheds (Benda, 1995).

3.5.4 Methods

Part II, Monitoring Procedures and Methods of this document covers in detail the procedures for evaluation of management system effectiveness. This section provides an overview.

Sediment Source/Delivery Monitoring

Level One: Effectiveness is evaluated using a field reconnaissance approach. A representative subset of multiple practices under each management system operating in the watershed is evaluated for implementation compliance and is qualitatively assessed for effectiveness in controlling erosion and/or delivery. The relative change in effectiveness is summarized for field surveyed practices and then extrapolated to the remaining unsurveyed practices.

Level Two: Each practice type within each management system is evaluated for its relative contribution of sediment. Site scale monitoring methods Level Two and Level Three are used to evaluate a subsample of practices. The results are extrapolated to closely similar practices. A sediment budget is calculated to contrast all sources of sediment (including surface erosion, channel bank erosion and natural processes) and to evaluate change in the amount of delivery by source or practice type.

Channel Response Monitoring

No less than three response reaches are evaluated for changes or effects from sediment deposition or suspended sediment.

A **Level One** approach is suggested in the following reference:

> Grant, G. 1988. The RAPID Technique: A New Method for Evaluating Downstream Effects of Forest Practices o Riparian Zones. USDA Pacific Northwest Research Station GTR-220.

Level Two methods are covered in the following references:

> Schuett-Hames, D., A. Pleus, L.Bullchild, and S. Hall.1994. Ambient Monitoring Program Manual. TFW-AM9-94-001. Northwest Indian Fisheries Commission and Washington Timber-Fish-Wildlife, Olympia, WA.

> Ramos, C. 1996. Quantification of stream channel morphological features: recommended procedures for use in watershed analysis and TFW Ambient Monitoring. TFW-AM9-96-006. Washington Timber-Fish-Wildlife, Olympia, WA.

3.6 Analysis and Reporting Results

The analysis should include an evaluation of multiple practice type under varying site condition and an interpretation of trends in aquatic condition. Effectiveness is reported by percentage of observed practices preventing mass wasting and sediment delivery and those practices that did not prevent mass wasting or delivery. A discussion with an explanation of cause for failure in effectiveness and the relative effect on the aquatic resource is included for ineffective practices or management systems. As discussed in the previous section, the conclusions of effectiveness from the analysis are dependent on the length of time and exposure to storm related triggers. Trend in change of mass wasting rate or extent can be described at any time period but should be related in context to lag times for some mass wasting processes to occur. A discussion formulating recommendations for improved performance is included

An analysis of effectiveness of management systems to recognize hazard is conducted. Recommendations for improvements to hazard identification and recognition are included in the discussion of results of the analysis.

If channel response monitoring is conducted with source monitoring, an analysis integrating understanding of input sources, influence of other variables such as stream discharge and geomorphic process, predicted effects, and observed changes in channel conditions should be used to draw conclusions about trends in aquatic condition.

All assumptions, data, and results are discussed and included in the report. Tabular summaries by TFW stratification categories are used to facilitate data entry into TFW's corporate database. A level of certainty is provided for data collection, extrapolation, field reconnaissance, and in the interpretation. If models are used, assumptions and calibration factors are documented.

An adaptive management section is included which discusses the conclusions of effectiveness of each management system and practice types and recommends any further actions or improvements, if any.

Monitoring reports should include:

- A brief review of the monitoring plan's purpose and methods
- A description of the site selection process
- A discussion of how and why methods may have been altered from the plan
- A review of the results relative to the monitoring questions/hypotheses
- A tabular summary of observations and a discussion of results
- A section on adaptive management discussing effectiveness of practices and recommended improvements
- An appendix with raw data.

A copy of the monitoring report, data, and maps showing monitoring site locations should be archived with the TFW Monitoring Program's information system. A system for permanent data storage locally is also recommended.

4.0 Quality Assurance

Monitoring is a commitment in personnel and funding resources that warrants that the outcome be useful to many. To assure that monitoring objectives are addressed appropriately, it is advised that monitoring plans be developed under the co-guidance of management personnel and technical personnel. Management personnel can help clarify purpose and scope of the project. Technical personnel should have experience in developing study designs, in performing data analysis and be a qualified analyst in Watershed Analysis. Methods may be carried out by those with a variety of skills. But it is recommended that a qualified earth scientist experienced in evaluating geomorphic processes and hazard be available to oversee field evaluation and to respond to more complex evaluation situations. The best combination of skills for field diagnosis of a practice is personnel with local knowledge of the watershed and practice implementation and personnel with experience in sedimentation processes and practices designed to control surface erosion and delivery of fine sediment. Skills needed for channel response monitoring are experience in evaluating fluvial geomorphic processes.

Reviews of monitoring plans and reports by others with monitoring experience will bring added assurance that resources are used efficiently and effectively. Review of monitoring plans and monitoring reports should be an established role of the TFW Monitoring Steering Committee.

Part II: Monitoring Procedures and Methods

5.0 Site Scale Monitoring

This section covers procedures and methods for conducting an evaluation of individual practices or restoration measures at the site scale. These procedures are intended to guide the implementation of monitoring plans using TFW guidelines covered in the previous section, *Part I – Study Design Guidelines.* Evaluated are practices or restoration measures under one site condition or varying site conditions. Effectiveness is evaluated for one treatment or a series of related treatments when effectiveness is contingent upon a series of related treatments.

The purpose of site level monitoring is two-fold: 1) to evaluate effectiveness of individual practices in preventing impacts from management-related mass wasting inputs and 2) to diagnose causes for ineffectiveness and recommend improvements for better effectiveness.

5.1 Summary of Approach

Monitoring methods conduct an evaluation of mass wasting associated with the individual practice and use a qualitative confirmation of triggering mechanisms. When mass wasting is found to be associated with the practice, practice design, site factors and triggering mechanisms are analyzed to develop a diagnosis for the cause of the failure. Recommendations for improvement are made based upon the diagnosis and show a clear pathway from failure and diagnosis to the recommendation.

There are two levels of analysis that determine the level of data collected during monitoring. Level One uses a qualitative approach. Effectiveness is addressed by “yes/no” and “why”; that is, the site has a mass failure or it does not and the reason is explained by a narrative. Results are reported in percentage of monitoring sites representative of the practice that are effective and sites not effective. Level Two quantifies the volume of sediment and particle size so that a sediment budget can be calculated. Results are reported in cubic yards delivered. Both levels conduct the same diagnosis/recommendation step.

A Level Three approach may be warranted under some circumstances. Methods are not covered here as it is beyond the scope of this document. Level Three employs the use of instrumentation to monitor ground movement or soil hydrology where a high degree of certainty in findings is desired. Level Three may be appropriate in deep seated landslides where a site specific study plan and monitoring procedure is developed to evaluate changes in movement and triggering mechanisms over time. Level Three also covers research interests and validation of the qualitative assessments used in Level One or Level Two.

Procedures are organized in the following order:

- **Step One:** Review project objectives, monitoring questions and hypotheses.
- **Step Two:** Identify candidate monitoring sites.
- **Step Three:** Screen activities for implementation compliance.
- **Step Four:** Gather site level plans. Pre-inventory candidate sites. Select monitoring sites.
- **Step Five:** Inventory selected practices to characterize site factors.
- **Step Six:** Evaluate practice effectiveness and diagnose ineffective practices. Level Two – measure volume delivered.
- **Step Seven:** Summarize. Report findings and recommendations.

5.2 Procedures

Step One: Review project objectives, monitoring questions and hypotheses

Review the problem statement, monitoring questions, and hypotheses in the monitoring plan. Before proceeding, clarify purpose and study design elements to assure the monitoring effort will meet project objectives. Discuss monitoring plan and project objectives with stakeholders (e.g., management representative, monitoring plan author, TFW Monitoring Steering Committee) for clarification. Refine the monitoring plan in collaboration with stakeholders, if needed. Identify whether a monitoring pre-test is warranted to become familiar with methods. If the monitoring plan does not state, determine whether Level One or Level Two methods will be conducted.

Step Two: Identify candidate monitoring sites

Delineate site condition categories and locations of the practice or restoration measures in the potential project area. This process varies depending on scale of the project. For project area selection for regional and statewide evaluations, potential project areas are selected based on site stratification using Physiographic Region and Geology Groups and where the practice is known to be represented. For local or landowner specific projects, the potential project area is usually predetermined by landownership or watershed boundaries.

Once the potential project area is known, locations for the practice or measure to be evaluated are identified and marked on a map at 1:24,000 scale. Delineate stratification categories including Landtypes (see Section 2.5 and Appendix A) at the same scale, 1:24,000. Landtypes are mapped using 7.5 minute USGS topographic quadrangle sheet and orthophotography (optional) as a base and stereo-pair aerial photography. The landform component of landtypes is recognized using stereo-pair aerial photography and contour shape of the topographic maps. Geology group categories (see Section 2.5 and Appendix A) are identified from geologic resource maps at 1:100,000 or 1:250,000 scale, whichever is available. Some refinement in locations of surface deposits can be aided by soil survey maps.

Develop other stratification layers pertinent to the problem statement and hypotheses, (e.g., slope gradients, soil parent material sub-categories, and azimuth). Once developed, these maps represent the locations of various situations, both site and practice, that are available for sampling within the project area.

Overlay maps. Identify where the union of site conditions and practice location appear to meet the scope and needs for testing hypotheses as stated in the monitoring plan. These become the initial list of potential candidate sites.

Step Three: Screen activities for implementation compliance

Potential candidate sites identified in Step Two are then discussed with the local managers, foresters, engineers or forest practice foresters familiar with the project area and the practice to gather local knowledge about each site. Documentation of activities will vary with landowner and often, verbal history may provide important details about the compliance of a practice or history of changes to the site. Some questions to ask are:

1. What site level decisions were made in the design or implementation that are different that the WA prescriptions or FPA?
2. Do you feel that the activity was in compliance with the prescription or forest practice rules? Why or why not?
3. Are there particular locations of the practice that stand out as different from others? If so, how did they affect application of the activity or performance history?

Practices at potential candidate sites will most likely fall into one of three categories:

- High level of confidence in correct implementation
- Not implemented according to prescription
- Unsure if implemented according to prescription

The first and third categories remain candidate sampling sites. Activities in the third category should be visited in the field, with the local administrator if possible, to eliminate any doubt if the practice at that particular site was implemented correctly or not. A spreadsheet or form created to track each candidate site through the screening procedure is recommended. Table 12 illustrates a spreadsheet with the key elements to track through the entire screening process. Formats for tracking the screening process are at the discretion of the practitioner.

Table 12. Candidate sites for site scale monitoring.

Part 1: Office Screen

Site Number	Practice Type	Date Implemented	Landtype	Soil Parent Material	Slope Gradient (Map est.)	Delivery potential (yes/no)	Accessibility to site for monitoring	Implemented according to plans	Additional notes on local site conditions or on implementation or practice	Sample site candidate
1	*Road aband-onment*	*1996*	*53*	*Crescent Basalt*	*70%*	*y*	*10 miles on good road*	*Yes; according to abandonment design no. 1*	*Road engineer says the project is a good example of the site conditions in the watershed. Contractor met all the contract specifications without a problem.*	*yes*
2	*Road aband-onment*	*1996*	*53*	*Crescent Basalt*	*30%*	*n*	*5 miles on good road*	*Yes; according to abandonment. design no. 1*	*Road engineer says there were no perennial stream crossing and very little sidecast pullback. The site is representative of abandonment of a low impact road.*	*No (limited site variables).*

Part 2: Field Screen

Site Number	Practice Type	Implementation Date	Landtype	Soil Parent Material (actual)	Slope Gradient (actual)	Delivery potential (yes/no)	Accessibility to site for monitoring	Implemented according to plans (field)	Isolation of practice	Good control nearby	Sample Population site
1	*Road aband-onment*	*1996*	*53*	*Crescent* **Basalt**	*73%*	*y*	*10 miles on good road*	*Yes; according to abandonment design no. 1*	**Yes**	*Yes*	*Yes*
2	*Road aband-onment*			Candidate site deleted – not representative of test site variables							

Step Four: Gather site level plans. Pre-inventory candidate sites. Select monitoring sites.

The candidate sites that have been identified through Step Three pass through one more screen in Step Four. Candidate sites for sampling are visited in the field to assure they are representative of the site variables, to evaluate available control sites if needed, and to assure that the practice can be adequately isolated from factors unrelated to the study design. This step verifies that candidate sites are fully qualified as representative of the practice or restoration measure.

If possible, visit each candidate site with local managers familiar with the implementation or maintenance of the practice. They can provide the best background to evaluate whether the site will be a good representative candidate for the practice and site conditions.

It is important that this step be conducted objectively. This step is not to bias the sample selection but to assure that candidate sites are representative of conditions established by the monitoring problem statement and hypotheses. This step also is a cost savings step to avoid wasting time on sampling sites that would be discarded later because of an anomaly.

Make a note of all locations where practices and site factors meet the selection criteria. A good place to keep track of this evaluation is on the same spreadsheet developed for the office screening procedure. Example entries in Table 12, Part 1 and Part 2 illustrate a hypothetical candidate site tabulation.

Randomly select the number of sites identified in the monitoring plan from the candidate pool. A random selection process that is commonly used is to assign a number to each site. Then use a random number generator to select numbers randomly. In some cases, stratification and screening may limit the number of candidate sites to a level where certainty as established in the study design can not be met. If this occurs, the project area and candidate list must be expanded or the monitoring plan must be revised to lower certainty in the monitoring results.

Step Five: Inventory selected practices to characterize site factors.

Characterize site factors at each monitoring site. Site factors described should include:

- Slope gradient: field measured above and below the practice location
- Slope shape (vertical and horizontal plane): convex, concave, planar, complex
- Slope position
- Delivery distance to stream channel
- Azimuth
- Elevation
- Site description of structure and weathering characteristics of regolith and geology

- Depth of soil and regolith at the site
- Vegetation cover of erosion source: species and percent cover
- Slope hydrology: perched water tables, concentrated runoff, etc.
- Plant community description: overstory and understory indicators of climatic regime or Plant Association
- Diagnostic features indicating slope instability

Review the TFW effectiveness evaluation criteria in Part I, Section 2.4 and any project specific evaluation criteria described in the monitoring plan. Forms 1 through 3 provide a general format for data collection. This data will accompany summarized results in the monitoring report. You may design your own form to accommodate project specific needs. For consistency in data collection, take care to collect the elements in the TFW forms.

Step Six: Evaluate practice effectiveness and diagnose cause of *ineffective practices*

At each monitoring site, work through the evaluation pathway in Figure 1, Part 1, Section 2.4, to determine practice effectiveness. The possible outcomes of the evaluation are:

> **Outcome One:** Effective – no landslides associated with the practice.
> **Outcome Two:** Effective – landslide present but sediment was not delivered to the stream system or to a wetland.
> **Outcome Three:** Not effective – landslide or diagnostic features of instability indicate landslide is imminent. Delivery to the stream system has occurred or will occur.
> **Outcome Four:** Indeterminate – unable to discern whether landslide is related to the practice.

The effectiveness evaluation can be recorded for each site at the bottom of the site characterization forms (Forms 1-3).

Form 1 – Mass wasting and harvest practices site characterization

Harvest Unit ID:______________________ Database No. (optional):_______________
Location: T____R____Sec. _______ Date:_______________________________
_____¼ 0f ______1/4 Landowner Contact:___________________
Reviewer(s): _________________________

Silviculture

☐ Clearcut Harvest date:_________
☐ Clearcut w/leave strips
Leave strips: TPA left:_____ Ave. DBH:_____ Species by %:______ _______ _______
☐ Partial cut
TPA left:_____ Ave. DBH:_____ Species by %:______ _______ _______

Harvest Method: ☐ Ground-based ☐ Cable ☐ Full Suspension ☐ Unknown Other:_________

Site Prep: ☐ Broadcast burn ☐ YUM ☐ Hand pile/burn ☐ Tractor pile/burn ☐ None

Site Characteristics: (as identified in the field)
Slope gradient: ____% Azimuth: ________
Slope position: ☐ Upper 1/3 ☐ Mid ☐ Lower 1/3
Slope shape (Concave=C: Convex=X; Planar=P): ___/____ Complexity: _____complex ______smooth
(vertical/horizontal axis)

Hydrologic Characteristics:
Stream Order: _____ ☐ Springs/Sag ponds/wet depressions/Seeps ☐ Springline
Evidence of Wet Soils (optional): ☐ FeO2 mottles w/in 1 meter ☐ Gleyed
Discharge estimate(optional): _____cfs

Bedrock Characteristics: (as identified in the field)
Formation (optional):__________________ Rock Type:______________ Weathering: _____________
Structure: ☐ Massive ☐ Interbedded ☐ Dipping downslope ☐ Massive beds over soft, erodible beds
Other:____ ☐ Highly fractured/jointed

Surficial Materials (Soil Parent Material): (as identified in the field)
Depth to bedrock (ft):________________ Impermeable Layer (y/n):_______ Depth (ft):___________
Material Type: ☐ Colluvium ☐ Till ☐ glaciofluv/fluv ☐ lacustrine/marine

Geomorphic Process and Instability indicators: (as identified in the field)
Landtype:_______________________________________
LandUnit: ☐ Convergent drainage-head ☐ Bedrock hollow ☐ Low Order Inner Gorge*
☐ High Order Inner Gorge* ☐ Shoulder ☐ Sideslope
☐ Other:____

Instablity Features: ☐ Tension Fractures ☐ Landslide deposits ☐ Landslide paths ☐ Creep Other:____
____________________ ____

EFFECTIVENESS EVALUATION

Mass failure present(y/n)____ Type: ☐ Shallow-rapid ☐ Debris Torrent
☐ Deep seated-small,sporadic ☐ Deep seated-large,persistent
Mass failure imminent (y/n)_______Explain:

Delivery to stream channel (y/n)____ Stream Type (DNR):______ Volume (optional):___w___d___l
Particle size (%vol):___<2mm;____2-75mm
*Low Order=Stream Orders 1&2 High Order=Stream Orders >3 ____76-250mm;____250-600 mm

Figure 1. Site characterization and effectiveness evaluation field form for harvest activities.

Form 2 – Mass wasting and road practices site characterization

Road No. ______________________ Database No. (optional):________________
Milepost: ____________ Date:________________________________
Location: T____R____Sec. ______ Landowner Contact:__________________
_____¼ 0f ______1/4 Reviewer(s): __________________________

Road Management Practice:

(Select One) (Select One or more for site)

☐ DESIGN/CONSTRUCT Relief Culvert:__Outfall; ___Spacing; ___Size;___Removal
Road prism:___fill; __cut; __gradient; __sidecast removal; ___Scarify
☐ MAINTENANCE Stream crossing failure: __ponding;__diversion; __culvert size;__Removal
Location:____midslope; ____upper slope;__lower slope
☐ ABANDONMENT Drainage:___ ponding; ____outsloped w/o ditch; ____insloped w/ditch
___ditch performance;___restore natural;___waterbars
Other:____________ Other:_____________

Comments:____

Site Characteristics: (as identified in the field)
Slope gradient: ________% Azimuth:_______
Slope position: ☐ Upper 1/3 ☐ Mid ☐ Lower 1/3
Slope shape (Concave=C: Convex=X; Planar=P): _______ Complexity: _____complex ______smooth
(vertical/horizontal axis)

Hydrologic Characteristics: (as identified in the field)
Stream Order: ______ ☐ Springs/Sag ponds/wet depressions/Seeps ☐
Evidence of Wet Soils (optional): ☐ FeO2 mottles w/in 1 meter ☐ Gleyed
Discharge estimate (optional): _____cfs

Bedrock Characteristics: (as identified in the field)
Formation (optional):_________________ Rock Type:_____________ Weathering: _____________
Structure:☐ Massive ☐ Interbedded ☐ Dipping downslope ☐ Massive beds over soft, erodible beds
Other:____ ☐ Highly fractured/jointed

Surficial Materials (Soil Parent Material): (as identified in the field)
Depth to bedrock (ft):________________ Impermeable Layer (y/n):_______ Depth (ft):___________
Material Type:☐ Colluvium ☐ Till ☐ glaciofluv/fluv☐ lacustrine/marine

Geomorphic Process and Instability indicators: (as identified in the field)
Landtype:____________________________________
LandUnit: ☐ Convergent drainage-head ☐ Bedrock hollow☐ Low Order Inner Gorge*
☐ High Order Inner Gorge* ☐ Shoulder ☐ Sideslope
☐ Other:____

Instablity Features: ☐Tension Fractures ☐Landslide deposits ☐ Landslide paths ☐ Creep

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EFFECTIVENESS EVALUATION

Mass failure present(y/n)____ Type: ☐Shallow-rapid ☐Debris Torrent
☐ Deep seated-small,sporadic ☐ Deep seated-large,persistent
Mass failure imminent (y/n)_______Explain:

Delivery to stream channel (y/n)____ Stream Type (DNR):______ Volume (optional):___w___d___l
Particle size (%vol):___<2mm;____2-75mm
*Low Order=Stream Orders 1&2 High Order=Stream Orders >3 ____76-250mm;____250-600 mm

Figure 2. Site characterization and effectiveness evaluation field form for road management.

Form 3 – Mass wasting and restoration measures site characterization

Site ID:______________________ Database No. (optional):_______________
Road No/Milepost:_____________ Date:________________________________
Location: T____R____Sec. ______ Landowner contact: __________________
_____¼ 0f ______1/4 Reviewer(s): _________________________

Restoration Measure:

☐ Sidecast Removal ☐ Road decommission
☐ Stream crossing restoration ☐ Chronic Erosion Practices: __Broadcast seeding: ___Planting;
☐ Road drainage stabilization ____ Bioengineering;___Mulch;___erosion mats:___other

Other/Comments: (Vegetation cover/species,etc)

Site Characteristics: (as identified in the field)
Slope gradient: _____% Azimuth:_______
Slope position: ☐ Upper 1/3 ☐ Mid ☐ Lower 1/3
Slope shape(Concave=C: Convex=X; Planar=P): _______ Complexity: _____complex ______smooth
(vertical/horizontal axis)

Hydrologic Characteristics: (as identified in the field)
Stream Order: ______ ☐ Springs/Sag ponds/wet depressions/Seeps ☐
Evidence of Wet Soils (optional): ☐ FeO2 mottles w/in 1 meter ☐ Gleyed
Discharge estimate (optional): _______cfs

Bedrock Characteristics: (as identified in the field)
Formation (optional):__________________ Rock Type:______________ Weathering: _____________
Structure:☐ Massive ☐ Interbedded ☐ Dipping downslope ☐ Massive beds over soft, erodible beds
Other:____ ☐ Highly fractured/jointed

Surficial Materials (Soil Parent Material): (as identified in the field)
Depth to bedrock (ft):________________ Impermeable Layer (y/n):_______ Depth (ft):___________
Material Type:☐ Colluvium ☐ Till ☐ glaciofluv/fluv☐ lacustrine/marine

Geomorphic Process and Instability indicators: (as identified in the field)
Landtype:_________________________________
LandUnit: ☐ Convergent drainage-head ☐ Bedrock hollow☐ Low Order Inner Gorge*
☐ High Order Inner Gorge* ☐ Shoulder ☐ Sideslope
☐ Other:_______________________________________

Instablity Features: ☐Tension Fractures ☐Landslide deposits ☐ Landslide paths ☐ Creep

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EFFECTIVENESS EVALUATION

Mass failure present(y/n)____ Type: ☐Shallow-rapid ☐Debris Torrent
☐ Deep seated-small,sporadic ☐ Deep seated-large,persistent
Mass failure imminent (y/n)_______Explain:

Delivery to stream channel (y/n)____ Stream Type (DNR):______ Volume (optional):___w___d___l
Particle size (%vol):___<2mm;____2-75mm
*Low Order=Stream Orders 1&2 High Order=Stream Orders >3 ____76-250mm;____250-600 mm

Figure 3. Site characterization and effectiveness evaluation field form for restoration.

All monitoring sites are diagnosed for causes for failure in preventing mass wasting whether they deliver or not. Sites that have a landslides but did not deliver are diagnosed for the reason the reason the landslide occurred and why delivery did not occur. Only practices that demonstrate they controlled delivery are rated effective. In many case, although there are exceptions, delivery is more a function of slope morphology and drainage patterns and management systems' ability to recognize delivery hazard than a function of practice design.

This diagnostic step gathers information needed to support a recommendation for improvement of a practice. The approach requires good detective work, using observations during site characterization of signatures or "footprints" of runoff or erosion and constructing an understanding of the triggering mechanisms at the site. Practice design is evaluated for whether the design addresses the triggering mechanisms and whether site conditions influenced the design's effectiveness. Imagine how water and sediment moved through the area before and after the practice was put in place. How did the forest practice alter natural processes? What role did site factors play in affecting landslide and delivery response?

Appendix B contains a **Key to Diagnosing Causes of Management-Related Mass Wasting** which provides a guide to systematic diagnosis of triggering mechanisms and evaluating prescription performance. To experienced practitioners this Key will provide a systematic way of structuring the diagnoses of causes and for less experienced, this Key serves as an introduction to the more common erosion situations in the forest management environment and their causes. Practitioners may find a need to expand or combine some of the triggering mechanisms to adequately represent mechanisms occurring at a site. Certainty can be improved by comparing a reference condition from similar site conditions without the practice. In the absence of a reference site nearby, an empirical reference can be developed through evaluation of the mass wasting inventory for the watershed using landtypes to stratify historical mass wasting response to storm recurrence and other forms of disturbance. A flowchart illustrating the considerations that one should make in obtaining a reference condition is provided in Appendix C.

Level Two

If Level Two is being conducted, measure the dimensions of the landslide scar or tension crack which ever is applicable. Form 1 through Form 3 have an area to record landslide scar dimensions. If conducting qualitative monitoring of deep seated failures, shallow rapid landslides may occur along the margins and slope breaks of these features. Dimensions can be measured. For those evaluations where change in rate of movement is being monitoring, establish several permanent points to measure to the tension crack and then measure the width, depth (if possible), and length. Shallow rapid landslide scars are usually wider at the initiation point and width tapers to the lower extent. Measure the cross-sectional area of at least points along the scar and average the area. (Percent of volume delivered is estimated which does not support the need for a high level of accuracy in measuring cross-sectional area of the landslide scar).

Estimate the percent of sediment volume that delivered to the stream system using the following standard:

100% delivery – landslide toe connects with channel.
Partial % delivery – compare deposit volume with landslide volume. The difference was delivered.
0% delivery – landslide toe is greater than 150 feet from channel.

Examine soil regolith and estimate or conduct sieve analysis to determine percent fines (<2mm) and three classes of rock fragment sizes (2-75mm; 76-250mm; 250-600mm.)

Record results for each monitoring site on Form 4 – Summary of individual practice effectiveness - mass wasting. Italicized entries in this form illustrate an example summarizing the effectiveness evaluation at each monitoring site.

Summarize for practices with associated landslides, the cause of failure and recommend an approach for practice improvement on Form 5 – Practice diagnosis report and recommendation for practice improvement. Use statements that show a clear pathway demonstrating how the diagnosis supports the recommendation.

Form 4 – Summary of individual practice effectiveness – mass wasting.

Practice ID	Monitoring Site Practice Type	RX or Treat-ment	Effective (E) or Ineffective(I) (Landslide Type/Size)	Trigger or causative agent	Physiog. Region	Geology Group	Land Type	Local Strata:		Sediment Delivery: Level One (y/n) Level Two: cu yds
								Slope Position	*MWMU Map A-4*	
R-001	*Road abandonment*	*Stream crossing restore*	*I mass bank erosion; moderate*	*Culvert pulled from fill stream eroding to original base level through fill (80% fill delivered fine sediment)*	*Southern Cascade*	*Andesite*	*53*	*mid slope*	*3*	*y*
R-002	*Road abandonment*	*Stream crossing restore*	*E*		*Southern Cascade*	*Andesite*	*53*	*mid slope*	*2*	
R-003	*Road abandonment*	*Stream crossing restore*	*E*		*Southern Cascade*	*Andesite*	*53*	*mid slope*	*3*	
R-004	*Road abandonment*	*Sidecast pullback removal*	*I imminent shallow rapid landslide w/delivery; large*	*Unstable sidecast remaining; Tension cracks in fill and leaning 20 year old alder on concave/concave slope and 70% gradient w/direct delivery. Sidecast disposal is directing runoff to unstable sidecast.*	*Southern Cascade*	*Hard Sedimentary*	*53*	*mid slope*	*3*	*y*
R-005	*Road abandonment*	*Sidecast pullback*	*E*		*Southern Cascade*	*Hard Sedimentary*	*53*	*mid slope*	*2*	
R-006	*Road abandonment*	*Sidecast pullback disposal*	*E*		*Southern Cascade*	*Hard Sedimentary*	*53*	*mid slope*	*2*	
R-007	*Road abandonment*	*Sidecast pullback disposal*	*I Shallow rapid; small*	*Material piled in concave/concave draw diverted seasonal runoff to fill slope*	*Southern Cascade*	*Hard Sedimentary*	*53*	*midslope*	*5*	*y*

Form 5. Practice diagnosis report and recommendation for practice improvement.

WAU: *Example Creek*
Practice Reference Number: *R-001*

Situation Sentence: *Fine and coarse sediment from a shallow rapid landslide initiating from roadfill positioned in a concave O order drainage which was saturated by outfall from relief culvert drainage. This landslide delivered to a Type 4 channel.*

Triggering Mechanisms: *Relief culvert spacing is over 1000 feet distance between culverts. Ditch scour indicates large volumes of runoff flow to this relief culvert. Location of culvert directs outfall onto toe of fillslope that is resting on a steep (65% slope gradient) concave O order drainage.*

Additional Comments: *One mile of this road was evaluated for culvert spacing and location. Several other relief culverts direct outfall onto concave O order drainages. Some signs of gully erosion are evident.*

Suggested Corrective Action: *Landslide removed 50% of road prism presenting a safety hazard to vehicular traffic. Relocation of relief culvert should be incorporated with road prism reconstruction. An application of mulch will reduce chronic erosion. Natural revegetation is expected within 5 years.*

Recommendations for Practice Improvement: *Roads drainage systems located in Landtype 77 and Mass Wasting Map Units 1 should be closely reviewed for stable dispersion of road runoff and signs that current runoff presents further hazard for shallow rapid landslides. The overall concave nature of this landform presents difficulty in dispersion of runoff. Relief culvert outfall onto O order drainage with no defined channels appears to present a stability hazard. Outfalls are best located onto bedrock outcrops, into defined channels, and on to convex positions.*

Step Seven: Summarize. Report findings and recommendations.

Review data and evaluate relationships between results and site factors characterized at the site and those site conditions stratified by the study design. Consider under what conditions results might apply to similar situations outside the project area.

Prepare a monitoring report that presents the following elements:

- A brief review of the monitoring plan’s purpose and methods
- A description of the site selection process
- A discussion of how and why methods may have been altered from the monitoring plan
- A review of the results relative to the monitoring questions/hypotheses
- A tabular summary of observations, Form 4, and a discussion of results including site conditions that influenced effectiveness at each monitoring site

- A section on adaptive management, and Form 5, discussing practice effectiveness and recommended improvements
- An appendix presenting raw data, photographs, site characterization data (Forms 1, 2 and 3)

Discussions should include a statement of level of confidence in the work, how the findings should be used or limited in linking to other monitoring efforts, and what adjustments or additions are recommended to TFW standard methods used.

5.3 Outline of the Monitoring Report

The following outline provide a guideline for monitoring report. Reports are concise and at a minimum, cover the following areas:

I. Executive summary of findings
- Key findings and overview of monitoring objectives

II. Overview of monitoring plan and project area
- Review of monitoring plan: problem statement, monitoring questions and hypotheses
- Description of site conditions and practice types evaluated.
- Reference to other monitoring efforts with similar objectives
- Any other pertinent information relative to how the monitoring effort was implemented that may be helpful to others interpreting results

III. Discussion of methods and procedures
- Descriptions of stratification used, the site selection process, and choice in method used
- Specific project evaluation criteria and discussion on how TFW evaluation criteria was used to evaluate effectiveness
- Changes or additions to standard procedures and methods
- Recommendations for change of standard procedures and methods

IV. Discussion of effectiveness of the practice or measure evaluated and under what site conditions
- Summary of monitoring observations - Form 4 and discussion results for each monitoring question/hypothesis. Discussion includes sites that were effective and those not effective, and why. What aspects of site conditions characterized at the site and those stratifying the study design influenced effectiveness
- Recommendations for adaptive management - Form 5 and with explanation of what site conditions the recommendation for improved practice applies

V. Appendix
- Field data, worksheets, Forms 1, 2, and 3
- Background on procedures used other than standard, as approved by TFW Monitoring Steering Committee
- Photographs

6.0 Watershed Scale Monitoring

This section covers procedures and methods for conducting an evaluation of multiple practices and management systems at the watershed scale. These procedures are intended to guide the implementation of monitoring plans developed using TFW guidelines covered in the previous section, *Part I – Study Design Guidelines*.

The focus is different from site level monitoring. Watershed scale monitoring evaluates effectiveness of all practices combined and the effectiveness of management systems in directing practices that protect the aquatic resource from adverse impacts or allow for recovery of an impaired aquatic environment.

6.1 Summary of Approach

There are three TFW Framework monitoring questions for watershed scale monitoring. These questions are:

- What effects or changes in mass wasting processes are observed in response to multiple practices in the watershed?
- Are management systems effective in recognizing mass wasting and sediment delivery hazard?
- Are management systems effective in controlling levels of sediment input that prevent adverse change or encouraging recovery of impaired aquatic resource condition over time?

For the first and third question, two levels of procedures are covered: Level One – A Reconnaissance Method and Level Two – A Sediment Budget Method.

Level One conducts a reconnaissance mass wasting inventory and compares performance in preventing mass wasting by multiple practice activity category. Effectiveness in controlling sediment input is evaluated using visual indicators of mass wasting and sediment delivery to stream channels. The percentage of effective versus ineffective multiple practice categories is contrasted by subwatershed and site condition categories. Level One provides a simple, cost-effective method intended for quick assessments and is the minimum level for five-year reviews. Level One supports channel response monitoring by providing qualitative information on location by subwatershed and extent of sources within the watershed. Combining data collected for watershed analysis and cumulative five-year reviews provides information on how sediment sources change over time which can be compared to response observed in the stream system.

Level Two conducts a sediment budget analysis by multiple practice activity category. Effectiveness is evaluated based on change in rate, or rate, frequency, and extent of sediment input from mass wasting and contrasted with a background rate or rate, frequency and extent. This level supports synthesis with channel response monitoring by providing a numerical index of sediment input, both management-related and natural background.

The monitoring plan is an important support document to these procedures. It establishes all aspects of study design for the monitoring project including selection of either the Level One or Level Two approach, identifies project-level monitoring questions if any, and specifies situational categories to be evaluated.

Procedures for each level are discussed in the following order:

- **Step One**: Review project objectives, monitoring questions and hypotheses.
- **Step Two**: Gather existing data, become familiar with watershed conditions, and delineate situational categories.
- **Step Three**: Evaluate mass wasting and delivery from multiple practices and management systems.
- **Step Four**: Compare change or effects in sediment input (mass wasting).
- **Step Five**: Evaluate management systems effectiveness in identifying hazard and impact.
- **Step Six**: Conduct synthesis of channel response monitoring results and sediment source/delivery monitoring results. Interpret effectiveness of protecting or allowing for recovery of aquatic resource condition.
- **Step Six**: Diagnose for improved effectiveness.
- **Step Seven**: Summarize. Report findings and recommendations.

6.2 Procedures

Step One: Review project objectives, monitoring questions and hypotheses.

Review the problem statement, monitoring questions, and hypotheses in the monitoring plan. Discuss monitoring plan and project objectives with stakeholders (e.g., management representative, plan authors, TFW Monitoring Steering Committee) to resolve any questions.

Step Two: Gather existing data, become familiar with watershed conditions, and delineate situational categories.

Gather data needed to become familiar with site conditions and forest practices that are influencing mass wasting processes in the watershed. Watersheds with assessments (e.g., watershed analysis or habitat conservation plans) will have maps identifying hazard, mass wasting inventories, and prescriptions for conducting forest practices. Watersheds without assessments will have Forest Practice Applications and sometimes, Special Class IV conditions and geotechnical reports. Become familiar with local site conditions by reading the watershed analysis, other planning documents, documents supporting the Forest Practice Application, driving or flying over the watershed, and by interviewing local administrators and technical experts. Gather information on intensity, duration and frequency of storms to establish an understanding of long term pattern.

Obtain field data sheets from previous mass wasting inventories. If surface erosion sources are active in the watershed, gather existing data and plan to integrate surface erosion monitoring with the mass wasting evaluation.

Collect the most current year of aerial photography and available historical aerial photography. Historical photography is needed to evaluate historical mass wasting and channel response.

Stratify the watershed into situational categories using the TFW Framework discussed in *Part I: Study Design Guidelines.* Develop project specific stratification pertaining to watershed-specific site conditions and monitoring questions.

TFW Framework site condition stratification categories are:

- Climate (Physiographic Region)
- Subwatershed
- Watershed analysis unit (WAU)
- Landtype

Most monitoring projects will be within one Physiographic Region and one WAU, requiring no stratification of these categories. These site categories become descriptors of the project area. For regional or statewide projects, they will be stratification categories. A minimum of five stratification layers is used to stratify monitoring in the watershed: subwatershed, management systems, landtypes, location of multiple practices, and surface erosion/delivery hazard identification. Project specific stratification may be added if needed.

Create a map delineating subwatersheds based on hydrologic boundaries at 1:24,000 scale using 7.5 minute USGS quadrangle maps. (If subwatersheds have been previously delineated by watershed analysis, every effort should be made to use boundaries consistent with previous delineations.)

Draft a Landtypes map at 1:24,000 scale using 7.5 minute USGS quadrangle maps and orthophotography (optional) as a base. A Landtype mapping legend is developed from combining Landforms of Washington and Geology Groups of Washington (see Appendix A). The landform component is identified using the topographic map and aerial photography. The geology group component is identified using geologic resource maps at 1:100,000 or 1:250,000 scale, whichever is available. Some refinement in locations of surface deposits can be aided by soil survey maps

Determine if other local site categories are needed to meet project objectives or to further stratify important site differences in the watershed. Develop a map delineating these categories. Some examples of local categories are lithologic units that have contrasting mass wasting processes that may have been combined in the TFW Geology Groups.

Map areas of the management systems currently operating in the watershed, at 1:24,000 scale.

TFW Framework management system categories are:

- **Forest Practices Rules: standard and conditioned**
- **Watershed Analysis**
- **Landscape Plans (proposed management system)**
- **Habitat Conservation Plans**
- **National Forest Management Plans or other**
- **Total Daily Maximum Load (TMDL) Plans**

If a watershed has been operating under watershed analysis for the last five years and under forest practice rules prior to watershed analysis, many practices were designed under forest practice rules. They are presently being managed under watershed analysis and are evaluated under watershed analysis. Monitoring evaluations should assume legacy practices are the responsibility of the current management system. An optional local stratification for multiple practices might be “legacy” practices if the issues in the watershed warrant the separation from similar practice types.

Collect information and create a map, “Location of Multiple Practices,” locating forest practices situation categories that have occurred within the period to be evaluated.. Multiple practice activity categories and corresponding practice type categories are presented in Table 13 below.

Table 13. Multiple practices: activity and practice categories

Activity Categories	Practice Categories	
Road Design/Construction	Location Drainage Road prism	Stream crossings
Road Maintenance/Management Practices - Active - Inactive - Abandoned	Drainage Disposal of maintenance spoils	Sediment delivery control Sidecast Removal Stream crossings
Harvest	Clearcut Clearcut w/no cut leave area	Clearcut w/partial cut leave area Partial cut
Site Preparation	Slash burning	Non-applicable
Restoration/ Mitigation	Revegetation Bioengineering Road obliteration	Stream crossing Retaining structures Disposal sites

The map is drafted at 1:24,000 scale. For roads indicate the following: locations where specific road maintenance practices have occurred, locations of different road management and use levels (e.g., inactive, active, abandoned, etc.), and locations of new road construction. For harvest units indicate practice categories and site preparation practices. Locate all restoration measures that have occurred within the last five years.

Identify the areas of mass wasting/delivery hazard on a 1:24,000 scale map. For watersheds with a completed watershed analysis, this map is completed and is Map A-2. For watersheds without watershed analysis, a map is created from the following sources: areas where Class IV special forest practice conditions have been applied for mass wasting hazard; management system guide to local administrators; by interviewing local administrators of the watershed or other. If information is unavailable or in a format unsuitable for creating a sensitivity map, use the Landtype map to predict areas of sensitivity.

Make a list and locate on a 1:24,000 scale map previously identified mass wasting sources from past inventories. This list should include both natural and management related sources.

Using the Watershed Analysis Mass Wasting Module procedures (WFPB, 1997) update or if no past inventories are available, develop a mass wasting inventory for the watershed. Watersheds without current plans or analysis may not have an inventory so this step will be the initial inventory.

It is desirable to have current year aerial photographic coverage to update mass wasting inventories or to develop one. Lack of current year aerial coverage can be augmented by field surveys or aerial flight surveys. Still photos or video taken during these surveys support the mapping and any future conclusions. For first time inventories, a chronosequence of aerial photography can greatly enhance the understanding of changes in rate, extent, and frequency of mass wasting in the watershed. It is recommended that photo dates be selected to coincide with changes in management system direction of practices or "eras" and pre-management, if possible.

Complete or add to the Watershed Analysis Mass Wasting Inventory Form A-1 by including a column for stratification layers if not using GIS to do so. Note the management system in place at the time of the event. It is important to estimate the year or age of the mass wasting event as well for later use in analyzing stochastic sediment budgets and in separating out "design era's" within the same management system. For example, if a watershed has been managed under the Forest Practices Rules for a long time period it is useful to note a time period. This takes into account any change of sensitivity toward mass wasting hazard that may have occurred in this management system and allows the analyst to sort for variation.

Below is an example of an adapted watershed analysis Form A-1illustrating how the aerial photo mass wasting inventory data can be catalogued. This form should be referred to as Form 6 in the monitoring report.

Form 6. Mass wasting inventory (aerial photo evaluation)

Landslide ID*	Event ID (if more than one failure per site)	Land-slide type*	Size	Sediment Delivered y/n* Stream Order	Age	Photo No. (opt-ional)	Slope form or land unit*[1]	Slope % Or Class[2]	Landtype		Activity Category	Management System (FPA, WA, HCP, LP or other)[1]	Mass Wasting Map Unit Map Symbol or Number
									Land-form	Geology Group			
11N05WL	*1*	*SR*	*Small*	*Y/2*	*5*	*1-2*	*Inner Gorge*	*75%*	*92*	*Crescent Basalt (MB)*	*Road Mainten.*	*FPA-1993*	*Class IV Special*
11N05WQ	*1*	*SR*	*Small*	*N*	*5*	*1-3*	*cc*	*65%*	*77*	*Crescent Basalt (MB)*	*Harvest*	*FPA-1990*	*Class IV Special*
11N05WP	*1*	*SR*	*Small*	*Y/1*	*5*	*1-4*	*Complex*	*30-50%*	*35*	*Glacial Till (GL)*	*Harvest*	*FPA-1993*	*None*

Table heading notes:

* Procedures and codes consistent with Watershed Analysis Mass Wasting Module (WFPB,1997).

[1] FPA = Forest Practices Act; WA = Watershed Analysis; HCP = Habitat Conservation Plan; LP = Landscape Plan

Step Three: Evaluate mass wasting and delivery from multiple practices and management systems.

Overlay the situational category maps: Subwatersheds, Management Systems, Landtype, Mass Wasting Hazard Identification, and Location of Multiple Practices. Overlay the mass wasting inventory map. Select candidate areas for monitoring based upon the following criteria:

- Represent a significant land area within the watershed
- Represent the full range of site variation in the watershed
- Represent the range of activity categories and practice categories within the watershed and for the management system
- Represent situations predicted to be the most sensitive to surface erosion and fine sediment delivery
- Target activities or practice categories as established in the monitoring plan (Targeted categories are those practices that have been established through analysis to be potential sources for fine sediment while other sources are not significant. Targeted categories also may be established by the monitoring plan’s scope to only evaluate those practices.)
- Representative situations identified in the mass wasting inventory.

Identify monitoring situations based upon combinations of situational categories that meet the criteria. Use Landtypes and Subwatersheds to stratify site condition situations. Use Management Systems, Location of Multiple Practices, sites identified by the surface erosion inventory, and Mass Wasting Hazard Identification to stratify multiple practice/management situations.

Identify monitoring situations that need replicated observations based upon the need for certainty in results and confidence in extrapolation of observations. All mass wasting events occurring during the period of the most recent management system should be evaluated in the field. If conducting the mass wasting inventory for the first time or for those mass wasting inventories conducted without field verification, select representative sites in the watershed based upon site and management category stratification to evaluated in the field.

Once candidate monitoring sites are selected, create a “field-going” map of locations of all situations that will be monitored in the watershed. Using a map base showing transportation routes is helpful in planning efficient access to monitoring sites. Design a field form similar to or use Form 7 or Form 8 below to keep track of observations at each monitoring site. Photographs are also useful documentation. Another option is to complete the more detailed site characterization form for site scale monitoring for each monitoring situation and then summarize onto Form 7 of Form 8. Complete the site scale diagnostic step at each site with a landslide occurrence.

Form 7. Management system and multiple practices field monitoring form (mass wasting) – Roads (Level One and Level Two)

Physiographic Region: *Willapa Hills* **Watershed Analysis Unit:** *Example Creek*

Management System: *WA* Observer (s):___________

Date:___________

Situational Category	Site Identification				Site Stratification		Practice Stratification		Site Characterization			Effectiveness Rating		
	Sub-watershed	Road Number	Seg. ID No. (miles)	Landslide Inventory No.	Landtype: Landform	Landtype: Geology Group	Activity Category	Practice Category	Slope Position	Aspect	Slope Gradient	Sediment Delivery: Landslide (volume – cu yds)	Sediment Delivery: Delivery (% delivered)	Effectiveness and Casual Interpretation
A	*Browns*	*2300-010*	*1 5 mi*	*12N05W25L*	*53*	*MB.*	*Road maintenance*	*Road grading*	*upper*	*E*	*60-80%*	*Yes* *6500*	*High* *100%*	***Ineffective.*** *Sidecast failure in bedrock hollow. Road drainage diverted by berm along shoulder of road to hollow and outsloped grade diverted to sidecast.*
B	*Rogers*	*2400-001*	*2 3 mi*		*51*	*MB*	*Road maintenance*	*Pullback; Add cross drains*	*mid*	*W*		*No*	*N/A*	***Effective.***
C	*Rogers*	*2400-001*	*3 2 mi*	*12N05W15P*	*40*	*MB*	*Road maintenance*	*Add cross drains*	*mid*	*W*		*Yes* *3000*	*No* *0%*	***Effective.*** *Sidecast failure on concave/convex slope. Landslide deposited on break in slope gradient 200 feet below.*

Form 8. Management system and multiple practices field monitoring form (mass wasting) - Harvest (Level One and Level Two)

Physiographic Region: *Willapa Hills* **Watershed Analysis Unit:** *Example Creek*

Management System: *WA* Observer (s):__________________

Date:____________

Situational Category	**Site Identification**			**Site Stratification**		**Practice Stratification**		**Site Characterization**				**Effectiveness Rating**		
	Sub-watershed	Harvest Unit ID	Landslide Inventory No.	Landtype		Activity Category	Practice Category	Regen Age/ stocking	Aspect	Slope Gradient (field)	Other	Sediment Delivery		Effectiveness and Casual Interpretation
				Land-form	Geology Group							Landslide (volume – cu yds)	Delivery (% delivered)	
A	*Browns*	*H-1*	*11N05W21A*	*53*	*MB.*	*Harvest*	*Clearcut 7 yrs old*	*5 yrs old 500 TPA*	*E*	*75%*	*Bedrock hollows and knife edge ridge*	*Yes 6500*	*High 100%*	***Ineffective.*** *SR initiated in drainage head of 0 Order changing to DT in 1st and 2nd Order channel*
B	*Rogers*	*H-2*	*11N05W22M*	*51*	*MB*	*Harvest*	*Clearcut 10 yrs old*	*10 yrs old 200 TPA*	*W*	*65%*	*convex/convex with springline*	*Yes 3000*	*100%*	***Ineffective.*** *Two SR's initiated along springline midslope and mid-unit*
C	*Rogers*	*H-3*		*42*	*MB*	*Harvest*	*Clearcut 7 yrs old*	*5 yrs old 600 TPA*	*W*	*45%*		*No*	*N/A 0%*	***Effective.***

Level Two

For Level Two be sure to conduct a Level Two site scale for each monitoring site measuring the dimension of the landslide scare and noting whether the landslide fits within the small, medium, large, or very large category. Not all landslide scars need to be measured. Calibrating ocular estimates with measured landslides is an efficient means to collecting volume data. To assure that ocular estimates are accurate, measure several landslides dimensions after estimating them and compare the result. (Laser survey technology may provide an efficient and accurate means to measure all landslide areas within a short period of time).

Table 14. Landslide size and volume (WFPB, 1997)

250-500 cubic yards = small	2000-5000 cubic yards = large
500-2000 cubic yards = medium	5000 cubic yards = very large

Using the landslide dimension calculate volume of sediment in cubic yards. Use the field measured data set and the table above to extrapolate to the rest of the data set in the mass wasting inventory. The ranges in Table 14 are broad and for sediment budgeting a numerical value instead of a range will be needed. Evaluate the measured data set and determine the average volume within each size category for the project area's data set. Apply this numerical value to the corresponding size recorded on the rest of the data set.

Channel Response

This section is intended to supplement currently available references for channel response monitoring. This section covers a site selection procedure that integrates monitoring of channel response with sediment source/delivery monitoring. Provided here is a procedure to identify candidate channels for monitoring based upon stratification of terrestrial and fluvial geomorphic processes.

To select candidate channels, overlay the Landtype map with the Subwatershed map. This provides a visual array of geomorphic processes for the entire watershed at a glance. Identify sub-watersheds that have a similar array of landtypes and sub-watersheds with a unique array of landtypes. Review historical patterns of sediment delivery from natural and management related sources in each subwatershed. Overlay the Locations of Multiple Practices map onto the subwatershed and landtype layers.

Identify candidate channels in sub-watersheds and mainstem based upon the following criteria:

- Representative landform patterns and geology (geomorphic process) within each subwatershed
- Unique geomorphic processes by subwatershed that significantly influence response in the mainstem
- Historical land use or current land use that may be significantly influencing channel response to sediment yield

Identify a network of candidate channels using the criteria above. At least two tributary channels and a mid and lower mainstem location should be selected. The more sample sites established near sediment sources, the higher chance of isolating input and routing mechanisms. Use guidance in the following references for reach selection and monitoring procedures.

Ramos, C. 1996. Quantification of stream channel morphological features: recommended procedures for use in watershed analysis and TFW Ambient Monitoring. TFW-AM9-96-006. Washington Timber-Fish-Wildlife, Olympia, WA.

Schuett-Hames, D., A. Pleus, L.Bullchild, and S. Hall.1994. Ambient Monitoring Program Manual. TFW-AM9-94-001. Northwest Indian Fisheries Commission and Washington Timber-Fish-Wildlife, Olympia, WA.

Also, a qualitative, less intensive monitoring method using aerial photography is available from the following reference: (This method is analogous to a Level One approach in sediment source/delivery monitoring and is used to evaluate coarse changes in channel morphology.)

Grant, G. 1988. The RAPID Technique: A New Method for Evaluating Downstream Effects of Forest Practices o Riparian Zones. USDA Pacific Northwest Research Station GTR-220.

Step Four: Compare change or effects in sediment inputs (mass wasting).

Level One

Using the mass wasting inventory and the field monitoring forms, Forms 6 through 8 address the following questions:

- How has the number of landslides changed over time in the watershed?
- How has the number of landslides changed over time by subwatershed?
- How do rate and frequency of landslides compare with an approximated background or reference condition?
- Has the number of landslides changed over time with changes in management systems?
- What potential for change exists in the watershed? Is the extent of effective practices increasing in the watershed?

Select a minimum of four management time periods and one pre-management time period of relatively similar length to illustrate change over time in the watershed. These time periods should coincide as closely as possible to landslide "response eras" corresponding to significantly different management systems or eras of the same management systems. Generally landslide events cluster around certain years related to storm recurrence and response lags to design eras of management systems. These clusters are not to be confused with landslides dated for the year the aerial photograph was taken instead of the year of the event. If using a previous mass wasting inventory that recorded photo date instead of age of landslide, data should be adjusted to reflect the date of the landslide. For some watersheds on the westside of the State, time periods that seem to coincide with management systems/response eras are: 1950-1962; 1963-1977; 1978-1985; 1986-1995; 1996-2005.

By subwatershed and for the entire watershed, chart the number of landslides by management/response era. The graph in Figure 8 is an example. This graph illustrates the change in number of landslides over time for management and non-management related landslides for each subwatershed and compares subwatersheds with the total effect to the watershed.

Discuss changes in the number of landslides observed over time and relative to those associated with management or natural causes. For deep seated landslides describe the number and size of incidence where landslides have occurred over the period when management systems where in operation. Compare with the present condition.

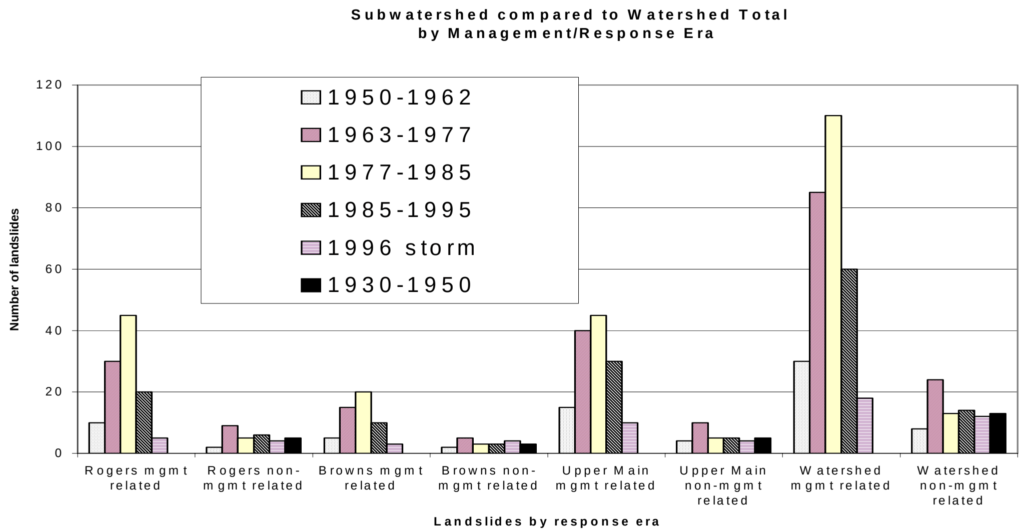
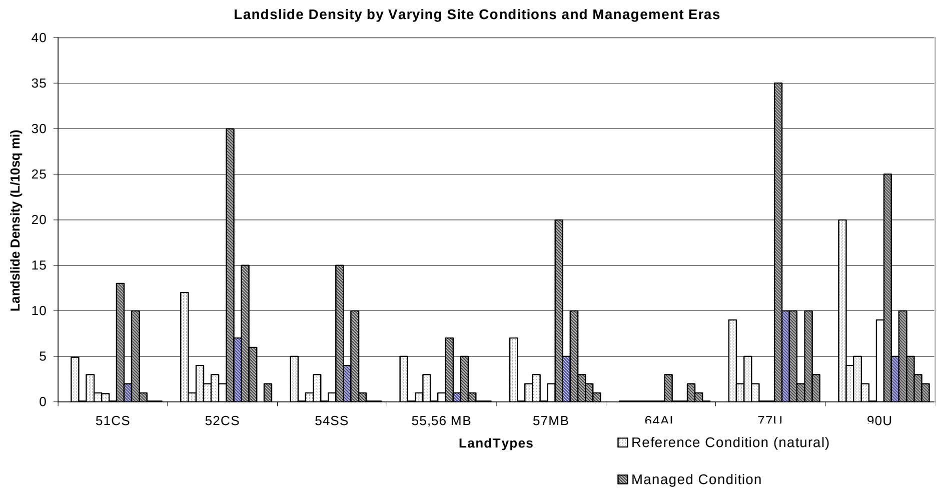


Figure 8. Change in number of landslides over time within the watershed and by subwatershed. (1930-1950 pre-management or background rate).

Develop an understanding of reference condition by varying site conditions using landtypes. Create a table that compares landslide type, size, and density (number of landslides per area) for each landtype, for management- related and non-management-related landslides, and over the same time periods. Title this table, Form 9 – Landslide density under varying site conditions and management systems. If historical landslide data is available, include pre-management landslides for a similar length of time. Separate dormant ancient deep seated landslides from those that have been activated either by natural or management-related causes.

(Optional) – Another option is to normalize landslide density over a per year basis. This should be done with caution in that normalizing on a per year basis may mask peak years of landslides averaging them across several low response years. If landslide density is normalized by year be sure to select time periods that separate important response/management eras. Both approaches, selecting similar time period lengths or normalizing on a per year basis provide an indices for frequency of landslides. Produce a graph to visualize changes over time similar to the example in Figure 9.



From left to right, oldest to most recent management eras: (1950-1962;1963-1977;1978-1985:1986-1995;1996-1987)

Figure 9. Comparison of landslide density over varying site conditions and management systems eras.

Discuss changes in landslide density over time. Discuss and compare management and non-management related landslide density between landtypes. Use this comparison and the extent of each landtype in the watershed to formulate a reference condition for sediment input over time. Compare the reference condition with current conditions.

Using Forms 7 and 8, summarize the relative effectiveness by activity category and practice category observed during field monitoring. Extrapolate findings across the watershed overlaying landtypes, the mass wasting inventory map and the map locating and showing status of activities in the watershed. Discuss any relationships with effectiveness and site conditions observed. Discuss the relative extent of effective/ineffective activities in the watershed and how future conditions may be effected. Record the current status and summary of effectiveness of multiple practices on Form 10. Other tabular summaries are encouraged to support conclusions.

Form 10. Management system and multiple practice evaluation (mass wasting): summary of effectiveness by activity type and management system.

Management System	Activity Category	Practice Type	Percent of Practices Effective From Past Inventory (WA- 1993)	Percent of Practices Effective From Current Inventory (1998)	Reasons for Effect or Change
FPA	*Harvest*	*Cable*	*60%*	*70%*	*No change in effectiveness. Harvest prescriptions evaluated where under FPA Harvest units with hazard leave areas are 3 years old. RMZ prescriptions have protected some high hazard inner gorge landforms (LT90) from landslides through avoidance of harvest.*
Watershed Analysis	*Road Manage ment*	*Drainage maintenance*	*60% of roads with landslides and delivery*	*10% of roads with landslides and delivery rating*	*Cross drains and sidecast pullback appear to have reduced landslides. Recent landslides associated with roads were in areas where grading was the only maintenance practice. .*
Watershed Analysis	*Road Manage ment*	*Abandonment*	*100 % of Orphan roads contributed landslides.*	*50 miles of high priority roads abandoned under design specification* *10% sampled received effective rating.*	*Road abandonment designs appear to be effective. Minor instances where abandonment plans were not implemented correctly, landslides occurred.*

Level Two

Using a static sediment budget method to reflect stochastic events

Select a minimum three management time periods of relatively similar length representative of differences in management systems. A suggestion for time periods are: 1950-1964; 1965-1985; and 1985 to present. Total the amount of fine and coarse sediment yielded and calculate Tons/year from mass wasting for each time period and management system for each subwatershed. If practices under the newest management system have been fully tested by storm events and time periods long enough for lag response for mass wasting, calculate tons/year for the time period covering the new management system. (Many initial five year reviews will not meet this requirement. Comparing tons/year of a less than fully tested management system with fully tested management systems will provide false findings).

Using the field measurements from the monitoring data set of landslide scars, extrapolate volumes by size class (see Table 14) and particle size analysis to calculate fine and coarse sediment yield of all the landslides in the mass wasting inventory. Total fine and coarse sediment yield for the three time periods identified by subwatershed. Normalize sediment yield to sediment rate by dividing by the number of years to calculate Tons/year.

Calculate background rate for each subwatershed by using the watershed analysis erosion (WFPB, 1997) and adding sediment yields from landslides noted on the mass wasting inventory with a high level of certainty as non-management related.

Compare these sediment yields with the calculated background rate. Report fine and coarse sediment yield in Total Tons/Year and Tons/Year by activity category for each subwatershed.

Integrate these results with sediment yields calculated for surface erosion to analyze the cumulative effect of sediment delivery to the aquatic ecosystem.

Stochastic Sediment Budget

From the mass wasting and surface erosion inventories, determine total sediment yield per ten year period from forest practices. Estimate the amount of fine and coarse sediment using soil surveys or field sampling. Using historic wildfire or of other natural erosion triggers and geomorphic process and rate indicated by landtypes, predict the "natural" rate and frequency of sediment delivery per ten year period and through several disturbance cycles. The R1-R4 sediment yield model (USDA, 1991) provides a format to organize this analysis.

Totals for fine and coarse sediment yield are reported in Tons/Year by subwatershed for ten year increments over the time period the watershed has been under forest development. Compare sediment yields from forest practices era with the natural background rate for the same time frame. Compare the analysis for the development era with a longer timeframe over several natural disturbance regime cycles. A frequency distribution of sediment yield can be created to illustrate the frequency of different rates or pulses of sediment delivered in the watershed. Benda (1995) provides an example. Address where sediment yields from forest practices falls within the frequency distribution. Discuss differences in sediment yields based upon activity categories and inputs from different natural sources.

Acreage and a description of geomorphology for each subwatershed is reported with the analysis as sediment routing is closely tied with watershed area and watershed geomorphology.

Step five: Evaluate management systems effectiveness in identifying hazard and impact.

There are four evaluation questions to address effectiveness of management systems in recognizing hazard:

- **Are hazard and triggering mechanisms consistently identified throughout the watershed ?**
- **Are triggering mechanisms correctly identified?**
- **Is there is a direct correlation with practice design and type with hazard and triggering mechanisms identified.**
- **Are timing and design of practices responsive to the level of hazard and risk to the aquatic resource?**

For watersheds that have a completed watershed analysis, compare the mass wasting inventory with the Mass Wasting Hazard Map, A-2. For watersheds without an analysis, use the map created in Step Two that delineates areas of sensitivity identified by management systems. If there are no designated hazard areas, use landtypes to stratify areas of resource sensitivity.

For watersheds with completed watershed analysis, overlay the Location of Multiple Practices Map with the Mass Wasting Hazard Map, A-2 and the mass wasting inventory map. Evaluate the location of recent activities that have occurred since watershed analysis (e.g., abandoned roads, adding cross drains, erosion control) in relation to identified hazard and response (mass wasting inventory). Watersheds without an analysis, evaluate locations of practices by overlaying the activity category map with either the landtype map or the map created to illustrate management systems' identified hazard areas.

Select monitoring sites based upon the following:

- All activities that have taken place within an identified area of resource sensitivity or mass wasting hazard.
- A sample of mass wasting sites noted that fall outside identified hazard areas stratified by activity and landtype. (This most likely will be the same sample set used for Step Three).

At each sample site, address the following questions:

- Was the practice implemented as directed by the management system and is it effective in preventing mass wasting? Or is there direct evidence the management system correctly predicted no delivery of a mass failure?

- Did the approach to identifying hazard accurately identify hazard at the site? If no, then why not?

Discuss observations in terms of the evaluation criteria questions. Management systems must demonstrate all of the items listed below to be considered effective at recognizing hazard:

- **Success in all four criteria elements with an adaptive management program that identifies and improves upon each of the four areas as needed or success in at least 90% of the land area in the watershed.**

  - **A plan for addressing all high and moderate risk areas.**

  - **Reasonable progress in mitigating high and moderate risk situations.**

Step six: Conduct synthesis of channel response monitoring results and mass wasting monitoring results. Interpret effectiveness in on protecting or allowing for recovery of aquatic resource condition.

Overlay channel monitoring site locations with mass wasting monitoring locations and mass wasting inventory map. (Note this should be done for all sediment sources for complete synthesis). Using the graphs developed in Step Four, compare change in mass wasting sediment input above channel monitoring site with change in channel diagnostic features influenced by fine and coarse sediment. Estimate the period of time expected for sediment input to route to the channel site. Correlate any changes in diagnostic features with sediment input and discuss level of confidence in the correlation. Stream traverses to observe intermediate channel storage between channel monitoring site and highest input sources may increase certainty in estimate of routing.

The following scenarios are offered to guide synthesis and the interpretation of effectiveness in protecting or allowing for recovery of aquatic resource condition:

Scenario One:
Decreasing trend in sediment input from forest practices/Relative risk to aquatic resource is low (Table 15)/Trend indicates a high residual amount of sediment in streambed – EFFECTIVE (high potential for recovery or channel has naturally moves high volumes of sediment).

Scenario Two:

Increasing trend or no change in sediment input from forest practices/Relative risk to aquatic resource is moderate or high (Table 15)/ Trend indicates a high amount of sediment streambed. – INEFFECTIVE
Scenario Three:
Increasing trend in sediment input from forest practices/No adverse indices in channel response – INEFFECTIVE (high risk of adverse change)

Scenario Four:
Decreasing trend in sediment input from forest practices/No adverse indices in channel response – EFFECTIVE

Scenario Five:
Trend in sediment yield from forest practices is insignificant compared to background rate/Relative risk to aquatic resource is low (Table 15) – EFFECTIVE

For watershed evaluations that have no channel response monitoring information or time period for channel response monitoring has not been adequately long enough to evaluate trend, use Table 15 below to evaluate relative risk to the aquatic resource using sediment input/delivery evaluations. Relative risk is used to discuss trends and provides an index to discuss risk but should not be used to make direct conclusions about aquatic resource condition. Only channel monitoring provides a measure for direct conclusions on habitat condition and species monitoring provides a measure for direct conclusions on aquatic biota condition.

Table 15. Rating effectiveness in protecting the aquatic resource from fine and coarse sediment input.

Relative Risk to Aquatic Resource	Level One **(Averaged percent of situational categories effective in preventing fine sediment delivery)***	Level Two
Low risk of effects	**>90% Number of landslides/sq mi are < 20% over reference condition by landtype.**	**<50% increase in rate; no increase in extent or frequency over background index**
Moderate risk of effects	**75-89% Number of landslides/sq mi are 21-40% over reference condition by landtype**	**50-100% increase in rate, < 20% increase in extent, and < 40% increase in frequency over background index**
High risk of effects	**<75% Number of landslides/sq mi is greater than 40% over reference condition by landtype.**	**>100% increase in rate or >20% increase in extent or >40% increase in frequency over background index**

Step Seven: Diagnose for improved effectiveness.

Review evaluations in Step Five and Step Six. Discuss trends in effectiveness of management systems by practice types and in hazard identification. Describe where management systems are being particularly effective in preventing mass wasting or recognizing hazard of sediment delivery from mass wasting. Where indicated, suggest improvements to increase trends in effectiveness. Record findings and recommendations on Form 11. Below is an example of a completed form.

Form 11. Management system and multiple practice diagnosis report and recommendation.

WAU: *Example Creek*
Situation Reference Number: A

Situation Sentence: *Management systems have not recognized the mass wasting hazard associated with springlines. Fine and coarse sediment from shallow rapid landslides initiating along springlines in clearcut harvest have delivered fine and coarse sediment to Type 3 and 4 channels in the X and Y subwatersheds.*

Triggering Mechanisms: *Springlines produced by somewhat impervious strata in the Crescent Sedimentary Formations increase pore pressure creating zones of instability. Clearcut harvest reduces root strength and may increase pore water pressure by removing tress upslope.*

Additional Comments: *Springlines can be predicted by the following characteristics: horizontal repeating patterns of understory vegetation indicating wet zones usually midslope; repeating patterns of channel heads originating midslope unlike the more typical channel heads originating in the upper third of the slope; signs of natural instability.*

Suggested Corrective Action: *Restoration actions for the landslide will reduce chronic erosion and delivery. Prompt aerial seeding of erosion control species with mulch will accelerate revegetation and erosion control.*

Recommendations for Management System Improvement: *In order to protect aquatic habitat from sediment delivery increases from mass wasting, management system's hazard identification should include springlines and should develop prescriptions to address retention of root strength and utilization of pore water pressure to maintain frequency of mass wasting within effective levels.*

Step Eight: Summarize. Report findings and recommendations

Prepare a monitoring report. Be sure to present a balanced review of effectiveness, noting where advances in effectiveness have been made as well as where further improvement should be considered.

6.2 Outline of Monitoring Report

The following outline provides a guideline. Reports are concise and at a minimum, cover the following areas:

I. Executive Summary of findings
- Key findings and overview description of monitoring effort

II. Overview of monitoring plan, project area, and review of previous watershed analyses
- General description of site conditions in the watershed influencing mass wasting, the previous analyses conducted, resource sensitivity identified and the management systems currently in effect
- Review of monitoring plan: problem statement (purpose/scope), monitoring questions, and hypotheses
- Any other pertinent information relative to how the monitoring effort was implemented that is helpful to others interpreting the results. For example, the rationale for selecting Level One or Level Two assessment methods

III. TFW Monitoring Question One: Evaluation of change or effects in sediment inputs
- Graph illustrating number of landslides over time for management and non-management related landslides for each subwatershed and total for watershed (Level One)
- Graph illustrating fine and coarse sediment yield over time for management and non-management related landslides for each subwatershed and total for watershed (Level Two)
- Form 9: Graph and/or table illustrating landslide density under varying site conditions and management systems (Level One) or same with sediment yield (Level Two)
- Form 10, a tabular summary of effectiveness evaluation by activity category
- Address each question in Step Four. Discuss effectiveness of management systems over time, with regards to varying site conditions over time, and extent of current effectiveness in the watershed

IV. TFW Monitoring Question Two: Assessment of effectiveness in identifying hazard and implementing practices
- Address each question in Step Five. Summarize effectiveness.

V. TFW Monitoring Question Three: Evaluation of effectiveness in preventing adverse changes or encouraging recovery of aquatic resource condition

- Channel response monitoring results
- Discussion integrating channel monitoring results with sediment source/delivery monitoring results
- If no channel monitoring is conducted, discuss interpretations from the evaluation of Monitoring Question One relative to effects on the aquatic ecosystem. Use Table 15 as a guide.

VI. Summary of overall effectiveness and recommendations for improvement

- Summarize overall effectiveness. Discuss certainty in diagnosis and recommendations and possible application elsewhere.
- Complete Form 11, Multiple practices and management system diagnosis and recommendation for change when improvement will benefit the aquatic resource
- Recommendations for further site scale evaluations (if any)

VII. Appendix

- Management System and multiple practices field monitoring forms, Form 7 and Form 8.
- Mass wasting inventory data, Form 6 and watershed analysis Form A-1.
- New Maps: Landtypes, Location of Multiple Practices, Monitoring Sites, Subwatersheds
- Calibration and adjustment factors used in sediment yield modeling
- Photographs

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Appendices

Appendix A: **Landtypes of Washington (provisional)**

Landtypes of Washington provides a consistent structure for stratifying landscapes, to interpret geomorphic processes, and to observe performance of forest management practices under varying site conditions. The components of a landtype are uniquely qualified combinations of landform and soil parent material/geology. They are identified by associating measurable geomorphic processes with a set of visible and distinct landform features and geology that form a repeating pattern across the landscape. This repeating pattern allows monitoring observations and forest practice prescriptions to be extrapolated between similar landtypes and distinctions made between dissimilar landtypes.

To use Landtypes for extrapolation purposes, it is important that a structure be provided for consist application. Landtype identification can be learned quickly and, with a small amount of training, can be applied consistently. A physical science background with exposure to terrestrial geomorphology and experience in technical management services is all that is needed.

A basic structure is provided in this appendix in the form of a legend for landform identification and a legend for soil parent material/geology groups. A landtype is created when the two are combined and when mapped, delineate important and a distinctly different set of geomorphic processes that have interpretative significance for forest practices.

The following are directions for mapping Landtypes to stratify TFW monitoring projects.

1. Select the project area using the higher level stratification defined in the study design guidelines, i.e. Physiographic Region and other as necessary to meet project objectives. Obtain USGS 7.5. minute quadrangle maps, 1:24,000 scale orthophotography (optional), and aerial photography (1:24,000 scale or similar) for the project area. The optimum combination for a mapping base is a mylar reproduction of the quadrangle map overlaying the orthophotograph. And if available, aerial photography at 1:63,000 – 100,000 scale can help identify patterns of landtypes quickly over a large area.

2. Obtain the best source for geology possible at no larger scale than 1:250,00. Categorize the project area’s lithologic units and surficial geology into the soil parent material/geology groups outlined in Appendix A, Part B. For consistency, most lithologic units identified in the State have been classified into groups. A portion of the database is provided as an example. The entire database is archived with the TFW Monitoring Steering Committee. If you are unsure of how to classify the project area’s geology into these categories, you may want to obtain a copy. Review the study design to see if further soil stratification is necessary and identify if dissimilar surface material overlies parent material as a category, if necessary for the study design. Make a pre-map overlay delineating the soil parent material/geology groups in the project area at 1:24,000.

3. Review the landform legend in Appendix A, Part A. Identify landform features in the project area that are associated with the various landforms on the legend by studying the topographic maps and aerial photography. (If you do not know these features, it is best to seek training in how to identify them). Develop a map unit identification legend of the combinations of landform and geology groups that exist in the project area. Map unit codes are provided in the landform and geology group legends for consistency. Use the last two letters in the geology codes in the map unit symbol following the numeric code for landform, (e.g., 90HS). Review this legend by evaluating each unit with your experience in observing geomorphic processes and response to forest practices for the terrain the map units will delineate. Evaluate whether a geology group separation of a landform is necessary to delineate the important processes. Sometimes, landform features dominate over geology in influencing process. In these cases, geology groups can be combined. An example of this case is in glaciated landscapes. Troughwall landforms consistently dominate geomorphic processes over numerous geology groups. Another example are stream breaks or inner gorge landforms. There are only a few geology groups where a distinction may be necessary in both of these landforms. The goal is to have the minimum number of landtypes to stratify the array of site variables that exist in the project area. For some study designs, it may serve to further aggregate landtypes when targeting specific site factors.

4. Once a map legend has been identified for the project area. Begin delineating map units using a stereoscope and aerial photography to help identify boundaries. Concurrently, to identify landtypes, you are observing features indicating current processes active in the watershed. You should see a pattern of relationships between rate and frequency of the more visible processes with Landtypes. Once familiar with this approach it becomes efficient to inventory mass wasting and larger scale surface erosion sources areas concurrently with landtypes.

5. With the map completed, conduct a reconnaissance field check of map unit boundaries and map unit components. This is to test whether the site factors exist that were predicted within the map units and the boundaries delineate important differences. There are two possible reasons why the mapping may fail this test. One is an inconsistent level of accuracy in interpreting landtype signatures from aerial photography and topographic maps and the other reason is errors in the choice of landtype components defined in the mapping legend. Make any adjustments necessary to the map to improve stratification prior to proceeding with selecting monitoring sample sites.

An issue that poses the possibility for confusion in identifying landtypes is the context of primary and secondary geomorphic processes. So the following discussion is offered to help understand the context useful to TFW purposes.

Secondary geomorphic processes are those processes that landscapes are experiencing today. Primary processes are often the geomorphic processes that have shaped the general landscape feature used to identify the landtype but no longer occur in today's climate. Secondary processes are influenced by these "legacy" features and often uniquely so. For example, glacial processes are the primary geomorphic process that shaped the landforms troughwalls, cirque basins, and moraines. It is the secondary processes of fluvial erosion or deposition and mass wasting that are occurring today on these landforms that interact with forest practices. The same present day secondary process, say fluvial erosion, occurs on each of the glacial landforms although different hydrologic regimes and mass wasting regimes exist in each one of them because of differences in soil depth, slope gradient and morphology, and other site factors. So in this case, landscape features shaped from the primary geomorphic process are used to identify landtypes. In other cases, secondary processes may be used to identify landtypes. An example taken from western Washington is the primary process of fluvial erosion versus mass wasting. Just below the elevation where the "Little Ice Age" carved small glacial cirques, previously created cirque basins underwent a different climatic regime. Some of these lower elevation cirques were transformed by fluvial erosion and mass wasting into convergent headwalls and, some became stable basins accumulating deep soils and thick vegetative cover. In some cases, this difference was probably influence by geology and in other cases, more by climatic regime (e.g., rain-on-snow versus rain dominated). The landforms that identify these differences in secondary processes are: cirque basin - alpine (Little Ice Age); convergent headwalls (fluvial erosion with mass wasting); cirque basin – subalpine and nivation (fluvial or pluvial processes with no mass wasting).

Part A: Landforms of Washington (draft)

Geomorphic Process	Landform	
PERI-GLACIAL (10) undifferentiated	(11) Frost churned summits	
GLACIAL – EROSIONAL (20) Undifferentiated	(21) Alpine ridges, aretes, col, Cirque headwalls	
	(22) Glacial Troughwalls	
	(24) Cirque Basins – subalpine	
	(25) Cirque Basins – alpine	
	(26) Nivation	
GLACIAL – DEPOSITIONAL (30) Undifferentiated	(32) Glacial Valley Train - < 35%	
	(33) Glacial Valley Train - >35%	
	(34) Glacial Moraine – weakly dissected, <35% slope	
	(35) Glacial Moraine – dissected with slopes >35%	
	(36) Glaciated mountainsides (troughwalls with lateral moraines, kames, etc)	
	(37) Glacial Outwash Terrace	
	(38) Glacially overridden hills	
FLUVIAL DEPOSITION (60) Undifferentiated	(64) Stream bottoms (stream channel including 100 yr floodplain)	
	(65) Stream terraces (above 100 yr floodplain includes escarpments)	
	(66) Lacustrine terraces	
	(67) Alluvial and co-alluvial fans	
FLUVIAL EROSION (50 and 90) Undifferentiated	(51) Weakly dissected mountain slopes >60% slope	
	(52) Moderately dissected mountain slopes >60% slope	
	(53) Highly dissected mountain slopes >60% slopes	
	(57) Weakly dissected mountain slopes < 60% slope	
	(58) Mod/Highly dissected mountain slopes < 60% slope	
	(90) Streambreak/Inner Gorge – 3 or greater stream order	
	(95) Remnant Stream Escarpments (stream no longer cutting toeslope)	
"PLUVIAL" EROSION (54) Undifferentiated	(54) Rounded, old erosional hills	
TECTONIC/STRUCTURAL (40) Undifferentiated	(42) Dip slopes, scarp slopes, hogback complex - <45% slope	
	(43) Scarp slopes, hogback complex - >45% slope	
VOLCANIC FLOWS (80)Undifferentiated	(81) Cone, dome	
	(82) Narrow drainageways formed by fluvial erosion of volcanic flows	
	(83) Lava Flow Plateau <20% slope w/weak dissection	
	(84) Lava Flow "Breaks" - >40 % slope gradient	
MASS WASTING (70) Undifferentiated	(71) Rock slides and Talus	(77) Convergent headwalls
	(73) Landslide Scarp Headwalls	(78) Shallow rapid/Debris Torrent Tracks
	(74) Deep seated – active	(79) Rock "glaciers"
	(75) Deep seated failures – ancient	
	(76) Snow avalanche	

Part B. Geology Groups of Washington (draft)

Lithologic Divisions	Database Code	Geology Groups and Description
Soil Surface Layers (surface erosion only)	A	**Volcanic ash influence loess** (Ashy or medial particle size classes)
	P	**Recent (17-2000 yrs) Pyroclastic** (Cindery or pumiceous particle size classes)
	use codes below	No surface/substrate discontinuity (Name substrate type from below)
Unconsolidated Deposits	UAL	**Alluvium, Fan Deposits,and Glacial Outwash**
	UGL	Glacial till
	ULS	**Landslide deposits**
	ULA	Lacustrine deposits
	UEO	Deep Eolian deposits
(U)	UPY	**Recent (17-2000 yrs) Pyroclastic deposits** (stratified ash, pumice, cinders)
Sedimentary	SVS	**"Very Soft" Sedimentary**: Bedrock or Formation units with weak enduration and/or easily weathered into deep regolith. Regolith particle size >2mm is minimal. Regolith has low angle of repose.
	SSS	**"Soft" Sedimentary**: Bedrock easily weathered into moderately deep and deep regolith. Regolith particle size >2mm ranges from minimal to < 50% by volume. Regolith has low to moderate angle of repose.
	SHS	**"Hard" Sedimentary**: Strongly endurated bedrock containing predominately moderately thick to massive beds resistant to weathering. Regolith depth is moderate to shallow. Bedrock outcrops and regolith has a relatively high angle of repose. Particle size >2mm is abundant.
(S)	SCX	**"Complexly Hard and Soft" Bedded Sedimentary**: Complex lithology usually containing strata layers of different weathering resistence. Hazard depends on thickness, position, and exposure of strata. Angle of repose is variable. Dip/slopes and other structural landform features are common.
Igneous – extrusive	VVC	**Volcaniclastic**: Strata of intermittent breccia and tuffs. (Some sedimentary lithologies are included here when volcanic origins cause strata to have more similar characteristics to volcaniclastic than sedimentary bedrocks.)
	VRH	***Rhyolite and Dacite*** *(includes shallow intrusives)*
	VAB	**Andesite and Basalt** (includes shallow intrusives)
	VMB	**Marine Basalt.** Predominately Crescent Basalt and other coastal marine basalt bedrocks.
(E)	VCRB	**Columbia River Basalt Group**
Igneous – intrusive (I)	VGR	**Acidic -** Granites, granodiorite, quartz monzonite
	VDI	**Basic** - Gabbro, diorite, quartz diorite
Metamorphic	MCM	**Melange Belt of the Cascades**: variable grades of hardness and weathering resistance
(M)	MLG	**Weakly Resistant Metamorphic**: Low grade phyllite, friable schist
	MHG	**Resistant and Highly Recrystallized Metamorphic**: High grade schist, gneiss, amphibolite, hard metasedimentary, and metavolcanic

Part B – 1. Landtypes of Washington – Lithologic Units/Formations Categorized by Geology Groups

Contained within this part is a summary of a draft master list of lithologic units and formations currently identified in the state of Washington classified into Geology Groups. This master list of lithologic units was created by the Division of Geology and Earth Resource, DNR from 1:100,000 geologic resource maps current completed for the state of Washington. The master list is a dynamic list, in that, as new areas are mapped, lithologic units may be combined, added or deleted.

Classification into Geologic Groups was accomplished using the assistance of local geology experts. The sedimentary and metasedimentary classes are provided here. The entire list could not be accommodated in this document. A computer disk has been provided to the TFW Monitoring Steering Committee with the entire master list classification..

When using this classification, it is necessary to understand characteristics within the same unit may vary with extent of the unit and classification targeted the general nature of the unit . This classification should serve best at the state or regional level and as a guide for watershed level stratification. Classifications can be altered at the local level when it serves to illustrate local conditions more effectively. Changes in classification should be documented in the monitoring report. Geologic Group classification should not preclude identifying the formation or unit name associated with sites where data is collected. And, with inherent in any project this size, errors may occur. A provision for changing the classification of a certain lithologic unit should be made. And if the lithologic name is always identified with data collected, changes in classification will not affect extrapolation of results.

Landtypes of Washington – Geology Group Classification for Sedimentary and Some Metasedimentary Geologic Units (complete list available from TFW Monitoring Steering Committee).

GEO GROUP CODE	**NEW** *SYMBOL* (DNR)	**OLD SYMBOL** (current 1:100,000)	LITHOLOGY	**GEOLOGIC UNIT NAME**
SCX	TKcg(b)	bc	continental sedimentary rocks, conglomerate	Bald Mountain, conglomerate of
MHG	JPMmc(b)	bc	metasedimentary rocks, cherty	Yellow Aster Complex of Misch (1966)
SCX	TKms(b)	bcs	metasedimentary rocks	Bald Mountain, conglomerate of
SHS	Ccb(l)	Ccb	metacarbonate	Limekiln Hill, carbonate rocks of
MLG	Ccb(m)	Ccb(m)	metacarbonate	Maitlen Phyllite
MHG	CDcb	CDcb	metacarbonate	---
MHG	CDmt	CDmt	metasedimentary and metavolcanic	---

			rocks	

Landtypes of Washington – Geology Group Classification for Sedimentary and Some Metasedimentary Geologic Units (complete list available from TFW Monitoring Steering Committee).

GEO GROUP CODE	**NEW** *SYMBOL* (DNR)	**OLD SYMBOL** (current 1:100,000)	LITHOLOGY	**GEOLOGIC UNIT NAME**
MHG	COcb	COcb	metacarbonate	---
SHS	COcg	COcg	continental sedimentary rocks, conglomerate (chert-pebble conglom.)	---
MHG	COmt	COmt	metasedimentary and metavolcanic rocks	---
MHG	Dcb	Dcb	metacarbonate	---
MHG	Dcb(v)	Dcb	metacarbonate	Valley, carbonate rocks near
VVC	Ec(i)	Ec(i)	continental sedimentary rocks	Island Mountain, volcanic rocks of
VVC	Ec(k)	Ec(k)	continental sedimentary rocks	Klondike Mountain Formation
SHS	Ec(o)	Ec(o)	continental sedimentary rocks	O'Brien Creek Formation
SHS	Ec(t)	Ec(t)	continental sedimentary rocks	Tiger Formation
SHS	Ecg(t)	Ecg(t)	continental sedimentary rocks, conglomerate	Tiger Formation
SHS	Jcg(e)	Jcg(e)	continental sedimentary rocks, conglomerate	Ellemeham Formation
MHG	Jcg(r)	Jcg(r)	continental sedimentary rocks, conglomerate	Rossland Group
MHG	Jm(fh)	Jhs	marine sedimentary rocks (ss., sltst., minor cgl. and chert)	Fidalgo ign. complex, Hunter Bay area
MHG	KJm(c)	JKc	marine sedimentary rocks (volcaniclastic ss, mudstone, ribbon chert)	Constitution Fm. (Decatur terrane)
MHG	KJm(lc)	JKl	marine sedimentary rocks (ss.&chaotic mudstone;chert,tuff,basalt)	Lopez str,cplx.,Const. Fm. derivative
MHG	KJm(ll)	JKl	marine sedimentary rocks (fol. graywacke, argillite, etc.)	Lopez str.cplx.,Lummi Fm. derivative
SHS	Jm(ch)	Jm(ch)	marine sedimentary rocks	Coon Hollow Formation
SHS	Jm(l)	Jm(l)	marine sedimentary rocks	Ladner Group
SHS	Jm(t)	Jm(t)	marine sedimentary rocks	Twisp Formation
MHG	Jmt(r)	Jmt(r)	metasedimentary and metavolcanic rocks	Rossland Group
SSS	JTRm(c)	JTRc	marine sedimentary rocks	Cultus Formation
MHG	JTRmt(h)	JTRhgs	metasedimentary and metavolcanic rocks	Hozomeen Group
SHS	Kc(m)	Kc(m)	continental sedimentary rocks	Midnight Peak Formation
SHS	Kc(w)	Kc(w)	continental sedimentary rocks	Winthrop Sandstone
MHG	TRms(cc)	Kcc	metasedimentary rocks	Cascade River Schist
SHS	Kcg(2)	Kcg(2)	continental sedimentary rocks, conglomerate	Virginian Ridge Formation

Landtypes of Washington – Geology Group Classification for Sedimentary and Some Metasedimentary Geologic Units (complete list available from TFW Monitoring Steering Committee).

GEO GROUP CODE	**NEW** *SYMBOL* (DNR)	**OLD SYMBOL** (current 1:100,000)	LITHOLOGY	**GEOLOGIC UNIT NAME**
SHS	Kcg(p)	Kcg(p)	continental sedimentary rocks, conglomerate	Patterson Lake conglomerate
SHS	Kcg(v)	Kcg(v)	continental sedimentary rocks, conglomerate	Virginian Ridge Formation
MLG	Jmt(em)	Kem	metasedimentary and metavolcanic rocks (mixed greenschist&phyllite[black])	northwest Cascade system
MLG	Jmt(ems)	Kems	metasedimentary and metavolcanic rocks (mixed greenschist&phyllite[silver])	northwest Cascade system
MHG	KJcb(n)	KJcb(n)	metacarbonate	Newby Group, undivided
MHG	KJms(g)	KJgs	metasedimentary rocks (fol. ss., sltst, and cgl.)	Goat Island area, rocks of
SHS	KJm(n)	KJm(n)	marine sedimentary rocks	Newby Group, undivided
SHS	KJm(n1)	KJna	marine sedimentary rocks	Nooksack Formation
SHS	KJm(n3)	KJng	marine sedimentary rocks	Nooksack Formation
SHS	KJm(n2)	KJnt	marine sedimentary rocks	Nooksack Formation
SHS	KJm(n4)	KJnv	marine sedimentary rocks	Nooksack Formation
SHS	KJm(r)	KJr	marine sedimentary rocks (sandstone, mudstone)	Russell Ranch Fm., clastic subunit
SHS	KJmct(r)	KJrc	chert-rich marine sedimentary rocks	Russell Ranch Fm., chert-tuff subunit
SHS	MZPZms(r)	KJrs	metasedimentary rocks	Rinker Ridge, slate of
SHS	Km(2)	Km(2)	marine sedimentary rocks	Virginian Ridge Formation
SHS	Km(g)	Km(g)	marine sedimentary rocks	Goat Creek Formation
SHS	Km(h)	Km(h)	marine sedimentary rocks	Harts Pass Formation
SHS	Km(p)	Km(p)	marine sedimentary rocks	Panther Creek Formation
SHS	Km(v)	Km(v)	marine sedimentary rocks	Virginian Ridge Formation
MHG	Km(ph)	Kpas	marine sedimentary rocks (with pillow basalt interbeds)	Portage Head/Point of Arches block
SSS	KJm(c)	Ks	marine sedimentary rocks (sltst.& shale with graywacke, tuff, etc.)	Constitution Fm.
MHG	JTRmt(e)	Ks	metasedimentary and metavolcanic rocks (marine)	eastern melange belt, rocks of the
MHG	JMmt(t)	Ktm	metasedimentary and metavolcanic rocks	Trafton terrane(Whetten,et.al.,1988)
VVC	Mc(e)	Mc	continental sedimentary rocks	Ellensburg Formation
VVC	Mcg(e)	Mcg	continental sedimentary rocks, conglomerate	Ellensburg Formation
SCX	Mcg(es)	Mcg	continental sedimentary rocks, conglomerate	Snipes Mtn. conglom.mem.of Ellens.Fm.

Landtypes of Washington – Geology Group Classification for Sedimentary and Some Metasedimentary Geologic Units (complete list available from TFW Monitoring Steering Committee).

GEO GROUP CODE	NEW *SYMBOL* (DNR)	OLD SYMBOL (current 1:100,000)	LITHOLOGY	GEOLOGIC UNIT NAME
SHS	MDcb(1c)	MDcb(1)	metacarbonate (lower)	Chewelah, carbonate rocks east of
SHS	MDcb(2c)	MDcb(2)	metacarbonate (middle)	Chewelah, carbonate rocks east of
SHS	MDcb(3c)	MDcb(3)	metacarbonate (upper)	Chewelah, carbonate rocks east of
MHG	Ocb(c)	Ocb	metacarbonate	Covada Group
MHG	Ocb(c)	Ocb(c)	metacarbonate	Covada Group
MHG	OCcb(d)	OCcb(d)	metacarbonate (bedded dolomite)	Metaline Formation, bedded dolomite
MHG	OCcb(l)	OCcb(l)	metacarbonate (limestone)	Metaline Formation, massive limestone
MHG	OCcb(l)	OCcb(l)	metacarbonate (massive limestone)	Metaline Formation, massive limestone
MHG	OCcb(m)	OCcb(m)	metacarbonate	Metaline Formation
MHG	OYcb(c)	OYcb	metacarbonate	Cayuse Mtn.-Mill Canyon area,metaseds
MHG	PMcb(k)	Pcb	metacarbonate	Kettle Falls, carbonate near
MHG	PMDms(c)	PDcs	metasedimentary rocks (argillite, volcanic sandstone)	Chilliwack Group of Cairnes (1944)
SSS	pKcs(b)	pKcs	calc-silicate rock	Brown Lake, calc-silicate rocks near
UAL	PLcg(t)	Plg	continental sedimentary rocks, conglomerate	Thorp Gravel
SSS	PLMc(r)	PlMc	continental sedimentary rocks	Ringold Formation
SHS	PLMcg(c)	PlMcg(c)	continental sedimentary rocks, conglomerate	Chamokane Creek area, cong. of
MHG	PMcb(s)	Pmcb(s)	metacarbonate	Spectacle Formation, Anarchist Group
SHS	pTmt	pTmt	metasedimentary and metavolcanic rocks	---
SHS	pTmt(m)	pTmt(m)	metasedimentary and metavolcanic rocks	McClure Mountain unit
MHG	PZcb	Pzcb	metacarbonate	---
MHG	PZcb(gu)	Pzcb	metacarbonate	Gardiner Creek, upper dolomite of
MHG	PZcb(gl)	Pzcb(1)	metacarbonate (lower)	Gardiner Creek, lower dolomite of
MHG	PZcb(gu)	Pzcb(2)	metacarbonate (upper)	Gardiner Creek, upper dolomite of
MHG	PZcb(s)	Pzcb(s)	metacarbonate	Swan Lake, metalimestone near
SSS	PLMc(r)	QPlc	continental sedimentary rocks	Ringold Formation
UAL	PLMc(t)	QTtd	continental sedimentary rocks	Troutdale Formation
SSS	Em(2hc)	rc	marine sedimentary rocks	HokoR.Fm,l.T.R.Gp,cob.&boul.chan.dep .
SSS	KJm(l)	s	marine sedimentary rocks (turbidite Seds:graywacke, sltst.,shale,cgl.)	---

SHS	Scg(b)	Scg	continental sedimentary rocks, conglomerate	Basalt Hill, qtz-granule conglom. on
SSS	Em(2a)	Ta	marine sedimentary rocks	Aldwell Formation
SSS	Em(2a)	Tal	marine sedimentary rocks	Aldwell Formation
SSS	Em(2as)	Tas	marine sedimentary rocks	Aldwell Formation, siltstone
SSS	Mm(1as)	Tas(1)	marine sedimentary rocks	Astoria Fm., Sipho. klein. zone (Saucesian)
SSS	Mm(1ar)	Tas(2)	marine sedimentary rocks	Astoria Fm.,Baggina wash. zone (Relizian)
SSS	Mm(1al)	Tas(3)	marine sedimentary rocks	Astoria Fm.,Rotalia becki zone (Luisian?)
SSS	Mm(1b)	Tasb	marine sedimentary rocks	Bald Ridge member, Astoria Fm.
SSS	Mm(1l)	Tasl	marine sedimentary rocks	Astoria Fm., lower member
SSS	Mm(1n)	Tasn	marine sedimentary rocks	Astoria Fm., Naselle member
SSS	Mm(1u)	Tasu	marine sedimentary rocks	Astoria Formation, upper
SCX	OEm(b)	Tb	marine sedimentary rocks	---
SCX	OEc(b)	Tb	continental sedimentary rocks (cgl., lithic ss., and sltst.)	Rocks of Bulson Ck. of Lovseth (1975)
SSS	Em(1bcc)	Tbcc	marine sedimentary rocks	Bear Creek, congl.& mudflow deposits
SCX	Em(1b)	Tbcs	marine sedimentary rocks	Brownes Creek, siltstone of
SSS	Em(1bcs)	Tbcss	marine sedimentary rocks	Bear Creek,carb.,lithof.,concret.ss.
SSS	Em(1bc)	Tbcst	marine sedimentary rocks	Bear Creek, siltstone & sandstone of
SSS	PLMcg(b)	Tbl	continental sedimentary rocks, conglomerate	Brays Landing, conglomerate of
CSX	EPAm(cb)	Tbm	marine sedimentary rocks (sandstone and argillite)	Blue Mountain unit of the CrescentFm.
SCX	EPAm(cbc)	Tbmc	marine sedimentary rocks (congl. & pebbly sandstone)	Blue Mountain unit of the CrescentFm.
SSS	Em(2b)	Tbs	marine sedimentary rocks	Bahobohosh, sandstone of
SSS	OEn(b)	Tbs	nearshore sedimentary rocks (ss., sltst., and coal)	Rocks of Bulson Ck. of Lovseth (1975)
SCX	Ec(c)	Tc	continental sedimentary rocks	Chuckanut Formation
SCX	Ec(2ch)	Tc	continental sedimentary rocks	Chumstick Formation
SSS	Mm(1c)	Tc	marine sedimentary rocks	Clallam Formation
SSS	On(s)	Tc	nearshore sedimentary rocks	Sooke Formation, Canada
SSS	On(s)	Tc	nearshore sedimentary rocks	Sooke Formation, Canada
SSS	Ec(2c)	Tca	continental sedimentary rocks	Carbonado Formation
SCX	Om(cc)	Tcac	marine sedimentary rocks	Cape Alava coastal block,conglomerate
SCX	Om(c)	Tcass	marine sedimentary rocks	Cape Alava coastal block, sandstone
SCX	Ec(2cc)	Tcc	continental sedimentary rocks	Chambers Creek, beds of
SCX	Ecg(2ch)	Tcc	continental sedimentary rocks, conglomerate	Chumstick Formation
SCX	Ecg(2chf)	Tcmf	continental sedimentary rocks, conglomerate	Chumstick Fm.monolith.fanglom.breccia
SCX	Ec(2chn)	Tcn	continental sedimentary rocks	Nahahum Canyon Member, Chumstick Fm.

SSS	Em(2cp)	Tcp	marine sedimentary rocks	Cliff Point, siltstone at
SCX	Ecg(2chr)	Tcr	continental sedimentary rocks, conglomerate	Chumstick Formation, red conglomerate
SCX	Ecg(2chr)	Tcrf	continental sedimentary rocks, conglomerate	Chumstick Fm. redbed fanglomerate
SCX	Em(1c)	Tcrs	marine sedimentary rocks	Crescent Formation sedimentary rocks
SCX	Em(1c)	Tcs	marine sedimentary rocks	Crescent Formation sedimentary rocks
SSS	En(c)	Tcz	nearshore sedimentary rocks	Cowlitz Formation
SSS	En(c)	Tcz	nearshore sedimentary rocks	Cowlitz Formation
VVC	PLc(d)	Tdl	continental sedimentary rocks	Dalles Formation
VVC	Mcg(ec)	Tec	continental sedimentary rocks, conglomerate	Eagle Creek Formation
SCX	Em(2ec)	Tec	marine sedimentary rocks	Elk Lake block,conglomerate&sandstone
VVC	Mcg(es)	Telc	continental sedimentary rocks, conglomerate	Snipes Mtn. conglom.mem.of Ellens.Fm.
SSS	Eme(e)	Tem	melange	Elk Lake block, melange unit
SSS	Em(2e)	Tes	marine sedimentary rocks	Elk Lake block, siltstone unit
MHG	MEms(e)	Tes	metasedimentary rocks (slate&phyllite with l.t.20%fol. ss,semischist)	Elwha lith. assem. (Tabor&Cady,1978)
SCX	Em(2esc)	Tesc	marine sedimentary rocks	Elk Lake block, ss. and congl. unit
SSS	Em(2es)	Tess	marine sedimentary rocks	Elk Lake block, sheared sltst. & ss.
VVC	Mc(ev)	Tesv	continental sedimentary rocks	Ellensburg Fm., Vantage Member
SSS	Em(1)	Teu	marine sedimentary rocks	---
SCX	Em(1c)	Tevc	marine sedimentary rocks	Crescent Formation sedimentary rocks
VVC	PLcg(g)	Tgrc	continental sedimentary rocks, conglomerate	Gamma Ridge, volcanic rocks of
SSS	Em(2h)	Th	marine sedimentary rocks	Hoko R. Fm., lower Twin River Group
SSS	Em(2hc)	Thc	marine sedimentary rocks	HokoR.Fm,l.T.R.Gp,cob.&boul.chan.dep.
SSS	Em(1h)	Tho	marine sedimentary rocks	Hoh Assemblage
SSS	Em(2hs)	Ths	marine sedimentary rocks	HokoR.Fm,l.T.R.Gp,turbidite sandstone
SSS	Em(2hsb)	Thsb	marine sedimentary rocks	HokoR.Fm,l.T.R.Gp,phyl.&basaltic sst.
SSS	Em(2ht)	Tht	marine sedimentary rocks	Humptulips Formation
MHG	TRms(cc)	TKcc	metasedimentary rocks	Cascade River Schist
MHG	JTRmc(e)	TKec	metasedimentary rocks, cherty	eastern melange belt, rocks of the
MHG	JTRmt(e)	TKev	metasedimentary and metavolcanic rocks	eastern melange belt, rocks of the
SCX	PAKme(p)	TKpam	melange	Portage Head/Point of Arches block
MHG	JMmt(t)	TKt	metasedimentary and metavolcanic rocks	Trafton terrane(Whetten,et.al.,1988)
MCM	KJmc(w)	TKwc	metasedimentary rocks, cherty	western melange belt, rocks of the
SSS	Em(2l)	Tl	marine sedimentary rocks	Lyre Formation, sandstone member
SSS	OEm(lc)	Tlc	marine sedimentary rocks	Lincoln Creek Formation

SSS	Em(2lc)	Tlc	marine sedimentary rocks	Lyre Formation, conglomerate member
SSS	OEm(lcs)	Tlcs	marine sedimentary rocks	Lincoln Cr.Fm,basaltic sandstone mem.
SSS	Em(2lb)	Tlfb	marine sedimentary rocks	Lyre Fm.,breccia&congl.ofCapeFlattery
SSS	Em(2ll)	Tll	marine sedimentary rocks	Lyre Fm., lower (conglomerate) member
SSS	Em(2lc)	Tll	marine sedimentary rocks	Lyre Formation, conglomerate member
SSS	Em(1l)	Tlls	marine sedimentary rocks	Lizard Lake, basaltic ss. & cgl. of
SSS	Ec(2lo)	Tlo	continental sedimentary rocks (sandstone)	Lookout Creek sandstone
SSS	Em(2ls)	Tls	marine sedimentary rocks	Lyre Formation, sandstone member
SSS	Em(2lt)	Tlt	marine sedimentary rocks	Lyre Fm. & Twin River Fm., undivided
SSS	Em(2lu)	Tlu	marine sedimentary rocks	Lyre Fm., upper (sandstone) member
SSS	Em(2lcu)	Tluc	marine sedimentary rocks	Lyre Formation, conglomerate member
SSS	Em(2lu)	Tlv	marine sedimentary rocks	---
SSS	OEm(m)	Tm	marine sedimentary rocks	Makah Fm., middle Twin River Gp.
SCX	Ec(1m)	Tm	continental sedimentary rocks	Manastash Formation
SSS	OEm(mb)	Tmb	marine sedimentary rocks	Makah Fm.,m.T.R.Gp.,Baada Point Mem.
SSS	OEm(mc)	Tmc	marine sedimentary rocks	Makah Fm,m.T.R.Gp,CarpentersCk.TuffM.
SSS	Em(2m)	Tmc	marine sedimentary rocks	McIntosh Formation
SSS	Em(2ms)	Tmcs	marine sedimentary rocks	McIntosh Formation, sandstone member
SSS	OEm(md)	Tmd	marine sedimentary rocks	Makah Fm.,m.T.R.Gp,Dtokoah Point Mem.
SSS	Em(1)	Tme	marine sedimentary rocks	---
SSS	OEm(mf)	Tmf	marine sedimentary rocks	Makah Fm.,m.T.R.Gp.,Falls Creek unit
SVS	Mc(m)	Tmh	continental sedimentary rocks	Mashel Formation
SSS	OEm(mj)	Tmj	marine sedimentary rocks	Makah Fm.,m.T.R.Gp.,Jansen Creek Mem.
SSS	OEm(mk)	Tmk	marine sedimentary rocks	Makah Fm.,m.T.R.Gp.,Klachopis Pt.Mem.
SSS	Mm(2m)	Tmn	marine sedimentary rocks	Montesano Formation
SSS	Mm(2mc)	Tmnc	marine sedimentary rocks	Montesano Formation, conglomerate
SSS	Mm(2ms)	Tmns	marine sedimentary rocks	Montesano Formation sandstone
SSS	Mm(2mt)	Tmnt	marine sedimentary rocks	Montesano Formation, siltstone
SSS	OEm(ms)	Tms	marine sedimentary rocks	Marrowstone Shale of Durham (1944)
SSS	OEm(mt)	Tmt	marine sedimentary rocks	Makah Fm.,m.T.R.Gp.,Third Beach Mem.
SCX	Ec(2na)	Tn	continental sedimentary rocks	Naches Formation
SCX	Ec(2na)	Tna	continental sedimentary rocks (feldspathic sandstone&volcanic rocks)	Naches Formation
SCX	Ec(2nag)	Tng	continental sedimentary rocks	Guye Sed. Member, Naches Formation
SCX	MEm(n)	Tnmu	marine sedimentary rocks (micaceous sandstone & slate,	Needles-GrayW.lith.as(Tabor&Cady,'78)

			undiff.)	
VVC	Ec(2nas)	Tns	continental sedimentary rocks	Naches Formation, ss. and vol. rocks
SSS	Em(2oc)	Tocc	marine sedimentary rocks (congl., sandstone, and siltstone)	Ozette Lake-Calawah Ridge block
SSS	Eme(o)	Tocml	melange (ss.&basalt in sheared concretionary sltst. matrix)	Ozette Lake-Calawah Ridge block
SSS	Em(1o)	Tocs	marine sedimentary rocks (siltstone with sandstone interbeds)	Ozette Lake-Calawah Ridge block
SSS	MEm(o)	Tocss	marine sedimentary rocks	Ozette Lake-Calawah Ridge block
SSS	Em(2op)	Tom	marine sedimentary rocks	Omeara Point, siltstone and sandstone
SCX	Ec(2pg)	Tp	continental sedimentary rocks	Puget Group
SSS	MOm(p)	Tp	marine sedimentary rocks	Pysht Fm., upper Twin River Gp.
SCX	Em(2phc)	Tpac	marine sedimentary rocks (conglomerate and sandstone)	Portage Head/Point of Arches block
SCX	Em(1pc)	Tpacb	marine sedimentary rocks (conglomerate and breccia)	Portage Head/Point of Arches block
SCX	Em(2p)	Tpas	marine sedimentary rocks (sandstone and siltstone)	Portage Head/Point of Arches block
SCX	Em(1ps)	Tpass	marine sedimentary rocks (sandstone and siltstone)	Portage Head/Point of Arches block
SSS	MOm(pc)	Tpc	marine sedimentary rocks	Pysht Fm.,u.TwinRiverGp.,conglomerate
SSS	Eme(pc)	Tpcm	melange (siltstone with phacoids of basalt,congl.,sandstone)	Petroleum Creek block
SSS	Em(2pc)	Tpcs	marine sedimentary rocks (siltstone and sandstone)	Petroleum Creek block
SCX	Ec(2pg)	Tpg	continental sedimentary rocks	Puget Group
SCX	Ec(2r)	Tpr	continental sedimentary rocks	Renton Formation, Puget Group
SSS	MOm(ps)	Tps	marine sedimentary rocks	Pysht Fm.,u.Twin River Gp.,sandstone
SSS	Ec(2t)	Tptm	continental sedimentary rocks	Tiger Mountain Formation, Puget Group
SSS	Em(2q)	Tq	marine sedimentary rocks	---
SSS	OEm(q)	Tq	marine sedimentary rocks	Quimper Sandstone of Durham (1944)
SSS	Em(2hc)	Trc	marine sedimentary rocks (conglomerate)	Hoko R. Fm., lower Twin River Group
MHG	TRcb	Trcb	metacarbonate	---
MHG	TRcb	Trcb	metacarbonate	---
MHG	TRcb(c)	Trcb	metacarbonate	Cave Mountain Formation
MHG	TRcb(mb)	Trcb(mb)	metacarbonate	Martin Bridge Limestone
MHG	TRmc(h)	TRhc	metasedimentary rocks, cherty	Hozomeen Group
MHG	JTRm(o)	TrJo	marine sedimentary rocks (ribbon chert,minor pillow basalt&limestone)	Orcas Chert (Deadman Bay terrane)
SHS	Ec(2rl)	Trl	continental sedimentary rocks	Roslyn Formation, lower member
SHS	Ec(2rm)	Trm	continental sedimentary rocks	Roslyn Formation, middle member
HMG	TRmt(dc)	Trmt(dc)	metasedimentary and metavolcanic rocks	Doyle Creek Formation

MHG	TRmt(ws)	Trmt(ws)	metasedimentary and metavolcanic rocks	Wild Sheep Creek Formation
MHG	TRPMmt	TrPmmt	metasedimentary and metavolcanic rocks	---
MHG	TRPMmt(k)	TrPmmt(k)	metasedimentary and metavolcanic rocks	Kobau Formation
SHS	Em(2r)	Trr	marine sedimentary rocks	Raging River Formation
SHS	Em(2r)	Trr	marine sedimentary rocks (ss.,siltstone,shale,&minor conglomerate)	Raging River Formation
SSS	MOm(ps)	Trs	marine sedimentary rocks	Pysht Fm.,u.Twin River Gp.,sandstone
SHS	Ec(2ru)	Tru	continental sedimentary rocks	Roslyn Formation, upper member
SSS	OEn	Ts	nearshore sedimentary rocks	---
SSS	Em(1sb)	Ts	marine sedimentary rocks	Scow Bay, sandstone of
SSS	On(s)	Ts	nearshore sedimentary rocks	Sooke Formation, Canada
SHS	Ec(1s)	Ts	continental sedimentary rocks	Swauk Formation
SHS	Ec(1sa)	Tsa	continental sedimentary rocks	Swauk Formation, arkosic
SSS	Em(2sb)	Tsb	marine sedimentary rocks	Shoalwater Bay, siltstone of
SSS	Em(1sp)	Tsbs	marine sedimentary rocks	Snag Peak block, basaltic siltstone
SSS	Em(2sk)	Tsc	marine sedimentary rocks	Skamokawa Creek, siltstone of
SHS	Ec(1s)	Tsc	continental sedimentary rocks	Swauk Formation
SHS	Ec(1sc)	Tsc	continental sedimentary rocks	Swauk Formation
SSS	Em(2)	Tse	marine sedimentary rocks	---
SSS	Em(2s)	Tses	marine sedimentary rocks	---
SHS	Ecg(1sf)	Tsf	continental sedimentary rocks, conglomerate	Swauk Formation, fanglomerate
SHS	Ec(1si)	Tsir	continental sedimentary rocks	Swauk Formation, ironstone
SSS	En(sk)	Tsk	nearshore sedimentary rocks	Skookumchuck Formation
SSS	Em(2scs)	Tsps	marine sedimentary rocks	Snag Peak block,concret. sltst.&clst.
SSS	Em(2sc)	Tspsc	marine sedimentary rocks	Snag Peak block, ss. and congl. unit
SSS	Em(2sm)	Tspsm	marine sedimentary rocks	Snag Peak block, sandstone unit
SSS	Em(2sp)	Tspsp	marine sedimentary rocks	Snag Peak block, ss. and sltst. unit
SSS	Em(2ss)	Tspss	marine sedimentary rocks	Snag Peak block, sltst. and ss. unit
SSS	OEm(s)	Tspst	marine sedimentary rocks	Snag Peak block, siltstone unit
SSS	OEn	Tss	nearshore sedimentary rocks	---
SHS	Ec(1f)	Tss	continental sedimentary rocks	Swauk Formation
SHS	Ec(1g)	Tssc	continental sedimentary rocks	Swauk Formation
SHS	Ec(1s)	Tssh	continental sedimentary rocks	Swauk Formation
SSS	Em(2hc)	Ttc	marine sedimentary rocks (conglomerate)	Hoko R. Fm., lower Twin River Group
SHS	PLcg(t)	Ttm	continental sedimentary rocks, conglomerate	Thorp Gravel
SCX	Ec(2t)	Ttm	continental sedimentary rocks	Tiger Mountain Formation, Puget Group

			(ss., sltst., conglomerate, & coal)	
SCX	OEn(t)	Tto	nearshore sedimentary rocks	Toutle Formation
SSS	Em(2tr)	Ttr	marine sedimentary rocks	---
SSS	Em(2lt)	Ttr	marine sedimentary rocks	Lyre Fm. & Twin River Fm., undivided
SSS	OEm(m)	Ttr	marine sedimentary rocks	MakahFm.,middle mem.of Twin River Gp.
SSS	OEm(t)	Ttr	marine sedimentary rocks	Twin R.Gp.,lower&middle mems.,undiv.
SSS	Em(2hc)	Ttrc	marine sedimentary rocks	HokoR.Fm,l.T.R.Gp,cob.&boul.chan.dep.
SSS	OEm(m)	Ttrm	marine sedimentary rocks	Makah Fm., middle Twin River Gp.
SSS	MOm(p)	Ttru	marine sedimentary rocks	Pysht Fm., upper Twin River Gp.
SHS	PLcg(t)	Tts	continental sedimentary rocks, conglomerate	Thorp Gravel
SCX	Oc(w)	Tw	continental sedimentary rocks	Wenatchee Formation
VMB	Em(2wc)	Twc	marine sedimentary rocks (sandstone & conglomerate)	Washburn Hill block
SSS	Em(2wq)	Twcs	marine sedimentary rocks	Waatch quarry,siltstone&sandstone of
SVS	Mc(w)	Twk	continental sedimentary rocks	Wilkes Formation
SVS	Mc(w)	Twk	continental sedimentary rocks	Wilkes Formation
SSS	MEm(o)	Two	marine sedimentary rocks	Ozette Lake-Calawah Ridge block
SSS	MEm(w)	Two	marine sedimentary rocks (ss, minor cgl; l.t.40% siltstone)	W.Olympic lith.assem(Tabor&Cady,1978)
SSS	MEm(wa)	Twoa	marine sedimentary rocks (argillite with limestone lenses&concretions)	W.Olympic lith.assem(Tabor&Cady,1978)
SSS	Em(2wp)	Twps	marine sedimentary rocks	Waatch Point, siltstone of
SCX	Em(2w)	Twsg	marine sedimentary rocks (sandstone and siltstone)	Washburn Hill block
SCX	Em(2ws)	Twss	marine sedimentary rocks (sandstone)	Washburn Hill block
SCX	Em(2wt)	Twts	marine sedimentary rocks (turbidite sandstone)	Washburn Hill block
SHS	Dcb(l)	uDcb	metacarbonate	Limestone Hill, limestone on
SHS	Kcg(s)	uKcg(s)	continental sedimentary rocks, conglomerate	Sophie Mountain Formation
MHG	Ycb(e)	Ycb(e)	metacarbonate	Edna Dolomite, Deer Trail Group
MHG	Ycb(s)	Ycb(s)	metacarbonate	Stensgar Dolomite, Deer Trail Group
MHG	Ycb(p)	Ycb(u)	metacarbonate	Priest River Group, carbonate rock
MHG	Ycs(p)	Ycs	calc-silicate rock	Priest River Group,calc-silicate rock
MHG	Yms(s)	Yms(a)	metasedimentary rocks	Striped Pk.Fm.,Missoula Gp.,Belt Supg
MHG	Yms(rb)	Yms(b)	metasedimentary rocks	Burke Fm.,Ravalli Group,Belt Supergp
MHG	Yms(s)	Yms(b)	metasedimentary rocks	Striped Pk.Fm.,Missoula Gp.,Belt Supg
MHG	Yms(rb)	Yms(bf)	metasedimentary rocks	Burke Fm.,Ravalli Group,Belt Supergp
MHG	Yms(bu)	Yms(bu)	metasedimentary rocks	Belt Supergroup, upper, undivided
MHG	Yms(s)	Yms(c)	metasedimentary rocks	Striped Pk.Fm.,Missoula Gp.,Belt Supg

MHG	Yms(s)	Yms(d)	metasedimentary rocks	Striped Pk.Fm.,Missoula Gp.,Belt Supg
MHG	Yms(p)	Yms(p)	metasedimentary rocks	Prichard Formation, Belt Supergroup
MHG	Yms(r)	Yms(r)	metasedimentary rocks	Ravalli Group, Belt Supergroup
MHG	Yms(rr)	Yms(r)	metasedimentary rocks	Revett Fm.,Ravalli Group,Belt Supergp
MHG	Yms(rrb)	Yms(rb)	metasedimentary rocks	Revett and Burke Fms., Ravalli Group
MHG	Yms(s)	Yms(s)	metasedimentary rocks	Striped Pk.Fm.,Missoula Gp.,Belt Supg
MHG	Yms(s)	Yms(sp)	metasedimentary rocks	Striped Pk.Fm.,Missoula Gp.,Belt Supg
MHG	Yms(sr)	Yms(sr)	metasedimentary rocks	St. Regis Fm.,Ravalli Group,Belt Supg
SHS	Yms(w)	Yms(w)	metasedimentary rocks	Wallace Fm., Belt Supergroup
SHS	Yms(w)	Yms(w)	metasedimentary rocks	Wallace Fm., Belt Supergroup
SHS	Yms(wl)	Yms(wl)	metasedimentary rocks	Wallace Fm., lower, Belt Supergroup
SHS	Yms(wu)	Yms(wu)	metasedimentary rocks	Wallace Fm., upper, Belt Supergroup
MHG	Zcb(m)	Zcb(m)	metacarbonate	Monk Formation, Winderemere Group
SHS	Zcb(s)	Zcb(s)	metacarbonate	ShedroofConglomerate,limestone,Wind. G
MHG	Zcg(h)	Zcg(h)	continental sedimentary rocks, conglomerate	Huckleberry Fm.,conglomerate mem.,W.G.
SHS	Zcg(s)	Zcg(s)	continental sedimentary rocks, conglomerate	ShedroofConglomerate,conglomerate,W. G.
MHG	Zmt(m)	Zmt(m)	metasedimentary and metavolcanic rocks	Monk Formation, Winderemere Group
MHG	Zmt(w)	Zmt(w)	metasedimentary and metavolcanic rocks	Windermere Group, undivided

Appendix B: **Diagnostic Key to Causes of Management-Related Mass Failures**

Note to Users:

This key guides diagnosis to causes of management-related mass failure. The key covers the more common, and a few less common, situations and triggering mechanisms that may be encountered in forest management. No key of this kind can cover all circumstances. It is not intended to replace, but to supplement, practical experience aided by local knowledge of site and climatic conditions and history of practice performance.

The following is a description of how the key is used. The key is organized by situation, as one might first observe arriving at a site. The site examiner uses evidence at the site to detect which triggers played a role in the mass failure or have the potential to play a role in mass failure. Look for a similar situation described in the key. Read the list of triggers. Does this describe the site? Continue through the key to find any other descriptions that may fit the site. Once all the situations are identified, use deductive reasoning to diagnose the cause of failure or potential for failure by testing field observations against the diagnosis in the key. Determine which prescription from the key may be an appropriate corrective action or application of a practice for the site. Compare the key's prescriptions with the site's practice and evaluate the difference. Describe how the site's practice addressed or did not address the trigger. Then proceed in developing recommendation for change or adjustment of the practice using the key's prescriptions as a guide. Be sure to qualify what site factors are appropriate for the recommendations. Describe the level of confidence in the diagnosis and the recommendations. Document any disagreements with the key. This serves two purposes: 1) demonstrating the key does not apply in the specific case requires systematic reasoning which assures the appropriate level of diagnosis has been conducted; and 2) the information provided can be used to continually improve and expand this guide.

Prescriptions listed in this key are purposely general to cover a variety of situations. The key is not intended to replace analysis that develops prescriptions tailored to each site. Recommendations for improvement or corrective action are arrived at through consideration of specific site conditions and local management requirements.

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Diagnostic Key:

SHALLOW RAPID LANDSLIDES

Road Management Activities:

I. Failure occurred within the road prism

A. Failure originates at road fill

1. Evidence of surface runoff flowing from ditch line to failure origin.

   Probable Trigger: Concentration of drainage causing increased pore pressure in or runoff over variably compacted fill.

   Prescriptions that address trigger:
   - Disperse runoff by adding relief drainage structures (e.g., culverts, waterbars).
   - Reduce sources of sediment filling ditches (e.g., cut-slope erosion, ditch erosion, road surface erosion).
   - Increase ditch clean-out maintenance activities.
   - Avoid low gradient ditches that encourages impoundment and then diversion.
   - In-slope road grade to ditch; Outslope road grade without ditch.
   - Add berms for short distances along outside edge of road to direct drainage to next drainage structure.

2. Sidecast constructed roads on slope gradients >55%.

   Probable trigger: Load of sidecast exceeds stable limits. Deterioration of buried organic debris causes instability. Pore pressure increased by concentration of road drainage.

   Prescriptions that address trigger:
   - Temporary measure: divert flow away from unstable sidecast; fill tension cracks.
   - Permanent measure: remove unstable portion of sidecast.
   - Disperse road surface runoff (e.g., outsloping, crowning, or rolling grade).

3. Sidecast constructed roads on slope gradients <55%. Evidence of springs and/or ponding in ditch due to nearly flat road gradient.

   Probable trigger: Pore pressures exceeded in roadfill from infiltration of drainage through road prism. (Note: Go to VI to evaluate association with deep seated landslide).

   Prescriptions that address trigger:
   - Control hydrology with site specific design (e.g., capture groundwater upslope and route to stable land surface or stream channel).
   - Remove sidecast.
   - Eliminate ditch and disperse drainage (e.g., outslope or roll grade; waterbars).

4. Evidence of overland flow originates from above cut-slope forming runoff features in roadbed that lead to failure origin.

   Probable trigger: Overland flow from rain-on-snow or extreme rainstorm. (Rare in forested environments but may occur on frozen or compacted soil or when soils with very little surface protection have reached saturation).

   Prescriptions that address trigger:
   - Avoid high concentration of road surface and landings (e.g.,“stacking” roads closely spaced in elevation).
   - Avoid large areas of hydrologically immature vegetation and roads in convergent headwalls susceptible to rain on frozen soil or rain-on-snow situations.
   - Avoid road junctions in convergent landforms.
   - Avoid road junctions on slopes >65%.
   - Reduce road width and road density.

B. Failure erodes road prism at or near stream crossing

1. Evidence of impounded water upstream of crossing or along road edge or ditch line.

   a) Partial failure of roadfill of the downstream edge. Evidence of water overtopping fill and erosion channeled into stream on downstream side of fill.

Probable trigger: Culvert undersized for storm event or plugged by debris. (NOTE: Stream crossing design most likely contributed to avoiding the much more damaging effect of stream diverting out of its original channel as a result of impoundment at the crossing.)

Prescriptions that address trigger:

- Replace culvert with larger diameter orifice that allows for higher flow volume.
- Provide for "pass through" of debris (e.g., bridge, arch).
- Provide for "pass over" of flow and debris without fill failure (e.g., harden fills sloped downstream to direct flow, fords).
- Add relief culvert above existing culvert to pass impounded waters prior to overtopping.
- Add diversion structure to catch debris prior to plugging culverts.
- Road decommissioning.

b) Failure of entire road prism at crossing.

Probable trigger: Culvert could not pass flow or debris for storm event. Structural failure of culvert. Debris flow scour. Fill structure did not support overtopping by stormwater.

Prescriptions that address trigger:

- Provide for "pass through" of debris (e.g., bridge, arch).
- Replace culvert with larger orifice to pass larger flow volumes.
- Provide for "pass over" of flow and debris without fill failure (e.g., harden fills sloped downstream to direct flow, fords).
- Place small outsloped dip in roadbed at crossing to reduce chances of stream diversion.
- Road decommissioning.
- Replace or repair old, leaking culverts prior to failure.
- Add diversion structure to catch debris prior to plugging culverts.

c) Evidence of impounded water at crossing diverted from channel to road ditch or road prism causing failure in roadbed down gradient from crossing.

Probable trigger: Culvert undersized for storm event or plugged by debris. Road design causes diversion of impounded waters (i.e., road bed at crossing is higher in grade than bottom of ditch and road gradient at crossing drains downslope away from crossing).

Prescriptions that address trigger:

- Lower crossing height to below ditch depth and outslope to minimize diversion potential.
- Same as a) and b).

2. No signs of impounded water upstream of road crossing.

a) Evidence of debris torrent scour, flow or "mud splash" in channel.

Probable trigger: Upslope trigger, unrelated to road. Fill adds to sediment volume.

Prescriptions that address trigger:

- Analyze upslope triggers and prevent management-related torrents.
- Reduce increased torrent energy/sediment delivery contributed by fill. Construct "pass over" designs at active crossings.
- Avoid crossing natural debris torrent tracks.

b) Partial fill removal. Culvert remains in place and has visible signs of wear (e.g., holes, crushed).

Probable trigger: Seepage either from culvert deterioration or other source in fill compromised culvert foundation.

Prescriptions that address trigger:

- Inventory culverts at expected wear life intervals. Replace or repair aging and worn culverts.
- Adequately compact fill.
- Design culvert or other structure specifically to address the site hydrology.

C. Failure originates in or immediately above roadcut

1. Failure erodes entire road prism.

Probable trigger: In this case, often landslides scars mask indicators of triggering mechanisms. Therefore, confidence in the diagnosis may be low. Some common triggers are: a). road directs water into unstable geologic layer, b) road cut oversteepened slope angle beyond natural stable angle, c) road location "loads" weak, unstable soil, d) a combination of any of these three, e) slope failure unrelated to the road. Conditions where the hazard is the greatest for these triggers are: bedrock hollows, slope gradients at the natural angle of repose for regolith, weak zones in bedrock caused by fracturing or fault shear or layers dipping parallel with slope angle; or zones of highly contrasting materials creating layers of impermeable and permeable or large mass over weak mass.

Prescriptions that address trigger:

- Site specific road design with slope reinforcement (e.g., retaining walls/buttresses, light weight fills, soil nails, bridging).
- Avoid locating roads trough high hazard conditions.
- Disperse road drainage away from bedrock hollows and other "0" Order channels.
- Conduct slope stability analysis to determine design limitations.

2. Shallow roadcut failure depositing into roadbed.

Probable trigger: Cutslope angle is not stable and road has oversteepened natural slope.

Prescriptions that address trigger:

- Avoid locating roads on slope gradients at or near natural angle of repose that creates very steep and long cutslopes.
- Construct cutslopes at stable angles and lengths.

3. Tension cracks upslope from landslide origin or trees leaning downslope or upslope.

Probable trigger: Cutslope undercuts slope above reducing resisting forces. Or, road is circumstantial to naturally unstable slope i.e. road may or may not have accelerated mass failure. (Note: before and after road placement monitoring is necessary to understand the contribution to instability in this case. Go to VI to evaluate association with deep seated landslide).

Prescriptions that address trigger:

- Avoid locating roads with active or inactive failures with delivery potential.
- Design roads using slope stability analysis.

4. Layered bedrock with dip angles parallel with steep slope gradient (dipslopes).

Probable trigger: Road concentrates drainage or changes "load" or "resisting forces" on a naturally unstable area. (Note: Go to VI to evaluate association with deep seated landslide).

Prescriptions that address trigger:

- Design roads using slope stability analysis.
- Avoid locating roads in these areas.

II. Failure occurred below road prism

A. Drainage structures divert flow onto slope above failure origin.

Probable trigger: Road drainage concentrated onto unstable slope.

Prescriptions that address trigger:

- Direct drainage to stable slopes and away from unstable slopes.
- Disperse drainage to reduce concentration of flow.

B. Persistent ponding of water in road ditch.

Probable trigger: Road drainage infiltrates to less permeable layers increasing pore water pressure of mass above layer. Nearly flat road gradient ponds water in ditches. Road located through a perched water table.

Prescriptions that address trigger:

- Disperse road drainage away from low gradient section to reduce volume of water that is infiltrated in area.
- Redirect outflow of water table to stable soils.

C. Thin layers of bedrock with dip near parallel with slope gradient

Probable trigger: Road concentrates drainage or changes “load” or “resisting forces” on a naturally unstable area.

Prescriptions that address trigger:

- Design roads to avoid concentration of drainage either by outflow or infiltration.
- Road location and design based upon slope stability analysis.
- Avoid locating roads in these areas.

III. No Failures Present but Indicators of Potential Road-related Mass Failure

A. Tension cracks or depressions in road bed.

B. Tension cracks parallel with road alignment associated with sidecasted fillslopes.

Probable trigger: Loading slope by unstable sidecast. Change in strength or volume of fill due to deterioration of buried organic debris. Increase pore pressure due to interception of runoff by tension crack.

Prescriptions that address trigger:

- Go to I.A.

C. Depressions or Cracks diagonal or perpendicular with road alignment.

Probable trigger: Settlement of roadfill from poorly compacted fill or deterioration of buried organic debris. Deep seated movement.

Prescriptions that address trigger:

- If trigger is deep seated related, go to VII. A.
- Reconstruct roadfill.
- Construct roads without buried organic debris in road fill

D. Depressions or Cracks diagonal or perpendicular with road alignment associated with stream crossings. Stream flow observed through fill along the outside of culvert.

Probable trigger: Structural failure of culvert. Removal of fines from flow through fill i.e. piping. Settlement of roadfill from poorly compacted fill or deterioration of buried organic debris. Deep seated movement.

Prescriptions that address trigger:

- If trigger is deep seated related, go to VII A.
- Go to 1.B.2. b).

E. Ponded water on road surface.

Probable trigger: Infiltration of water saturates fill increasing pore pressure.

Prescription tht address trigger:

- Adjust road grade to eliminate ponding (e.g., crown, inslope or outslope).
- Disperse runoff (e.g., rolling grades, water bars).

F. Severe tree leaning downslope below road or above road

Probable trigger: Cutslope under undercuts slope above reducing resisting forces. Infiltration or runoff from road is increasing pore pressure. Road is circumstantial to naturally unstable slope i.e. road may or may not have accelerated mass failure. (Note: before and after road placement monitoring is necessary to understand the contribution to instability in this case).

Prescription that address trigger:

- Redirect road drainage away from area. Monitor for progressive slope movement.
- Any aggressive reconstruction or decommissioning should be based on slope stability analysis.
- Avoid locating roads with active or inactive failures with delivery potential.

G. Plugged or damaged relief culverts. Signs of runoff diverted from ditch

Probable trigger: Diversion of road drainage away from designed structures.

Prescription that address trigger:

- Conduct routine maintenance based on site conditions (e.g., cutslope erosion, storm frequency, etc.) to reduce diversion potential.
- Add drainage relief structures to disperse flow to reduce the volume of flow that could be diverted.
- Restore function of drainage system.
- Inslope road, roll grade or construct intermittent berms for short distances to direct drainage on road surface away form failure prone areas.

H. Drainage structures divert flow onto failure prone slopes.

Probable trigger: Concentration of road drainage onto failure prone areas.

Prescription that address trigger:

- Relocate relief culvert or direct culvert outflow to stable slope.
- Rock armor fillslope at outflow.
- Reduce flow volume to culvert by adding relief culverts “upstream”.

Timber Management Activities:

IV. Failure originates within a 5-25 year old harvest unit

A. Failure originates in 1st Order channels

1. Clearcut harvest.

   Probable Trigger: Loss of root strength. Slash accumulation in channel.

   Prescriptions that address trigger:
   - Incorporate site characteristics from this failure into hazard identification and implement "Leave areas" in channel heads of 1st Order channels.
   - Use directional felling of timber to avoid slash accumulation in channels.

2. Clearcut harvest with "Partial Cut" or "No Cut" prescriptions in channel.

   Probable Trigger: Inadequate root strength from composition/structure of "leave area" stand. Root strength reduced in "leave area" from windthrow after harvest. Increase pore water pressure from storm event (natural) or from influence of management activities upslope.

   Prescriptions that address trigger:
   - No cut rather than partial cut may be more effective.
   - Improve "leave area" composition/structure with underplanting.
   - Include as buffer an expanded "leave area" to add root strength.
   - Design unit layout to provide maximum protection of "leave area" from windthrow.
   - Consider hydrologic influence from management activities above failure.
   - Design leave area using wet soil or vegetation indicators to locate springs and adjacent recharge areas in drainage heads.

B. Failure originates along banks of 1st or 2nd Order channel

1. Clearcut harvest.

   Probable Trigger: Increased pore water pressure in soils. Erosion of banks by peak flows or surface runoff in less defined channels. Loss of root strength.

   Prescriptions that address triggers:
   - No broadcast burn.
   - Prompt reforestation.
   - Full suspension to reduce ground disturbance.
   - Partial cut and/or smaller units in convergent areas prone to rain-on-snow.
   - Avoid "off-site" contribution of runoff to channels by roads.

2. Partial cut harvest.

Probable Trigger: Increased pore water pressure in soils. Erosion of banks by peak flows or surface runoff in less defined channels. Loss of root strength.

Prescriptions that address triggers:

- Full suspension to reduce ground disturbance.
- Smaller unit size in convergent areas.
- More trees per acre along channels.
- Avoid “off-site” contribution of runoff by roads.

C. Failure originates in bedrock hollows or “0” Order channels

1. Clearcut harvest.

Probable Trigger: Loss of root strength. Increase soil water pressure.

Prescriptions that address triggers:

- Design “no cut” leave area using wet soil or vegetation indicators to locate springs and adjacent recharge areas in drainage heads.
- Avoid “off site” contribution of runoff by roads.

2. Clearcut harvest with “Partial Cut” leave areas in bedrock hollows or “0” Order channel heads.

Probable Trigger: Increase soil water pressure.

Prescriptions that address triggers:

- Design leave area using wet soil or vegetation indicators to locate springs and adjacent recharge areas in drainage heads.
- Examine species composition/structure and alter prescriptions to maximize root strength and to reduce persistence and accumulation of snowpack.
- Avoid “off-site” contribution of runoff to channels by roads.
- Increase leave area size to expand buffer area.

3. Clearcut with “No Cut” leave area in bedrock hollows.

Probable Trigger: Increase soil water pressure.

Prescriptions that address triggers:

- “No cut” leave area is the most common prescription.
- Increase leave area size to expand buffer area.

Comment: This situation warrants further examination. Did management in the adjacent area contribute to an increase in soil water? Was there a significant storm event that caused failures in unmanaged stands? If failures occurred in non-managed bedrock hollows, the conclusion may be that management contributed very little to this failure. If the in-unit failure had no companion in a mature forest setting, then there is less certainty about the conclusion that the failure was not management related.

D. Failures coalesce in convergent 0 and/or 1st Order channels

1. Clearcut harvest.

Probable Trigger: Loss of root strength. Increase soil water pressure. Surface runoff erodes less developed channels.

Prescriptions that address triggers:

- Design "no cut" leave area using wet soil or vegetation indicators to locate springs and adjacent recharge areas in drainage heads. (Including recharge areas in convergent topography often creates leave areas for the entire headwall).
- Avoid "off-site" contribution of runoff by roads.
- Protect streambank structure from damage during logging or site preparation.

2. Clearcut harvest with "partial cut" leave areas in bedrock hollows or "0" Order channel heads.

Probable Trigger: Increase soil water pressure. Loss of root strength.

Prescriptions that address triggers:

- Examine species composition/structure and alter prescriptions to maximize root strength and to reduce persistence and accumulation of snowpack.
- Avoid "off-site" contribution of runoff to channels by roads
- Increase leave area size to expand buffer area.

E. Failure originates on planar, steep slopes.

1. Clearcut harvest.

Probable Trigger: Increased soil water pressure usually associated with spring lines. Loss of root strength.

Prescriptions that address triggers:

- Design "no cut" leave areas along spring line and adjacent recharge areas.

2. Clearcut harvest with "Partial Cut" leave areas along spring line.

Probable Trigger: Increase soil water pressure. Loss of root strength.

Prescriptions that address triggers:

- Examine species composition/structure and alter prescriptions to maximize root strength.
- Increase leave area size to expand buffer area.

F. Failure originates at top of unit associated with road.

Probable Trigger: Increased load from landings and/or sidecasted logging debris. Increase pore pressure or concentrated runoff from road drainage.

Prescriptions that address triggers:

- Avoid landings in high hazard landforms.
- Landings shall be consolidated and free of organic debris.
- Divert road drainage away from landings.
- Remove sidecast after logging is completed.

V. Failure originates within a densely stocked harvest unit older than 25 years

A. Failure originates in bedrock hollows, "0" or 1st Order channel or planar, steep slopes.

Probable Trigger: Increase pore pressure from storm event.

Prescriptions that address triggers:

- None, probably with natural range of variation for geomorphic process.

B. Failure along banks of 1st or 2nd Order channels or convergent headwalls.

Probable Trigger: Increase pore pressure from storm event. Road drainage diverted to channels exceeded channel capacity.

Prescriptions that address triggers:

- None, probably with natural range of variation for geomorphic process.
- Direct road drainage to defined channels that can carry flow without bank erosion.
- Avoid concentrated flow from roads in convergent headwalls.

C. Failure originates at top of unit associated with road.

Probable Trigger: Increased load from landings and/or sidecasted logging debris. Increase pore pressure or concentrated runoff from road drainage to landing or other sidecasted material.

Prescriptions that address triggers:

- Avoid landings in high hazard landforms.
- Landings shall be consolidated and free of organic debris.
- Divert road drainage away from landings.
- Remove sidecast after logging is completed.

DEEP SEATED MASS FAILURES

Note: This key assumes that activities were designed with the knowledge that deep seated mass movement was either dormant or slowly moving and persistent in the area. Differentiating between management related and natural causes of increases in movement are difficult. They require long term monitoring of hydrology, weather patterns, and physical changes of the mass failure feature. Before and after observations are necessary to link changes observed with causative agents. Listed below are situations that provide a very basic understanding between triggers and response. It is not intended to replace slope stability analysis or geotechnical expertise.

I. Increase in shallow rapid landslides along margins or sporadic movement along slope breaks within the feature, as a sign of episodic movement

A. Shallow rapid landslides along stream banks

a) Clearcut or Partial cut harvest adjacent to streambanks.

Probable Triggers: Harvest reduced vegetative anchoring and roughness which protected bank from stream erosion. Stream is undercutting mass failure removing toeslope buttressing. Increase pore pressure from drainage concentration of associated roads or altered snowpack accumulation associated with harvest or natural processes.

Prescription to address trigger:

- Avoid activities that increase peak flows.
- Restore roughness and armoring of banks to protect from further stream undercutting. CAUTION - this treatment can cause bank instability below depending on individual site conditions. This treatment does not stabilize deep seated movement initiated by previous undercutting.
- Avoid concentration of road drainage.
- “No Cut” leave areas along stream banks.
- Reduce harvest unit size or increase leave area buffer along channel.

b) “No Cut” leave area on and adjacent to streambanks.

Probable Triggers: Streams undercutting streambanks most likely due to increased peak flows. Stream is undercutting mass failure removing toeslope buttressing. Increase pore pressure from drainage concentration of associated roads or altered snowpack accumulation associated with harvest or natural processes.

Prescription to address trigger:

- Examine weather records, road drainage and hydrologic recovery of vegetation within the hydrologic influence of the channel to understand contributing factors to increased stream or groundwater flow.

- Avoid concentration of road drainage.
- Reduce harvest unit size or increase leave area buffer along channel.

c) Road drainage is either ponded adjacent to or runoff flows to point near origin of shallow rapid failure.

Probable Triggers: Concentration of road drainage increased pore water pressure.

Prescription to address trigger:

- Disperse road drain over larger area or route runoff away from benches above slope breaks and other failure prone areas.

II. Increase in tension cracks, trees leaning or splitting, or disrupted grade in road as a sign of sporadic movement

A. Road located through deep seated mass failure.

Probable Triggers: Road changes resisting or driving forces of mass movement. Concentration of road drainage increases pore water pressure. Natural causes, (e.g., series of wetter years, earthquake, internal change in hydrology).

Prescription to address trigger:

- Avoid locating roads through unstable area.
- Construct roads with the assistance of slope stability analysis and without changing current “forces” of slope (Rule of thumb: full bench/no fill at head; avoid locating road in middle; no cut along bottom; no cut into toe).
- Avoid concentration of road drainage by routing runoff or infiltration away from actively unstable areas.

B. Clearcut or Partial cut harvest upslope from signs

Probable Triggers: Increase of shallow ground water flowing along a less permeable layer. The amount contributed by harvest is indeterminate unless flow and precipitation measurements are available pre- and post- activity.

Prescription to address triggers:

- Avoid large harvest areas that will affect increases in shallow groundwater.

C. No recent adjacent forest practices.

Probable Triggers: Increase in pore water pressure by concentration or change in drainage to the failure either by activities or natural causes. (Relative contribution from activities or natural causes can be estimated through hydrologic analysis of hydrologic basin, although certainty in the results is commonly low.)

Prescription to address triggers:

- Design and locate management activities based on an understanding of rate of movement and hydrologic influence. Increase understanding through small steps by progressively monitoring through time.
- Avoid activities with direct effects to changes in hydrology or geometry of the area.

Appendix C: **Finding a Reference Condition**