ROAD SUB-BASIN SCALE EFFECTIVENESS MONITORING DESIGN

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SUMMARY OF MONITORING PROPOSAL

This document describes a proposed monitoring project to document changes in key indicators of forest road performance that result from changes in forest practices rules following the Forests & Fish Report (FFR). This summary section provides an overview of key elements, which are developed fully in the monitoring design and rationale.

Revisions to road rules involve two components: 1) Changes in rule language specifying site-specific requirements for road construction and maintenance, and 2) Broad-scale requirements for Road Maintenance and Abandonment Plans, an assessment and scheduling process to upgrade substandard roads over a 15 year period. The main focus of the study will be the assessment of the status and trend of basic road attributes that are known to be important controls on road sediment production and delivery. In addition to evaluating trends in key road attributes, this project is also designed to address the two performance targets for road connectivity and sediment prescribed in the FFR. Evaluating the effectiveness of mitigation strategies for other road effects, such as fish passage barriers and road-related landslides will be assessed in other monitoring plans because they require more process-specific sampling strategies.

The monitoring approach will involve field inspection of roads within sample blocks of Forests and Fish regulated timberlands that are similar in scale (i.e. 6 mi^2) to hydrologic sub-basins. This sampling scale is typically large enough to contain fish, amphibians and a sizable sample of the forest road network. All rule regions – coastal spruce, west Cascades and east Cascades – will be sampled proportional to their area. Each sample block will be re-monitored every 5 years through the RMAP implementation period (2005, 2010, 2016), to allow evaluation of trends in road attributes and performance target measures. Within each sample block, characteristics of the forest road prism will be measured or observed and reported along with FFR-established measures of road performance. Hydrologic connectivity will be determined by measuring the road length that drains into streams. Road attribute data will be compiled in an empirical model, the Washington Road Surface Erosion Model (WARSEM), which estimates average annual sediment inputs to the stream system, and the model output will be used to compare road conditions to the established sediment performance target. WARSEM is an empirical model based upon a variety of road research from Washington and neighboring states chosen as the data collection platform for this project because it accounts for all road attributes documented to affect surface erosion and calculates an estimated sediment volume index, yet has modest data requirements.

A target sample size of approximately 60 sample units was identified as providing sufficient power for our proposed analyses. However, because of the estimated costs associated with sampling it is unknown whether the sample size of 60 can be achieved given the current budget for this project. Therefore, we propose initially collecting the data for 30 samples and conducting a power analysis based on that data to more accurately determine sample sizes needed to achieve sufficient statistical power for both status and trend analyses.

The first sample is expected to cost approximately $476,900, based primarily on contracting the work. Results from the first sample will inform the remainder of the project and the larger road monitoring program.

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PART I INTRODUCTION

This document details a program for assessing the effectiveness of statewide forest practice regulations for roads at the sub-basin scale. Data collected at the sub-basin scale will determine the status and assess trends of key indicators of road performance through time. The project will also assesses the degree to which roads are meeting performance targets for surface sediment and hydrologic connectivity at the sub-basin scale (see Section 1.3), and therefore the degree to which resource objectives are being met throughout the state. This project does not address performance targets for roads relative to mass wasting erosion processes or fish passage, which are planned to be evaluated through other monitoring projects, because they require more process-specific sampling strategies.

Part I presents the context for the monitoring design that follows in Part II. Specifically, Part I includes an overview of road impacts on water quality and fish habitat, a review of Forests & Fish Report (FFR) performance targets or measures for roads, and an overview of the Cooperative Monitoring, Evaluation, and Research Committee (CMER) road monitoring program. In Part II, the details of the monitoring design for roads is presented. Part III provides a discussion on the integration of this monitoring plan with CMER, state and federal efforts. Part IV outlines the estimated cost of implementing this monitoring design and an implementation strategy. Part V discusses how the results of this study can be used to support adaptive management.

Many people contributed their vision, comments, and data to the development of this monitoring plan. The design benefited from GIS analysis provided by Laura Vaugeois and from reviews by members of the Upslope Processes Science Advisory Group (UPSAG), CMER members, Dan Miller, and the Monitoring Design Team. Members of the Scientific Review Committee for this project generously participated in an open review and stayed engaged through the process of fine-tuning the design.

1.1 Overview of Road Impacts Affecting Water Quality and Fish Habitat

Forest roads are a necessary and ubiquitous feature of managed forest lands that affect the natural physical processes in the landscape by altering hillslope hydrology and sediment production processes. These changes have both direct and off-site effects on channel morphology and water quality. The hydrologic and sediment-producing effects of roads are closely related. Roads affect hillslope hydrology by four primary mechanisms:

1. Generation of Horton overland flow on relatively impervious road surfaces and cutslopes;
2. Interception of subsurface stormflow by road cutbanks;
3. Concentration rather than dispersion of flow; and
4. Diversion or rerouting of water resulting in a change in flow pathways and potential extension of the channel network.

The hydrologic changes combined with road construction, maintenance activities (or lack thereof), and traffic produce sediment that exceed natural levels from the following sources:

1. Surface erosion of the road prism;
2. Erosion of the road ditch and fill;
3. Gullying of hillslopes; and
4. Landslides caused from misdirected road drainage and/or failure of the cutbanks, fillslopes, or the road fill at stream crossings.

The direct and off-site effects of roads on channel morphology, and therefore fish habitat, include: changes in channel structure and geometry from increased sediment loads and altered streamflow, interruption of sediment and wood transport at stream crossings, and road encroachment into the floodplain and/or stream channel. Surface erosion of roads introduces primarily fine sediment into the channel that contributes to degradation of spawning and rearing habitat and loss of pool volume. The chronic nature of road surface erosion also effects water quality, often creating extended and/or elevated periods of turbidity.

The magnitude of road-related effects on geomorphic and hydrologic processes is strongly influenced by local factors such as road age and construction practices, road use patterns, geology and soils, topography, climate, and storm history (Gucinski et al. 2000). Often, only a few sites produce a large percentage of the total erosion associated with a road network.

1.2 FFR Goals for Reducing Road Impacts

New Forest Practice Rules for roads are designed to protect water quality and aquatic resources primarily by controlling the source or delivery of sediment and water to streams (WAC 222-24). The intent of the rules is to address the resource impacts of roads by:

- Providing for fish passage at all life stages,
- Preventing mass wasting,
- Limiting delivery of sediment and surface runoff to all typed waters,
- Avoiding capture and redirection of surface or ground water,
- Diverting most road runoff to the forest floor,
- Providing for the passage of some woody debris,
- Protecting stream bank stability,
- Minimizing the construction of new roads, and
- Assuring that no net loss of wetland function occurs.

Road maintenance and abandonment plans (RMAPs) are a significant change to rules governing forest roads and provide the regulatory vehicle for upgrading existing roads to new standards. Forest landowners harvesting more than two million board feet per year are required to develop RMAPs based on the guidelines provided in the Forest Practices Board Manual (Washington Forest Practices Board 2001). The RMAPs must include the applicable standards or best management practices (BMPs) that will be applied to the road system with the proposed implementation schedule prioritized according to risk to resources.

1.3 FFR Road-related Performance Targets

The adaptive management procedure outlined in Appendix L of the FFR and permanent Forest Practices rules adopted in May of 2001 established a research and monitoring effort to evaluate the effectiveness of prescriptions. Revised Schedule L-1 identifies a list of key questions to address resource objectives and lists measurable performance targets designed to meet resource objectives. The box below contains the resource objectives for sediment and hydrology, and Table 1 lists FFR performance targets specific to roads for sediment input and hydrology.

FFR functional objective for hydrology:

> "Maintain surface and groundwater hydrologic regimes (magnitude, frequency, timing, and routing of stream flows) by disconnecting road drainage from the stream network, preventing increases in peak flows causing scour, and maintaining hydrologic continuity of wetlands."

FFR functional objective for sediment:

> "Provide clean water and substrate and maintain channel forming processes by minimizing to the maximum extent practicable, the delivery of management-induced coarse and fine sediment to streams (including timing and quantity) by protecting stream bank integrity, providing vegetative filtering, protecting unstable slopes, and preventing the routing of sediment to streams."

The performance measures in Table 1 represent the major erosion and hydrologic processes associated with roads. FFR resource objectives for road hydrology and sediment are linked to the same performance targets because these processes are closely related. For example, maintaining "surface and groundwater hydrologic regime…by disconnecting road drainage from the stream network" also results in a reduction of road sediment delivery to streams.

Table 1. FFR performance targets for roads (Forests and Fish Report, Schedule L-1, June 2000).

Input	Measures	Performance Targets	
		New Roads	***Old Roads***
Sediment	Road sediment delivered to streams	Virtually none	
	Ratio of road length delivering to streams/Total stream length (mile/mile)		Not to exceed: Coast (Spruce) 0.15 – 0.25 mi/mi West of Crest 0.15 – 0.25 mi/mi East of Crest 0.08 – 0.12 mi/mi
	Ratio of road sediment production delivered to streams/Total stream length (tons/year/mile)		Not to exceed: Coast (Spruce) 6 – 10 t/yr/mi West of Crest 2 – 6 t/yr/mi East of Crest 1 – 3 t/yr/mi
	Mass wasting sediment delivered to streams	Virtually none triggered by new roads	Favorable trend
Hydrology	Road run-off	Same as road-related sediment.	Same as road-related sediment.

In addition to evaluating trends in key road attributes, this project is designed to address the performance targets for existing or "old" roads which are road length and sediment delivering to streams per stream length. Road-related mass wasting will be evaluated in a separate monitoring project with a different sample design.

1.4 CMER Road Monitoring Program

Monitoring is a key element in the adaptive management program and provides the information necessary to evaluate and validate or adjust management activities and objectives. Because monitoring terms are not consistently used, MacDonald et al. (1991) suggest that a clear statement of the purpose is the best method for defining the different types of monitoring.

There are three types of monitoring identified in the FFR Schedule L-1, and each serves a unique function:

1. *Compliance monitoring* asks if management practices have been conducted in compliance with the prescriptions;
2. *Effectiveness monitoring* asks if the management practices and activities are meeting the performance targets; and
3. *Validation monitoring* asks if the performance targets produce the desired resource objective benefits.

Figure 1 illustrates the linkages between management practices for roads and resource conditions and where each type of monitoring is most appropriately applied. The monitoring approach in this document focuses on effectiveness monitoring.

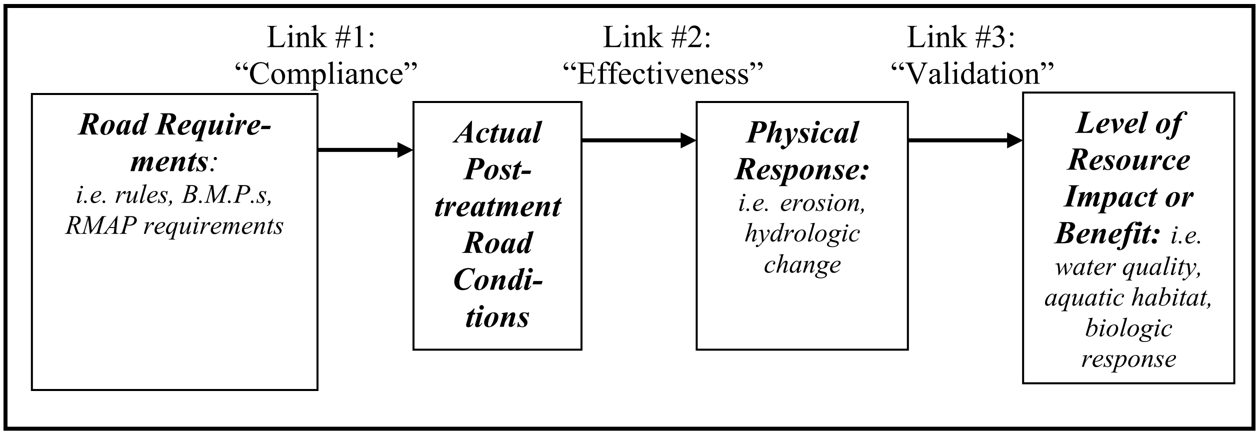

Figure 1. Diagram of the monitoring links necessary to connect road requirements with acceptable levels of resource impact (after Veldhuisen et al. 2000).

CMER has adopted a hierarchical framework for monitoring of forest practices that includes:

- *Extensive Monitoring* to evaluate the current status and future trends of key watershed input processes and habitat conditions;
- *Effectiveness Monitoring* to evaluate the performance of the prescriptions in achieving resource goals and objectives; and
- *Intensive Monitoring* to evaluate cumulative effects at the watershed scale and improve understanding of causal relationships between forest practices rules and biological effects.

Table 2 below identifies the elements of this monitoring approach at each scale as it applies to roads, and the following text elaborates on these applications.

Table 2. Correlation between common monitoring types and CMER monitoring types for the forest road monitoring program. The subject of this monitoring project is shown in bold.

Monitoring Type	CMER Equivalent	Scale	Purpose	What's Measured
Compliance		Site, planning	Rule implementation, rule compliance	Reporting of RMAP implementation measures; If FPAs, road maintenance and construction are done in compliance with rules
Effectiveness	Effectiveness	**Sub-basin**	**Rule effectiveness; degree to which resource objectives are met and performance measures are achieved**	**Indicators of road sediment production and delivery;** **FFR sub-basin performance measures**
		Site		Site scale performance measures, to be developed per FFR
		BMP	Focused BMP effectiveness monitoring; BMP techniques and refinement	Experimental design
	Extensive	Reach	Status and trend reporting of resource conditions	Resource and in-channel indicators
	Intensive	1-5 watersheds statewide	Cumulative effects	Sediment budget, upslope and in-channel indicators
Validation			Validate performance measures in 1-2 watersheds; applied research	Resource or habitat response to targeted performance measures
		Reach; sub-basin; watershed	Broad level validation of FFR performance measures where necessary	Resource or habitat response to targeted performance measures

- The *extensive* monitoring scale involves collection of status and trend data on indicators of key watershed input processes and habitat conditions at a network of sites distributed throughout the state. The intent is to track important and easily and consistently assessed indicators through time. Successive data from the extensive network of sites will be used to draw conclusions about statewide trends in the indicators. Data from intensively monitored watersheds will help interpret data from the extensive monitoring network. Currently, there are no road-related indicators planned for monitoring at the extensive level. However, performance measures included in this effectiveness monitoring program will produce status and trend data of road sediment and water input processes.

- As shown in Table 2, several scales and levels of monitoring for roads are applicable under the *effectiveness monitoring* label:

    1. *Sub-basin scale road effectiveness monitoring* (this study plan). At the sub-basin scale we are interested in the degree to which a sample of the road network functions

collectively to meet resource objectives and in evaluating the FFR sub-basin scale performance targets for roads.

2. *Site-scale effectiveness monitoring of prescriptions for road maintenance and abandonment and new road construction.* Site-scale road monitoring will focus on the degree to which the objective(s) of one or more BMPs is being met at a site or along a segment of road. Monitoring at this scale casts a broad net with a large number of sites being sampled at a low intensity, or routine level as termed by Gaboury and Wong (1999). Techniques include inexpensive and rapid or routine data collection using visual evaluation and qualitative variables on a sample of scheduled treatments in randomly selected RMAP units. Results from this broad-scale collection of qualitative data on roads can provide direct information about the effectiveness of road prescriptions applied to address specific resource objectives (i.e. protect unstable slopes, disconnect road system from typed waters) and can be used to focus more costly quantitative monitoring efforts where needed. This type of effectiveness monitoring is particularly applicable to forest roads because of the many miles of roads that occur in diverse landscapes, and because lessons learned from more focused studies may be limited and not readily transferable to larger areas.

3. *BMP effectiveness monitoring*, which is also at the site scale, investigates the effectiveness of individual or multiple BMP treatments where more information might be needed to diagnose problems identified by the sub-basin and site scale monitoring. Questions that could be answered include: How well are particular BMPs working to address resource objectives; what are the limitations of the BMPs with respect to terrain, climate, discharge, gradient, etc?

   Also at the BMP monitoring scale, testing and refinement of individual BMPs can answer highly specific questions on individual treatments, application techniques, equipment or materials, or cost efficiency (e.g. is hydroseeding more effective in reducing erosion on deactivated roads than dryseeding?). This level of inquiry is best for testing a new technique, application or technology in order to quantify effectiveness in achieving resource objectives or to determine the cost effectiveness (Gaboury and Wong 1999). The experimental design and level of monitoring are dependent on the objectives of each study. Results should provide a collection of information on the efficacy and cost of specific treatments to address resource situations in different physical settings. Testing and refinement of multiple BMPs or treatments will require site-specific monitoring plans developed prior to implementation (see Northwest Hydraulic Consultants 1999 for an example).

- *Intensive*, or watershed-scale, monitoring will primarily address cumulative sediment effects within a watershed, but could also provide a framework for validating road performance targets or sediment models. Intensive watershed monitoring is more expensive and time-consuming because of the complicated and specialized experimental design required in order to make statistically significant inferences about a population. Results can then be extrapolated to the road sub-basin and site-scale effectiveness monitoring results as appropriate.

The relationship between various monitoring types above is shown for context. The number and types of monitoring projects implemented through CMER will depend on priorities and available funding.

PART II MONITORING DESIGN

The sections below constitute the proposed monitoring design beginning with a statement of the study objectives, a discussion of the monitoring approach and rationale, and the monitoring questions and hypotheses. Following these three foundation sections are the sampling design and analytical methods to be employed.

2.1 Study Objectives and Overview of Monitoring Approach

The primary objective of this monitoring plan is to determine the degree to which road prescriptions are effective at meeting resource objectives (page 3) at the sub-basin scale. To meet the study objective, this project is designed to determine the degree to which road attributes or conditions that affect water and sediment production and delivery are improving over time. To accomplish this, the status and trend in characteristics of the forest road prism (Table 3) will be measured or observed and reported along with FFR-established measures of road performance (Section 1.3). Road attribute data will be compiled in an empirical model that estimates average annual sediment input to the stream system. The main focus of the study will be the assessment of the status and trend of basic road attributes known to be important controls on road sediment delivery. A similar approach has been used by the Oregon Department of Forestry (Skaugset and Allen 1998).

Sixty randomly selected samples will be selected from statewide forest lands under FFR rules, independent of ownership. Monitoring events will occur at five year intervals and extend through at least 2016, the year by which new road maintenance and abandonment rules are required to be fully implemented.

2.2 Rationale for Monitoring Approach

A viable method for evaluating sediment inputs from road surfaces should account for most if not all of the factors controlling road erosion. Road erosion is the result of the interaction between erosive forces, such as rainfall intensity and runoff energy, and the availability of erodible sediment (Reid and Dunne 1984, Luce and Black 1999; Ziegler et al. 2000). Road design plays an important role on runoff erosivity because sediment transport capacity is proportional to road drainage spacing (Luce and Black 1999), high cutslopes have a greater likelihood of intercepting subsurface stormflow (Wemple and Jones 2003; Wigmosta and Perkins 2001), and the shape and width of the road tread can influence runoff pathways

(Burroughs and King 1989). Factors that influence erodibility include native soil characteristics, road age, grading, and vehicle traffic rates (Megahan 1974; Burroughs and King 1989, Luce and Black 2001a; Ziegler et al. 2000; Reid and Dunne 1984; Luce and Black 2001b, Megahan et al. 2001).

Road sediment production and road runoff are inextricably linked because sufficient runoff is required to transport sediment along road-side ditches and into streams (Luce and Black 1999; Luce 2002). The likelihood of resource damage from road-generated sediment is not only related to the magnitude of road erosion and runoff, but also the degree of linkage between sediment sources and the channel network (Novotny and Chesters 1989, Furniss et al. 2000). According to the Washington Forest Practices Board Manual (M3-1), road sediment that is not "delivered" to the channel network does not constitute a public resource "problem" in the context of forest practices. Therefore the extent to which roads can meet the FFR performance targets for sediment is largely dependent upon road system connectivity, or hydrologic connectivity, to the channel network.

Hydrologic connectivity has been used to evaluate road impacts for studies in western Washington (Bowling and Lettenmaier 2001; La Marche and Lettenmaier 2001), western Oregon (Wemple et al. 1996), the Sierra Nevada of California (Coe and MacDonald 2001), and southeastern Australia (Croke and Mockler 2001). At the road segment scale, connectivity is evaluated based on the presence and character of sediment pathways below road drainage outlets toward streams (Wemple et al. 1996; Croke and Mockler 2001, Furniss et al. 2000). Although hydrologic connectivity can be assessed for a single road segment, it is more relevant to aquatic resources when assessed over a road network, or for a small or large drainage basin. Hydrologic connectivity can be viewed at the road network or drainage basin scale by compiling segment-scale findings to determine the percentage of connected road length across the road network (e.g. Wemple et al. 1996). Collecting information on connectivity becomes an important part of a road surface erosion study design (see Section 2.6.1), as well as a potential index of hydrologic effects (Furniss et al. 2000). By establishing road performance standards for connectivity at the sub-basin scale, the FFR established the spatial scale at which this road monitoring project must operate.

Road sediment production and delivery rates are highly variable over time and space (Megahan 1974; Reid and Dunne 1984; Luce and Black 1999; Luce 2001; Wemple and Jones 2003), and direct measurements of sediment delivery are typically too limited to predict long-term annual erosion rates or to extrapolate state-wide. The limitations arise from the inability of point sediment measurements to represent the range of conditions that affect sediment production and delivery and the potential to miss the intersection of large storm events with the transient effects of road traffic and road maintenance (Dunne 2001; Luce and Black 2001a; Luce and Black 2001b).

Modeling offers certain advantages over direct measurement because models simulate time-evolving and spatially distributed processes, along with process linkages and interactions. Models can also provide a conceptually sound basis for field data collection. However, models include quantitative and qualitative uncertainties, spatial and temporal limitations depending upon the choice of model, lack of local calibration, and limited testability (Lancaster and Grant 2003). When used for monitoring, scientists and policy makers must understand the limitations of a model and the limitations of the chosen modeling approach for policy and management decisions.

The spatial and temporal scale for road effectiveness monitoring (sub-watershed, multi-year), along with limitations of funding and time constraints precludes a direct sediment measurement approach for this road effectiveness monitoring plan. Conversely, results from an effectiveness monitoring study should not be reported solely in terms of modeled estimates because of the uncertainties in model predictions. A compromise between the direct sediment measurement approach and a modeling approach is to monitor the status and trend of important road attributes that affect sediment production and delivery. We have chosen this approach because the literature is in general agreement on which variables control road sediment production and delivery (Table 3). In addition, the road attributes will be integrated, using a road erosion model (i.e. WARSEM), into a single metric that represents the relative magnitude of sediment delivery.

Several empirical models are capable of predicting road sediment delivery. Models such as the Universal Soil Loss Equation (USLE) and the Revised Universal Soil Loss Equation (RUSLE) are not well suited for road sediment delivery prediction because they were developed for agricultural areas and do not take into account the effects of road traffic, road maintenance, or road design (Reid and Dunne 1996). The USDA Forest Service published methods to predict road sediment delivery using the R1-R4 and BOISED models (USDA 1981) based upon a six-year study of road erosion in the Idaho Batholith (Megahan and Kidd 1972; Megahan 1974). However, this model was developed for the granitic terrain of the Idaho Batholith, and includes erosion processes such as mass-wasting that are not applicable to this study.

An empirical model specifically designed for predicting road sediment production and delivery is the Washington Road Surface Erosion Model (WARSEM) (Dube et al. 2003). WARSEM is the most current iteration of the Road Surface Erosion module from the Washington Watershed Analysis Manual (WFPB 1997). WARSEM was created using data from multiple road erosion studies in the form of a multiplicative empirical model similar in structure to USLE discussed above. The model variables attempt to represent all important controls on road sediment production and delivery. A perceived disadvantage of the model is that coefficients were fitted graphically rather than by more rigorous statistical analysis. WARSEM requires regional calibration, as do most of the models.

Physically-based and spatially-distributed models are also available. Models such as the Watershed Erosion Prediction Project (WEPP), WEPP:Road, and the Distributed Hydrologic Soil Vegetation Model (DHSVM) are alternatives to empirical models because they have the potential to simulate the interaction of local scale conditions (e.g. soil properties, geology, and road traffic) under varying climatic scenarios (Wigmosta et al. 1994; LaMarche and Lettenmaier 2001; Bowling and Lettenmaier 2001; Elliot et al. 1995). A sediment yield module is currently in development for the DHSVM (Doten et al. 2003), but is unavailable for use at this time.

WARSEM was chosen for the following reasons:

1. WARSEM is closely related to the Road Surface Erosion module from the Washington Watershed Analysis Manual that was used to develop the FFR performance targets for sediment delivery;
2. WARSEM input variables include the important road attributes controlling road sediment production with categories that provide clear interpretation of improving trends;
3. Input data from WARSEM can be used in alternate models, such as WEPP:Road, if the need arises;
4. WARSEM is easy to use, and is well suited for estimating sediment delivery for large datasets.

The WARSEM structure and data input requirements provide a conceptually sound basis for field data collection, and the model results or predictions can be used as a relative index of road sediment delivery. Since sediment delivery is strongly controlled by the degree of linkage between road and stream networks, we also propose to directly measure the length of road segments draining to the channel network.

The uncertainties in WARSEM predictions can be addressed through a model calibration study using sample units from this project. Calibration requires direct measurements of sediment delivery at the site scale. However, because WARSEM estimates are average annual rates of sediment delivery, satisfactory calibration requires an adequate sample size and long sampling period. This would entail a separate project. However, postponing effectiveness monitoring until a calibration project is complete delays road monitoring for approximately 2-5 years or more. Should a future calibration project indicate that WARSEM requires modification, the 2005 field data can be reassessed by the modified model without additional field work. Model calibration and performance target validation could be combined into the same project, since the targets were derived from an earlier version of the road surface erosion model.

2.3 Monitoring Questions and Hypotheses

To provide meaningful feedback to the adaptive management process, we are interested in understanding the degree to which improvements in road characteristics that are controllable by management translate into the target measures of road performance for sediment and hydrology at the sub-basin scale. Monitoring Questions 1 and 2 relate to the status and trend of key road attributes identified in Section 2.5.1 below. Question 1 asks the status of road attributes or conditions and question 2 asks if an improvement in road attributes has occurred between sample events.

Monitoring Question 1: What is the condition of forest roads at each sample event, specifically those attributes management can change relative to sediment production and delivery?

Monitoring Question 2: Have road attributes that affect sediment production and delivery improved over time?

> Hypothesis 2a: No reduction in road drainage connectivity to streams has occurred since the previous sampling events.
>
> Hypothesis 2b: No improvement in road attributes that affect sediment production and delivery has occurred since the previous sampling events.

The FFR anticipates that, as new road rules are fully implemented across the state, road sediment delivery and runoff to streams will be reduced to an acceptable level as expressed by the performance targets. Monitoring questions 3 and 4 simply ask the status of the performance measures and how those compare to the targets at each sample event. The prediction, restated as monitoring questions 5 and 6, compares the outcomes of applying the new rules to those performance targets. Monitoring question 5 asks if improvement in performance measures has occurred between sample events, independent of whether the targets have been or are on a trend to be met by 2016.

Monitoring Question 3: What is the status of road performance measures for drainage connectivity and sediment delivery to streams at each sample event?

Monitoring Question 4: What is the status of road performance measures relative to their targets, by performance target region, at each sample event?

Monitoring Question 5: Have measures of road sediment performance improved over time?

> Hypothesis 5a: No reduction in the road drainage connectivity performance measure has occurred since the previous sampling event(s).
>
> Hypothesis 5b: No reduction in the road sediment delivery performance measure has occurred since the previous sampling event(s).

The FFR assumes that as roads come closer to meeting FFR standards they will also come closer to meeting the performance targets. Hypotheses for Monitoring Question 6 allows us to test this assumption by comparing performance measures to the percent of each sample unit meeting road standards at the end of the first sample. If there is a direct relationship between performance measures and percent road meeting FFR standards we can also evaluate the likelihood of meeting performance targets by 2016. In addition, this information will provide valuable monitoring design and implementation feedback over the course of the project. Section 2.6.3 and Part V provide further discussion on this analysis.

Monitoring Question 6: Will roads judged to meet FFR road standards meet the performance targets?

> Hypothesis 6a: There is no direct relationship between the percentage of the road system that is judged to meet road standards and the reported road drainage connectivity performance measures.
>
> Hypothesis 6b: There is no direct relationship between the percentage of the road system that is judged to meet road standards and the reported road sediment delivery performance measures.

2.4 Stratification

Stratification will not be used in the data analysis portion of the monitoring design. The number of strata and detail of data collected need to correspond to the monitoring objectives at the sub-basin scale of analysis. For practical purposes, the number of physical (Ramos 1997) and management variables potentially affecting road erosion and drainage is too large to factor into a stratification scheme at the sub-basin monitoring scale where the objective is to evaluate road drainage and sediment indicators statewide. However, a basic physical division of the state is inherent in the performance targets for roads, which are established roughly by climatic regions (east of Cascade crest, west of Cascade crest, and coast Spruce zone, Table 1). Therefore, the number of units sampled statewide will be distributed proportionally to the amount of area subject to FFR rules between each of the three performance-target regions of the state (see Section 2.5.4). Due to cost limitations, we do not propose sufficient samples in each performance target region to make statistical conclusions individually for each region. Available data suggests that precipitation may be a better predictor of road connectivity, but we will not be testing that potential stratification factor in this project.

2.5 Sampling Strategy

This section covers the details of the sampling strategy: what is proposed to be measured, how it will be measured, the duration of the monitoring program, how sample units are defined, selected, and distributed, and the frequency of sampling.

2.5.1 Sampling Plan

Road Attributes

The sub-basin scale road monitoring project will collect data on the condition of each part of the road prism for each road segment with drainage routing to surface water within a sample unit. For drainage structures routing to the forest floor, only the location will be collected. As shown in Table 3, road data will be obtained from field observations and measurements, landowner interviews, and office records. Data on key road attributes will be summarized by descriptive statistics described in Section 2.6; both the key attributes and the remaining road attribute data will be used in WARSEM to report the sediment performance measure or as contextual or interpretive information.

Table 3. Road attributes included in the sub-basin scale road monitoring project.

Attribute	Source		Attribute Type	Method	Potential for Change	Reported Road Attribute	WARSEM Variable
	Field	Office					
Landowner category (Large/Small)		☑	Categorical	Interview or records	Moderate	No	No
Road/Segment Number		☑	Discrete	Assigned	None	No	Yes
Road/Segment Location/Position		☑	Discrete	Map	None	No	Yes
Stream Length		☑	Continuous value	Map		No	No[1]
Geology	☑	☑	Categorical type	Geologic map imbedded in model or local data	None	No	Yes
Precipitation		☑	Categorical range	Ppt isohyets imbedded in model or local data	None	No	Yes
Construction Year		☑	Continuous value	Interview, records, or photos	None	No	Yes
Traffic use		☑	Categorical type	Estimate	High	Yes	Yes
General maintenance category	☑		Categorical type	Observation, Interview	High	No	No
Segment length delivering to stream	☑		Continuous value	Measurement	High	No	Yes
Road/drainage configuration	☑		Categorical type	Observation	Moderate	No	Yes
Surfacing	☑		Categorical type	Observation	High	Yes	Yes
Road slope class	☑		Categorical range	Measurement	Low	No	Yes
Road rutting category	☑		Categorical type	Observation	High	Yes	No
Tread width	☑		Continuous value	Measurement	Low	No	Yes
Ditch width	☑		Continuous value	Measurement	Low	No	Yes
Connectivity class[2]	☑		Categorical type	Estimate	Moderate	Yes	Yes
Ditch condition	☑		Categorical type	Observation	High	Yes	Yes
Cutslope height	☑		Categorical range	Average/Estimate	Low	No	Yes
Cutslope Cover	☑		Categorical range	Estimate	Moderate	No	Yes
Rule Standards		☑	Categorical range	Interviews	High	No	No

1. Used in the calculation of tons/year/mile of road/mile of stream
2. See Table 4

We examined the WARSEM road attributes to identify those that would provide appropriate indicators of changes in road management related to sediment production or delivery. Reporting the WARSEM categorical connectivity classes provides additional information about road conditions and delivery pathways to streams. Since road connectivity to streams will be field verified in this study, it was necessary to redefine the WARSEM connectivity classes, which in the model are based on road distance from the stream. The redefined connectivity classes are:

Connectivity classes:

0 – None (no connectivity signs below outfall with or without evidence of sediment transport below outfall)
1 – Direct delivery at stream crossing (via ditch)
2 – Direct delivery from ditch but some sediment trapped in designed ditch out or sediment trap (30% of sediment delivered)
3 – Evidence of sediment plumes to stream with sediment deposition on slope (10-35% of sediment delivered depending upon the distance of the road from the stream)
4 – Direct delivery below drainage outfall; ditch is connected directly to stream via a gully

Further discussion on connectivity is found in the sections on Data Collection and Calculation Methods and Monitoring Measures.

Road surfacing and traffic are both important attributes related to sediment production on roads. The WARSEM surfacing categories cover a range of surfacing conditions affecting surface erosion that are distinguishable upon field inspection. The WARSEM traffic categories and optional road classes defined in Tables 3 and 6 in the WARSEM manual were determined to adequately characterize both road type (mainline, spur, etc.) and traffic levels expected on an annualized basis. By defining WARSEM traffic levels <u>specifically</u> as those for the prior year of haul (instead of long term traffic trend) for this study, we satisfy the need for additional information on log traffic in the previous year. Road type is not expected to change over time, and will be used as additional information rather than a reported road attribute.

Road surfacing categories:

A – asphalt
G – gravel
Gr – gravel with ruts
P – pit run or worn gravel
N – native surface
Ns – grassed native
Nr – native surface with ruts

Generalized traffic categories for the previous year (see Table A-5 in WARSEM manual):

H – heavy
MH – moderately heavy
M – moderate
L – light

O – occasional
N – none (abandoned, inactive, or blocked)

Road class categories (optional in WARSEM – not used in model calculations):
M – mainline
P – primary
S – secondary
Sp – spur

We considered and dismissed several WARSEM road attributes for reporting. Road drainage configuration was thought to have debatable usefulness, as it is difficult to maintain the perfect crown, outslope, or inslope geometry to promote the sheet flow advantage implied by those categories. Road drainage configuration information will not be reported as a separate attribute, per se, but will be collected to calculate WARSEM estimates because of the general drainage implications (outsloped roads tend to have more diffused runoff compared to insloped roads which have more concentrated runoff). Rutting is thought to be a more important indicator of road condition. The rutting modifier in the road surfacing categories was expanded and added as a road attribute with categories listed below. We will also report cutslope cover conditionally because it may only be significant to erosion at a small percent of locations. The cover categories "bins" make it hard to differentiate change, and any increase in cover may be minimal between sample events where no specific treatments are applied.

Road rutting categories:

1. No ruts
2. Ruts present but not interfering with drainage to ditches, cross drains, or forest floor
3. Ruts present and inhibiting drainage to ditches, cross drains, or forest floor

Cutslope cover density categories:
90-100%
70-90%
50-70%
30-50%
10-30%
0-10%

Contextual information is largely missing from required WARSEM data fields, and certain types may be valuable in interpreting the monitoring results. Of particular interest is information on general maintenance levels at the time of data collection that could affect monitoring results. To keep data collection simple and repeatable, three general categories have been defined below based on clustering BMPs from the WARSEM list.

General Maintenance categories: (verified by landowner and/or assessed visually)
1 – No obvious recent maintenance activities
2 – Maintenance grading and ditch pulling only obvious (includes tread reshaping)

3 – Other road maintenance and repair activities obvious
  Includes: new surfacing or surface treatment; ditch seeding or armoring; culvert replacement or addition; driveable dips and waterbars; culvert inlet or outlet armoring; cut or fillslope treatment; abandonment or closure; fillslope pullback; settling basins; double or by-pass ditches; etc.

As a stand-alone attribute, ditch condition can be difficult to interpret for an improving trend because road grading destroys evidence and temporarily elevates sediment delivery, but it can be diagnostic of road hydrology. A ditch condition attribute is currently available as a placeholder in WARSEM but not used in the erosion calculation as insufficient data are available to assign a coefficient in the model. We have modified the WARSEM list to include the following ditch maintenance grading categories:

Ditch condition categories:
  P – Recently pulled (cleaned or graded)
  E – Scoured, eroding, or incising
  A – Aggrading
  R – Armored (grass seeded or rocked - BMP)
  S – Stable (previously eroded but now naturally armored or stable – no BMP)

Information on traffic levels – a WARSEM option – is particularly useful to capture the maintenance strategy (BMP) of restricting haul during wet road conditions; however, it might be difficult to uniformly obtain this BMP information for all roads and samples uniformly. We will attempt to collect this information during the landowner interview process, but may abandon the effort if little or inconsistent information is available. Storm frequency or history was also evaluated as another important contextual piece of information, but will not be required data. Local climate records could be examined post-data collection, if necessary.

The relationships between road attributes, performance measures, and contextual information will not be reported, but will be available for further investigation or interpretation of results. The road rutting and maintenance attribute additions to the WARSEM requirements can be added to the data collection protocols as a series of standardized codes in comment fields.

Data Collection and Calculation Methods

The WARSEM data collection protocols will be used to collect most of the road attributes (see discussion above). Sediment delivery is dependent upon the hydrologic connectivity of the road network to the stream system. For this reason, we are visually assessing hydrologic connectivity rather than using WARSEM's distance-dependent road delivery factor. This approach will improve the accuracy of sediment delivery estimates relative to the WARSEM methodology because the extent of road connectivity will be based on visible field evidence rather than empirical relationships between sediment delivery and distance from stream. The nature of hydrologic connectivity will be assessed using the methods similar to Wemple et al. (1996) and Croke and Mockler (2001), but modified to allow for quantitative estimation of sediment delivery (Table 4). Connectivity class 2 assumes a 65% trapping efficiency for silt fence sediment traps, a conservative estimate based upon the literature (Britton et al. 2000, 2001; Wishowski et al. 1998; Wyant 1980). Connectivity classes 2 and 3 assume connectivity through diffuse sediment plumes, with the sediment delivery dependent upon the travel distance of the sediment plume (Dube et al. 2003; Megahan and Ketcheson 1996). Connectivity class 4 assumes 100% delivery through concentrated flow via landslide scars and gullies. The primary assumption of the classification scheme is that road sediment is not delivered to the stream system unless geomorphic features are visibly connected to the stream channel, or the road intersects the stream channel (i.e. stream crossings).

Table 4. Revised WARSEM classification scheme for field evaluated road connectivity.

Connectivity Class	**Visible Geomorphological Impact**	**Sediment Delivery Potential**	**Percent of Sediment Delivering**
0	No signs of connectivity below culvert outfall with or without evidence of sediment transport below outfall	None	0
1	Drains directly into stream channel at a road crossing	High	100
2	Direct delivery from ditch but some sediment trapped in functioning and maintained ditch out or designed sediment trap; or Evidence of diffuse sediment plume to stream below drainage outlet that is within 100 feet of a stream	Low/ Moderate	35
3	Evidence of diffuse sediment plume to stream below drainage outlet that is between 100 and 200 feet from a stream	Low	10
4	Direct delivery below drainage outfall; is connected to bankfull edge of stream channel via gully or landslide scar	High	100

Beyond the WARSEM requirements for collecting data on road segments that are hydrologically-connected to streams, we will also be collecting minimum information on non-delivering drainage structures. Cross drain locations and distance between drains will be recorded. Cross drain spacing is not a focus of this monitoring plan, so it will not be reported; however, the data set could easily be analyzed for distance between cross drains as a separate effort. Locating non-delivering drainage points will not modify the data collection structure, because the field protocol requires that all drainage structures or points be located to evaluate delivery to streams. For non-delivering structures or drainage points, we will only record the location (mileage from beginning of survey and mark on a field map) and the connectivity class. If the segment delivers to a stream, then all data on the contributing road segment is collected. For clarity, the unique location identifier for delivering road segments will be the mileage point of the delivering point or structure.

To address monitoring questions 3 through 6, we chose to *measure* road length delivering to streams and to *model* the road sediment delivery measure, as explained in Section 2.2. The FFR sub-basin road sediment performance measure will be reported by using the revised Washington watershed analysis road surface erosion model (WARSEM). Modeled sediment delivery represents an average annual estimate or index of road sediment and not an actual measurement of sediment entering the stream system. When comparing model results with targets we will report the modeled number as a percent of the performance target, rather than modeled sediment output in tons/yr/mile of stream. This reporting format will emphasize the index value of the model and de-emphasize the model results as a measure of actual sediment delivery.

The performance measures are strongly influenced by the manner in which stream miles are calculated, as both measures contain stream length in the denominator. Available WADNR GIS stream mapping and USGS topographic maps rarely accurately capture all streams in a forested landscape. A simple adjustment is proposed to address this problem, which involves increasing the total WADNR GIS stream length for Type 1 through 5 streams by a correction factor. The correction factor is derived from the ratio of the number of actual streams crossed by the road, as determined from field work, to the number of roads crossing streams as shown on the DNR GIS hydrologic layer. This approach was commonly used during watershed analyses and found to be effective.

To address monitoring question 6, data will also be collected in each sample area to estimate the percent of the road length meeting FFR rule standards because either scheduled RMAP work has been implemented or the landowner judges it to already meet FFR standards. The percent of road meeting standards will be determined by one of two methods depending on the availability of maintenance information (Appendix B). In its most complete form, this metric will include the percentage of road maintenance and abandonment activities implemented relative to those proposed in the landowner's RMAP, where available. This information will be determined from review of the RMAPs covering the area and from interviews with landowners and local DNR Forest Practices foresters. In the simplest approach, it will consist of the landowner's estimate of the degree to which the roads presently meet the FFR road rule standards. The approach used in the monitoring project will depend on the findings of preliminary site selection work now underway (Appendix B).

Results of Observer Variability Test

The development of WARSEM included an evaluation of reproducibility of field observations and sensitivity of the model to input parameter variability (Dubé et al. 2003). Volunteers were used to test the instructions and methods. Because WARSEM is designed for several levels of use by field personnel and landowners of variable experience levels both untrained experienced and untrained inexperienced volunteers were used. Results indicate that both clarification of written instructions and training were needed to reduce the large observer variability produced by these field trials.

The sensitivity of the model to the input variables (Table 3) was evaluated to determine those variables responsible for large variability in sediment yield predictions between observers. The average sensitivity for each variable was evaluated at each of the three test sites by using the maximum and minimum observed value for each input variable to calculate sediment yield while holding all other values constant at their average observed value. The results were ranked and the average ranking (sensitivity) for all data are plotted in Figure 2. WARSEM sensitivity ratings form three categories: high sensitivity (>7), moderate sensitivity (5-7), and low sensitivity (<5).

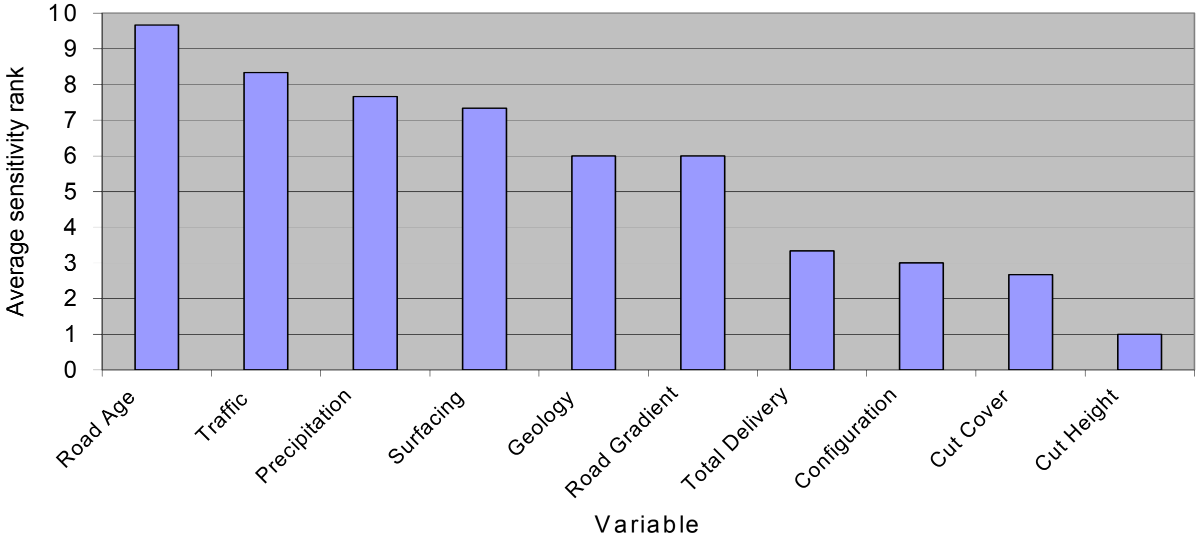

Figure 2. Average sensitivity ranking of WARSEM variables for all test sites (Dubé et al. 2003).

Observer variability is lowest for the most sensitive variables (Dubé et al. 2003, Figure D-22 and D-48), since three of the four variables, road age, traffic, and precipitation, are obtained from records and should show no operator variability during monitoring. The fourth highest sensitive variable, road surfacing, is observed in the field and has the highest operator variability in the field tests. In the moderate sensitivity category, geology obtained from records would have no operator variability, and road gradient has the lowest operator variability in the tests. Total delivery, road configuration, and cut height have high operator variability but low sensitivity to overall results, and cut cover has low operator variability and low sensitivity. Segment length, tread width and ditch width, components in the total delivery calculation, generally have a low variability. Segment length can have high variability, however, along nearly level roads. These sensitivity results represent the worse case situation for observer variability since a number of test observers were inexperienced and untrained and a variety of techniques were used to measure road length including pacing, tape, string box, measuring wheel, calibrated truck odometer, and a laser rangefinder.

Minimizing Among-Observer Variability

We propose to address among-observer variability through a two-step training and calibration process. During the first step, monitoring personnel will be trained before making field observations. At the end of the training, each observer will evaluate a standard road section that has been measured and assessed by an experienced professional. The results of this comparison will be reviewed with the observer and any large differences in interpretation highlighted and discussed. The goal of this step is to give observers a common background in the methodology to reduce observer variability.

Because hydrologic connectivity is a key monitoring variable, measuring road segment length draining to streams and evaluating road drainage configuration and delivery will be targeted for training and QA/QC. Targeting training and survey work during rainfall events can also reduce errors in measurements (Montgomery 1994).

Calibration is the second step of the process. Among-observer variability will be measured through a replicated sampling design. The results of the calibration test will not be shared with the observers. Three roads sections will be randomly assigned and evaluated by each observer. The calibration analysis will focus on the variability of the WARSEM output resulting from observer variability in input parameters. Among-observer variability will be measured at both the beginning and the end of each sample event.

Our approach to reducing variability among observers between monitoring events and maximizing the ability of WARSEM to detect change in road systems is straightforward. We will return to the same sites for each sample event and eliminate redundant observations where no evidence exits for a change in a particular parameter. For example, cutslope height and cover are unlikely to change between monitoring events and will not be re-evaluated unless evidence of change from either natural or management processes is observed. Original information for geology and precipitation will not be re-evaluated, unless to change from programmed model values to field determined values. In other words, the default observations and results for the second and third monitoring events would be "no change." This strategy will focus monitoring results on actual changes in the system, and reduce the potential for differences arising from observer error. During the first sample, each road segment will be marked in the field and captured on GPS where possible to ensure that the exact same road segments are being revisited. Photographs of each road segment will also provide a benchmark for comparison.

Monitoring Measures

The data reported for each sample area is summarized in Table 5 and consists of the basic or minimum measures. All of the attribute categories are measured by total length of road per sample area. We may add measures to compare road attribute data over time, but commit to reporting these minimum measures to answer the monitoring questions and to test the stated hypotheses.

Table 5. Reported measures for road sub-basin scale effectiveness monitoring questions and hypotheses.

Monitoring Questions & Hypothesis	**Reported Monitoring Measures (by sample area)**
MQ1	1. Total road length draining to streams (road miles/mi^2) 2. Percent of road network draining to streams 3. Percent of road in each surface category 4. Percent of road in each traffic category 5. Percent of road in each cutslope cover category 6. Percent of drainage points by connectivity class 7. Percent of road in each road rutting category
H2a	1. Total road length draining to streams (road miles/mi^2) 2. Percent of road network draining to streams
H2b	1. Road surfacing index 2. Road traffic index 3. Cutslope cover index 4. Miles of delivering road with ruts interfering with drainage
MQ3	1. Miles of forest road delivering to streams per miles of stream (road hydrology performance measure) 2. WARSEM modeled tons of road sediment delivered to streams per miles of stream per year (sediment performance measure)
MQ4	1. Miles of forest road delivering to streams per miles of stream (road hydrology performance measure) divided by the performance target by target region 2. 2.WARSEM modeled tons of road sediment delivered to streams per miles of stream per year (sediment performance measure) divided by the performance target by target region
H5a	Miles of forest road delivering to streams per miles of stream (road hydrology performance measure)
H5b	WARSEM modeled tons of road sediment delivered to streams per miles of stream per year (sediment performance measure)
H6a	Miles of forest road delivering to streams per miles of stream by percent of road length meeting performance standards
H6b	WARSEM modeled tons of road sediment delivered to streams per miles of stream per year by the percent of road length meeting performance standards

The road connectivity attribute for Monitoring Question 1 and Hypothesis 2a will be reported in two formats in addition to the performance measure described in Monitoring Questions 3 through 6. The performance target measure, listed third below, allows us to compare road connectivity between areas of differing stream density. Since our sample units are uniform in area, we can also report the stream-connected road density per sample unit, a measure that avoids the additional error introduced in measuring stream length. An additional connectivity measure is the ratio of stream-connected road to total road per sample unit, which is a commonly reported relationship but without correlation to road sediment per area.

1. Total road length draining to streams per sample or unit area (road miles/mi^2)
2. Percent of road network draining to streams (often reported but not related to total length of road draining to streams or sediment input)

3. Road length draining to streams per mile of stream length (the road connectivity performance measure)

The status of categorical road-prism variables (e.g. road surface types, road connectivity classes, etc.) at each sample event will be reported in terms of the percent of road length in each category by sample area. Trend (improvement) in categorical variables between sample events (Hypothesis 2b) will be determined by changes in an index defined as:

$$\text{Road Attribute Index} = \sum \frac{RM_i \times C_i}{RM_t \times C_b}$$

where RM_i is the road miles connected to the stream in each attribute category, C_i is the WARSEM coefficient for each attribute category, RM_t is the total road miles connected to streams in the sample unit, and C_b is the WARSEM coefficient associated with the least amount of erosion for the reported attribute.

The Road Attribute Index (RAI) is designed to express an improving trend between sampling events as a decreasing number because the smallest possible number associated with an improvement in road condition is in the denominator.

The road rutting attribute does not have coefficients in the WARSEM model. Improvement in this attribute will be determined by the change between sample events in the total number of miles of road draining to streams with ruts interfering with drainage to ditches, cross drains, or forest floor.

For Monitoring Questions 3 through 6, the road monitoring measures are the performance standards for surface erosion and hydrologic connectivity defined under "old roads" in the FFR performance targets (Table 1), and are:

- Miles of forest road delivering to streams per miles of stream, and
- Modeled tons of sediment delivered to streams per miles of stream per year.

These measures will enable FFR road hydrology and sediment performance targets (Table 1) to be evaluated on a statewide scale. Roads built under the new road construction rules are included in the monitoring project as they are also covered in required road maintenance and abandonment plans. Orphaned roads (those last used for forest practices activities prior to 1974), however, are not included in the project because there is a different risk evaluation process for them.

Monitoring Duration

An implicit assumption of the FFR road strategy is that with incremental implementation of road maintenance rules and higher standards for new road construction, road sediment and drainage will be reduced and sustained at performance target levels. This means that monitoring should record an improving and then sustained trend in road conditions and performance measures from a random sample of roads under FFR rules.

Beginning in 2001, large forest landowners have five years to develop RMAPs for all roads on their ownership (minimum of 20% of land base per year) and 15 years to fully implement those plans. Small forest landowners are exempt from submitting plans until they file a forest practices application, and then only an abbreviated checklist is required for those roads used during the permitted activity. Until 2016, RMAPs are expected to be implemented in a staged and block or patchwork manner, based on risk to the resource and harvesting priorities. Staged implementation means that not all roads within a planning area necessarily will be upgraded at the same time. Annual maintenance priorities may include site-specific maintenance work, such as replacing individual culverts and targeting the installation of additional cross drains, or may include bringing entire blocks of road up to new road standards.

A monitoring program for trends in road drainage and sediment delivery can be expected to last until at least 2016. We recommend that the initial data collection begin as soon as the study design is approved.

2.5.2 Sample Unit Selection

This project is designed to characterize roads at the sub-basin scale because the sub-basin is the minimum landscape unit likely to contain the three “public resources” protected under FFR: salmonid fish, amphibians and water quality. A sample unit with an area of 6 mi^2 was chosen to be consistent with the average area of the sub-basins from which the performance targets were developed (average area = 6.26 mi^2, n =60, SD = 3.96 mi^2)[1]. The 6 mi^2 sample area is also a sufficiently large portion of the landscape to capture localized sub-areas with unusually high or low road density, stream density, or sediment production. As a result, road sediment and road connectivity values for each sample area should integrate a realistic amount of small-scale variability, and their measures can be evaluated relative to performance targets without being aggregated.

Performance standards are established for the sub-basin. Actual hydrologic sub-basins are attractive as sample areas; however, this approach was rejected because of numerous sampling disadvantages, including: 1) a bias toward headwater portions of watersheds which could under-sample mainline roads that follow major valley-bottoms, 2) variability in sub-basin sizes, and 3) the lack of pre-existing sub-basin delineation statewide from which to select sample units. For these reasons, an arbitrarily shaped polygon containing 6 mi^2 of FFR forest land was selected for the basic sample unit.

Sample units will be located by randomly selected section corners and delineated by a set of GIS algorithms (Appendix A). DNR datasets composed of section and quarter-section corners will be filtered for FFR and State lands, and the randomly selected section corners will be located in this

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[1] Most eastside data were provided by WAU and not by sub-basin.

grid. County assessor records of land parcel boundaries and ownership will be searched to identify FFR land in a 16 mi^2 block around the section corner. A GIS buffer algorithm will be instructed to construct a polygon around the selected section corner using quarter-section size cells that contain only FFR land. The algorithm will progressively enlarge the buffer in all directions until it contains 6 mi^2 of FFR land.

The same sites will be repeatedly sampled during the 15 year duration of the study. Both annual and inter-annual sources of variation must be considered when comparing estimates of monitoring measures for samples collected in different time periods. Sampling the same initial pool of sites through time will reduce the variation between sites from sampling event to sampling event. This approach should increase the power of any hypothesis tests (Urquhart et al. 1998).

The disadvantage of this sample selection approach is the possibility that a landowner will disproportionately target the sampled unit for road improvements. However, we believe the potential for altered landowner behavior is low because of the long duration of road rule implementation, the long interval between monitoring events, the potential for sample areas to include multiple landowners, and the lack of landowner incentives - landowners will not be identified and the results will be reported by percent of the road system meeting rule standards in each sample area. Moreover, the additional costs arising from drawing a new sample and observing a previously unsampled site are eliminated when the same sites are resampled. Measuring new sites every time would also introduce greater variability and error, reducing the ability to detect change over time.

2.5.3 Sample Size

Two of the main road attribute metrics that will be used to assess the status of the resource are the WARSEM modeled tons of road sediment delivered per year per stream mile relative to the performance target (RSED%) and the ratio of road length delivering to streams to total stream length relative to the performance target (RLEN%). These metrics will be used to address Monitoring Questions 4 and 5 (see Section 2.3). There are FFR performance targets for each metric defined for three regions of the state (see Table 1). These two metrics relative to their targets can be expressed as either the percentage of the minimum target or the percentage of the maximum target.

The variability of the road monitoring metrics was estimated by combining data collected throughout the state. Data sources are watershed analyses in which the Washington watershed analysis road surface erosion model was used to estimate sediment delivery. These same data were also used in development of the FFR performance targets for roads (Table 1). The dataset included data from sites in the following ecoregions (n = sample size or number of sites sampled in an eco-region):

1. Cascades, n = 7
2. Coast Range, n = 54
3. Columbia Plateau, n = 5
4. Eastern Cascades Slopes, n = 28
5. North Cascades, n = 14

The distribution of these sites among the three performance target regions was

- Coast, n = 22 (20.4% of sites)
- East of Crest, n = 40 (37.0% of sites)
- West of Crest n, = 46 (42.6% of sites)

We used RSED relative to the maximum target for our sample size analyses. There was little difference in the overall variability of the RSED% data whether it was expressed as the percentage of the minimum or maximum target. We used the variability of the RSED% data for our sample size analyses because it was more variable than the RLEN% data (CV[2] for RLEN% ≈ 60% compared to a CV ≈ 120% for RSED%).

Figure 3 is a box-and-whiskers plot (Hoaglin et al. 1983) showing the distribution of RSED% values by eco-region, and Figure 3b is a box-and-whiskers plot showing the distribution of RSED% values by performance target region. Both plots show all data combined for comparison. Each plot displays the sample median (heavy horizontal line in the box), the central 50% of the data (enclosed in the box), and the lowest and highest data values not considered extremes or outliers (the box whiskers). Data values more than 1.5 box lengths from the edge of the box are considered outliers (indicated by o), and values more than three box lengths from the edge of the box are considered extremes (indicated by asterisks). The samples from the Columbia Plateau and East Cascade eco-regions have the highest RSED% values relative to their maximum target. By performance target region, the East of Crest data have the highest RSED% values.

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[2] CV = coefficient of variation which is the sample standard deviation divided by the sample mean.

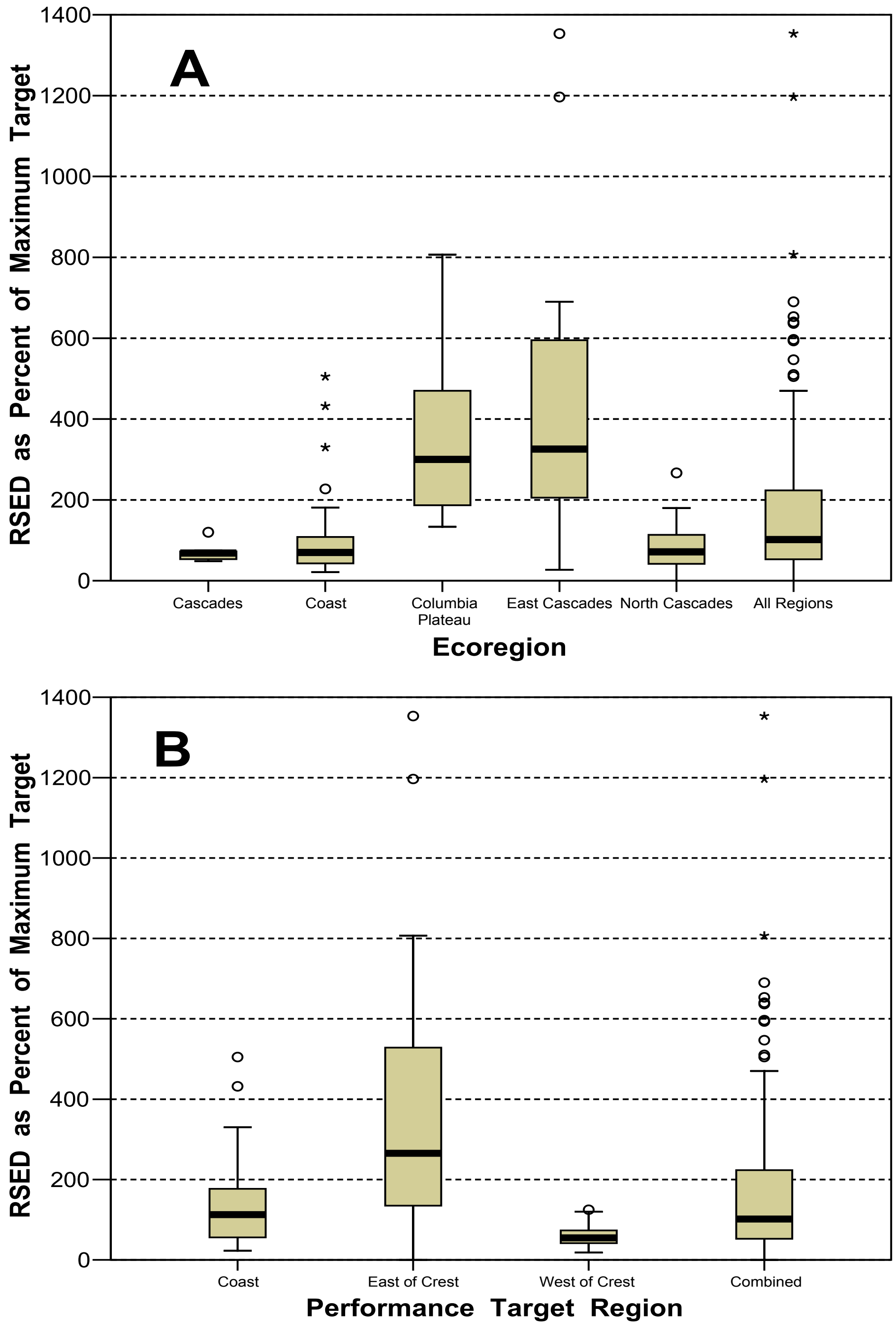

Figure 3. Box-and-whiskers plot comparing the distribution of RSED% values (as a percentage of the maximum target) for the combined data and for the (A) five eco-regions represented in the data and (B) for the three performance target regions represented in the data. The plot shows the sample median (heavy horizontal line in the box), the central 50% of the data (enclosed in the box), and the lowest and highest data values not considered extremes or outliers (the box whiskers). Data values more than 1.5 box lengths from the edge of the box are considered outliers (indicated by o) and values more than three box lengths from the edge of the box are considered extremes (indicated by asterisks).

These data are highly variable: mean RSED% = 188% and standard deviation = 232%. Sources of spatial variability in the data arise from several sources, including differences in the proportion of roads draining to streams and stream densities between the watersheds and in the model input parameters of geology, local traffic levels, and precipitation. Some variability in the sample data may also be due to allowed user adaptation in model application and a higher proportion of GIS modeled vs. field data modeled results in Eastern Washington. User adaptation to the revised model and field methods in this study are limited and explicit, and we expect variability of results to be less than these data.

For the combined data (all samples), 12 samples were identified as outliers or extremes and were omitted from the sample size analyses. Summary statistics for the combined data (omitting outliers) appear in Table 6. The mean and standard deviation for these data were used in the subsequent sample size analyses.

Table 6. Summary statistics for RSED% (as a percent of the maximum target) calculated from the combined data omitting outliers.

Mean	120.6%
Standard Deviation	103.4%
Standard Error	10.6%
Sample Size	96
Coef. of Variation	85.7%
Minimum Value	0.17%
Maximum Value	470%

The basic monitoring plan is simple. It involves reporting the status and estimating mean values for the monitoring measures in Table 5 for a statewide sample and then repeating the process every five years to detect changes in the central tendency. Considerations for determining target sample sizes include:

- The precision desired for the mean RSED% and RLEN% estimates for any specific time period. For example, should the estimates for the initial sample means have a 95% confidence interval with ±10% relative precision[3] for the mean? Or, is a less precise estimate acceptable for the time-period specific estimates of mean RSED% (e.g., 95% confidence interval with ±20% relative precision)?
- The effect size (Cohen 1988) that is desired to be detected by the monitoring. For example, do we want to be able to detect a 10% decrease in mean RSED values over a specified period with 95% confidence? Or are we interested in detecting grosser changes, such as a 25% decrease in the mean from one time period to the next with 90% confidence?
- The ability to do post-implementation stratification to detect regional, climatic, or eco-region differences with any statistical power.

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[3] Relative precision expresses the half-width of a confidence interval relative to the mean value of the parameter.

Tables 7 and 8 provide guidance on the possible precision and power (Peterman 1990) for a range of sample sizes. In Table 7, the sample sizes required to estimate mean RSED% values for any specific time period are provided for two levels of confidence and five levels of relative precision. They were estimated based on the mean and standard deviation for the combined eco-region RSED% sample in Table 6 and generated using the formulae for continuous data in Cochran (1977). No reduction was applied to sample sizes to account for finite population sampling. This analysis assumes that the variation in RSED% for future statewide sampling will not be greater than for these samples. These sample size recommendations address the "status of the resource" objective.

Table 7. Sample size requirements to estimate mean RSED% with different levels of relative precision and for two levels of confidence.

Relative Precision	Confidence Level 95%	 90%
	Required Sample Size	
±5%	1,132	798
±10%	285	201
±15%	128	90
±20%	73	52
±25%	48	34

Another monitoring objective is to assess changes in mean RSED% and RLEN% over time. Before the sample size necessary to compare sample means between two periods of time can be specified, the effect size that is desired to be detected and the level of power[4] desired for the test comparing means must be specified prior to analysis (Cohen 1988). After these two parameters have been specified, and assuming that a t-test is appropriate for comparing sample means, sample size requirements can then be estimated. Based upon the previous analyses, and the mean and standard deviation for the combined eco-region RSED% sample (omitting outliers and extremes), the power of seven different sample sizes to detect a range of effect sizes[5] was estimated following procedures of Cohen (1988). These analyses are summarized in Table 8.

The data in Table 8 indicate that to reliably detect reductions in mean RSED of 25% or greater with power greater than 80% (a commonly used power standard) with 95% confidence requires a sample size of at least 100. It may not be practicable to try to detect reductions in the mean RSED% of 10% or less. However, we propose to also use a paired t-test approach to evaluate the mean reduction in RSED% between sampling events. We expect this test to have greater

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[4] Power is the probability of correctly rejecting the null hypotheses. For example, correctly rejecting the null hypothesis of no change in mean RSED% values between a baseline sample and a sample collected sometime after implementation of new road rules, when there has been an actual reduction in mean RSED%.

[5] Effect size is defined here as the percent decrease in the mean RSED% from the baseline value. A 15% difference is then a 15% decrease in mean RSED% from the baseline, e.g., from 200% of the maximum target (baseline value) to 170% of the maximum target.

power than the two-sample t-test. However, we recommend basing sample size decisions on the two-sample t-test guidelines because of the status of the resource objective.

Based on our sample data, a sample size of 60 with $\alpha = 0.10$ provides about the same power for detecting a change in mean RSED of 30% as a sample size of 100 with $\alpha = 0.05$ for detecting a change in means of 25% (assuming that the variance of RSED% in the first sample is similar to or less than that used in this estimate). This level of precision is also consistent with the use of a model for estimating sediment production, where small changes in estimated sediment production are less meaningful than moderate to large changes. Precision and power for RLEN% will be greater since RLEN% is less variable than RSED%.

Table 8. Estimated power of a one-sided t-test to correctly reject the null hypothesis of no change in mean RSED% values between a baseline and second later sample for a range of sample sizes and percent decreases in mean RSED% from the baseline value (shaded cells indicate region where power is approximately 80% or greater).

Sample	Difference in mean RSED% values between baseline and second sample[a]				
Size	20%	25%	30%	40%	50%
Test at α = 0.05					
40	30%	42%	56%	80%	95%
50	35%	49%	64%	87%	98%
60	40%	56%	71%	92%	99%
70	44%	61%	77%	95%	100%
80	49%	66%	81%	97%	100%
90	53%	71%	85%	98%	100%
100	56%	75%	88%	99%	100%
Test at α = 0.10					
40	44%	57%	69%	89%	98%
50	50%	64%	77%	94%	99%
60	55%	69%	82%	96%	100%
70	59%	74%	86%	98%	100%
80	63%	78%	90%	99%	100%
90	67%	82%	92%	99%	100%
100	70%	85%	94%	100%	100%

[a] Percent reduction from baseline mean RSED%.

A target sample size of approximately 60 sample units was identified as providing sufficient power for our proposed analyses. However, because of the estimated costs associated with sampling at this time, it is unknown whether the sample size of 60 can be achieved given the current budget for this project. Therefore, we propose initially collecting the data for 30 samples and conducting a power analysis based on that data to more accurately determine sample sizes needed to achieve sufficient statistical power for both status and trend analyses.

2.5.4 Sample Distribution

The proposed monitoring strategy assumes that the sample frame consists of all forest roads within state and private forest land under FFR rules. State and commercial timber lands covered under separate Habitat Conservation Plans (HCP) are not included within the sample frame. The target number of statewide samples will be distributed proportionally to the area in each performance target region: western Washington, eastern Washington, and coastal spruce. Distributing the statewide sample proportionally between the three regions will allow examination of the data by these strata as a post-stratification analysis. However, testing of any stratification hypotheses (i.e., differences between regions) is not included in this design.

Estimates of the total area of land under FFR rules by rule regions are shown in Table 9. The numbers were obtained from the Final EIS for the FFR (WFPB 2001) and from a GIS analysis of the estimated area in FFR rules done by the Monitoring Design Team (MDT) (Benkert et al. 2002). The MDT estimates were further divided into area in each of the three rule regions. Totals are cited in English units for comparison with the sample unit area of 6 sections (6 mi^2).

Table 9. Area in Washington State forest lands subject to RMAP rules (excluding areas under HCPs).

Region	Estimate of area under FFR rules (mi^2)	Estimate of area under FFR rules from Final EIS (mi^2)
Western Washington	4,239	9,483
Eastern Washington	5,691	6,287
Coastal Spruce	1,295	Not separated from w. WA
TOTALS	11,225	15,770

Dividing the estimated potential area in FFR RMAP rules by sample unit size (6 mi^2) indicates 1,870 to 2,628 possible sample units are available statewide. The proposed sample size of 60 is approximately 2.3 to 3.2 percent of the available population. Based on the estimated areas of the west/east/coastal spruce region in Table 9, approximately 51 percent of the sample units will be located in eastern Washington, 38 percent in western Washington, and 11 percent in the coastal spruce region. Based on the 51:38:11 area distribution ratio, the sample will draw 30 sample units from the eastern Washington region, 23 sample units from the western Washington region, and 7 sample units located in the coastal spruce region.

2.5.5 Sampling Frequency and Distribution

Re-sampling of all sites should be conducted at least three years after the first survey. Because we are unsure of the expected rates of change (projected decrease) in the monitoring indicators, sample frequency recommendations are largely guesswork at this time. The power analyses for the hypothesis tests which compare RSED% means (Table 8) indicate that detecting reductions in mean RSED% of less than 25 to 30% is unlikely with 60 samples[6]. Therefore, we propose that the first re-sampling of sites be conducted at least three years after the first sample. Three years should be sufficient time for measurable changes in mean RSED% and RLEN% to occur. Timing is critical because if sites are re-sampled too soon after the initial sample, change may not be detected, or if too late valuable information might be lost for modifying the sampling plan. We conclude that conducting the first re-sample after 5 years is a good balance between these two competing problems. Analysis of the data from the first re-sample will be used in assessing whether the frequency of subsequent samples requires adjustment.

Since the time necessary to detect a trend between sampling events is largely guess work, prior to conducting each resample, the percent of road length up to standards (Monitoring Question 6) will be re-evaluated first to determine if a sufficient change is likely based on the increase in roads brought up to new road standards. In addition to providing information on the relationship between the performance targets and road standards, this metric will also provide a trend for road standards implementation.

2.6 Analytical Procedures

This section describes the statistical procedures for reporting the status of the monitoring measures and for testing the null hypotheses summarized in Table 10.

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[6] Available data for one watershed following post-watershed analysis road plan repairs, however, shows an average reduction in RSED of 69% over pre-road plan conditions (sd=20.3%, n=9) (Toth, 2000).

Table 10. Analytical methods for reported measures and for road sub-basin scale effectiveness monitoring questions and hypotheses.

Monitoring Questions & Hypothesis	**Reported Monitoring Measures (by sample area)**	**Analytical Methods**
MQ1	1. Total road length draining to streams (road miles/mi^2) 2. Percent of road network draining to streams 3. Percent of road in each surface category 4. Percent of road in each traffic category 5. Percent of road in each cutslope cover category 6. Percent of drainage points by connectivity class 7. Percent of road in each road rutting category	For each sampling event, summary statistics for each attribute and category by state and by performance target region.
H2a	1. Total road length draining to streams (road miles/mi^2) 2. Percent of road network draining to streams	A. Summary statistics of differences between sampling events for each attribute by state and performance target region B. Significance of differences between sampling events (paired t-test)
H2b	1. Road surfacing index 2. Road traffic index 3. Cutslope cover index 4. Miles of delivering road with ruts interfering with drainage	A. Summary statistics of differences between sampling events for each attribute category pooled by MQ1 groupings B. Significance of between-event differences (paired t-test)
MQ3	1. Miles of forest road delivering to streams per miles of stream (road hydrology performance measure) 2. WARSEM modeled tons of road sediment delivered to streams per miles of stream per year (sediment performance measure)	For each sampling event, summary statistics of monitoring measures at the state level.
MQ4	1. Miles of forest road delivering to streams per miles of stream (road hydrology performance measure) divided by the performance target by target region 2. WARSEM modeled tons of road sediment delivered to streams per miles of stream per year (sediment performance measure) divided by the performance target by target region	For each sampling event, summary statistics of performance measures by performance target region
H5a	Miles of forest road delivering to streams per miles of stream (road hydrology performance measure)	A. Summary statistics of differences between sampling events at the state level B. Significance of test whether mean differences are equal to 0
H5b	WARSEM modeled tons of road sediment delivered to streams per miles of stream per year (sediment performance measure)	A. Summary statistics of differences between sampling events at the state level B. Significance of test whether mean differences are equal to 0
H6a	Miles of forest road delivering to streams per miles of stream by percent of road length meeting performance standards	Bivariate regression of reported measures
H6b	WARSEM modeled tons of road sediment delivered to streams per miles of stream per year by the percent of road length meeting performance standards	Bivariate regression of reported measures

2.6.1 Status and Time-period Specific Estimates

The initial status of each monitoring parameter will be estimated from common summary statistics (mean, standard deviation, etc.) from a randomly selected statewide sample (distributed among regions as described above). These data will be examined to determine if confidence interval estimation and hypothesis testing procedures, which assume normally distributed data, are appropriate. A mean value with an accompanying 90% or greater confidence interval will be estimated for each monitoring parameter.

2.6.2 Trend Monitoring

Trend monitoring data will be collected at approximately 5 year intervals from the same sites as the initial sample. These data will be analyzed similarly to the first samples.

At each sample event, mean values will be estimated. Although we project that our analyses will use the mean, other measures of central tendency may be used (e.g., median or a trimmed mean). The mean for a sampling event at time t will then be compared to the mean of the previous event to determine if there has been a significant decrease in the mean.

A paired t-test (or its nonparametric equivalent if needed) will be used to test for changes in the mean value for the road monitoring measures specified in Hypotheses 2 and 5 between two sample periods. The null and alternative hypotheses tested are:

$$H_o : \overline{D} \geq 0,$$
$$H_A : \overline{D} < 0,$$

where $\overline{D}$ = the mean of the differences between values at time i and time $i+1$ for individual sample units (e.g., $\text{RSED\%}_{i+1} - \text{RSED\%}_i$). If the null hypothesis is not rejected, a power analysis will be conducted to determine the power of the test to detect changes in means of various magnitudes.

An additional statistic that will be calculated at each sampling interval after the initial sample is p, the proportion of sample sites that show a reduction in RSED% between the two sampling events. RSED% and RLEN% are assumed to be measured without error. P and its variance are estimated as follows:

$$\hat{p} = \frac{r}{n}, \text{ and}$$
$$Var(\hat{p}) = \frac{\hat{p}\,(1-\hat{p})}{n-1},$$

where r = the number of sites with a reduction in RSED% and n = the total number of sites sampled. Methods in Fleiss (1981) will be used to estimate confidence intervals for $\hat{p}$. A similar analysis will be done for RLEN%.

Monitoring changes in p over time will also provide an indication if there are general statewide reductions in sediment delivery and drainage to streams from roads. Fisher's exact test and the chi-square statistic (Fleiss 1981) will be used to test the hypothesis that the $\hat{p}$ estimates for two different sampling events (after the initial sample) are equal.

2.6.3 Relationship between performance measures and road standards (H6a and H6b)

The relationship between the percentage of the road length meeting performance standards (%RSTAN) and the performance measures RLEN and RSED will be examined using regression analysis using data from the first monitoring round. We expect to see a declining trend in RLEN and RSED with increasing %RSTAN, as shown in Figures 4 and 5 for hypothetical data. To maximize the usefulness of the regression analyses, additional samples will be collected as necessary to obtain a minimum number of samples in the 70 to 100% range for %RSTAN. Because these additional samples will not be random, they will not be used in the analysis of the performance measures. Standard ordinary least squares linear regression methods will be used to estimate the slope of the relationship between each dependent variable (RSED and RLEN) and %RSTAN. Data transformations and non-linear or logistic regression methods will be used if appropriate.

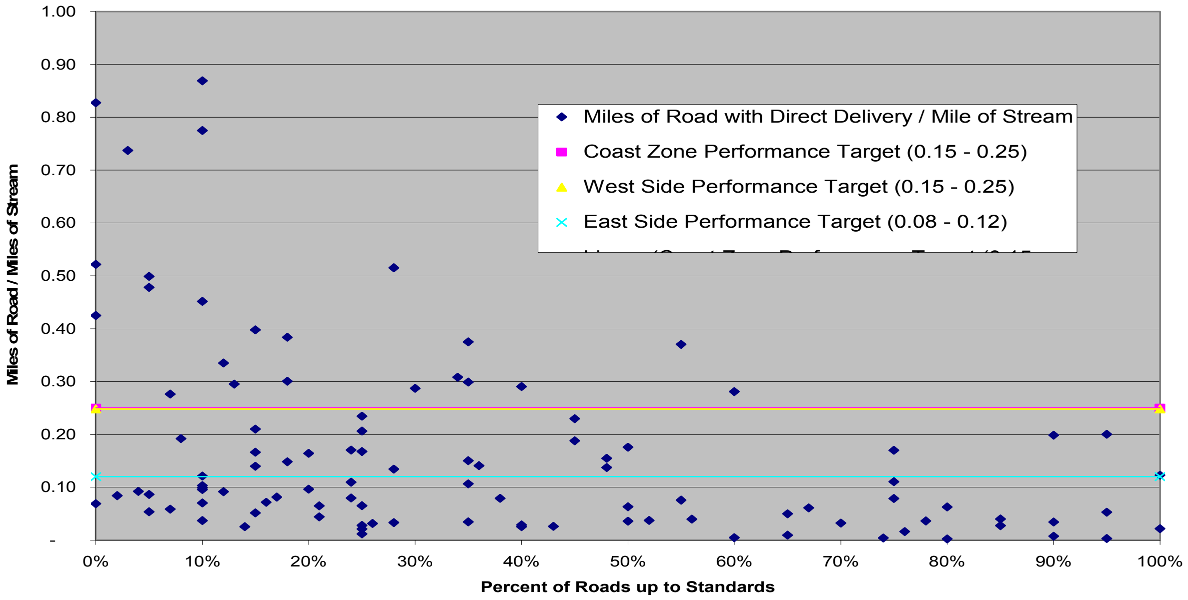

Figure 4. Hypothetical relationship of road connectivity to streams (miles of road with direct delivery/mile of stream) by percent of road length up to road standards.

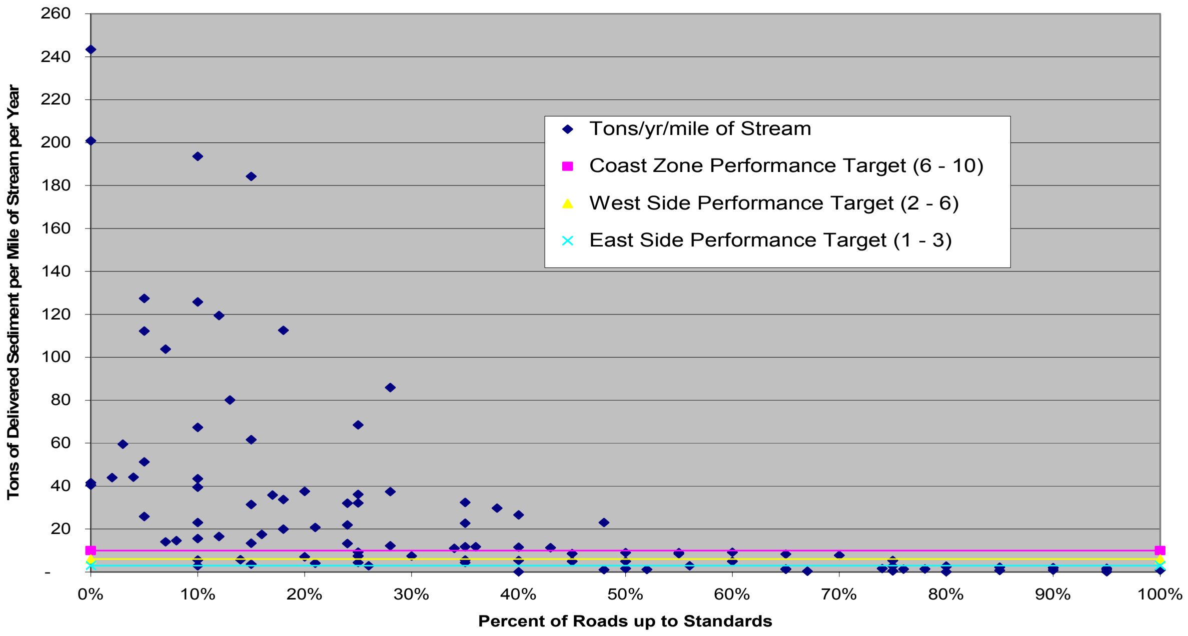

Figure 5. Hypothetical relationship of road sediment delivered to streams (tons/yr/mile of stream) by percent of road length up to road standards.

PART III INTEGRATION WITH OTHER MONITORING EFFORTS

3.1 Integration within the CMER Monitoring Framework

Within the proposed CMER monitoring framework, results from both intensive-level monitoring and site-scale monitoring should provide information on the local factors effecting road surface erosion and drainage at the sub-basin scale. This information can be used to further interpret the sub-basin monitoring results. Road site-scale monitoring will provide data on the effectiveness of treatments at the site scale, which can be analyzed by a number of physical and management variables and aggregated to a number of scales (ownership, ecoregion, state).

Validation monitoring for roads should focus on correlating values of the FFR performance targets for roads to biologic or habitat indicators or water quality measures. A correlation resulting from validation monitoring may look something similar to the hypothetical graph in Figure 6.

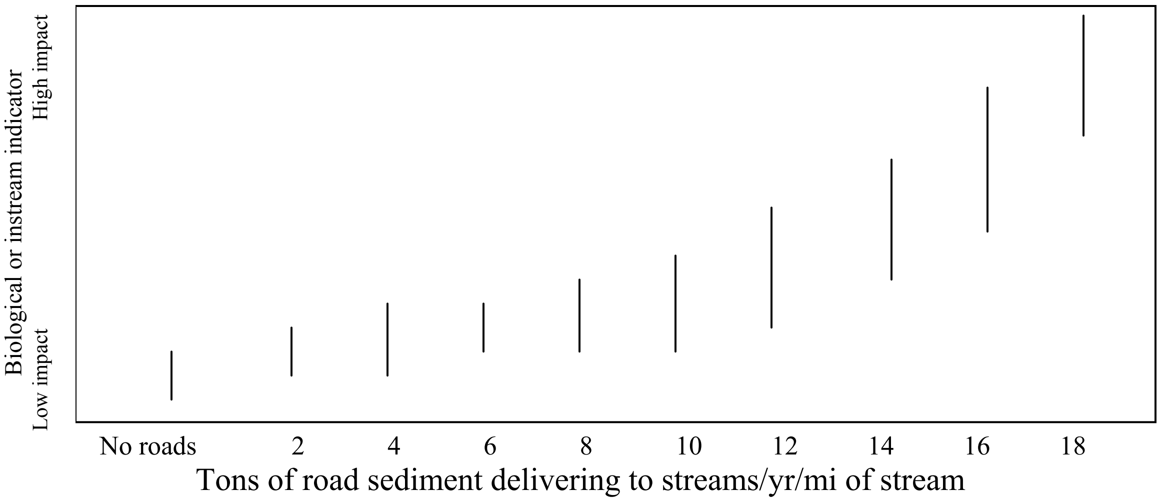

Figure 6. Hypothetical validation monitoring correlation between biological or habitat indicators and road performance targets.

3.2 Interrelationship with Other Monitoring Programs

A number of significant monitoring efforts related to salmon recovery are in progress or planned, including efforts by the NOAA Fisheries, State of Oregon, the U.S. Forest Service, Bureau of Land Management, and the Northwest Power Planning Council. Most of these efforts concentrate on water quality, habitat, and biological indicators. The Northwest Forest Plan Aquatic Riparian Effectiveness Monitoring Program under implementation includes upslope, riparian, in-channel, and biological indicators (Hohler et al. 2000).

Northwest Forest Plan (NFP) core indicators related to roads include both road density (length and proportion of road network hydrologically connected to the stream channel) and stream crossing density (number of stream crossings per square mile) (Hohler et al. 2000) reported for 6th field watersheds estimated at 5 to 20 mi^2. Our proposed measurement of road connectivity to streams is reported as the proportion of roads draining to streams per mile of stream rather than the length of roads draining to streams per area. Since our proposed sample areas are uniform, we can easily report our results in the same units to compare with Northwest Forest Plan road densities.

The FFR (Appendix D.1 (e)) directs the DNR to keep and summarize the following data on an annual basis. Results from this monitoring program could be compared with some of these data.

- Miles of road under plans;
- Miles of abandonment,
- Miles of active and orphan roads;
- Miles of fish passage opened; and
- Number of fish-bearing stream crossings replaced.

PART IV COST AND IMPLEMENTATION

The cost of this monitoring program, and therefore the current CMER budget allocation, was based on a sample size of 50, the sample size determined for the same power analysis for reporting the RSED measure. Following SRC review of the monitoring plan, the metric was changed to RSED% which increased the variance and therefore the sample size for the same power. Rather than adjust the estimated cost for an additional 10 sample units at this time, we propose collecting the data for 30 samples initially, conducting a power analysis based on that data to more accurately determine sample sizes needed to achieve sufficient statistical power for both status and trend analyses, and then estimating additional budget needs if needed based on actual costs per site. The following cost analysis for 50 sites has been left in this section for reference:

The initial costs for program startup and the first sample will include site selection costs not associated with subsequent samples. Purchasing data stations and GPS units may provide a cost savings over contractor rentals, and equipment will be available for other CMER studies between sampling for this project.

To estimate the cost associated with field data collection, we estimated average road densities. Typical sub-basin road densities from 10 sampled watershed analyses[7] vary from 3 to 7 mi/mi^2. The 64 sub-basins in these 10 WAUs had an average road density of 5.1 mi/mi^2 and there was essentially no difference between the eastern and western Washington averages (west 5.13 mi/mi^2, n=47; east 5.07 mi/mi^2, n=17). The cost associated with the field data collection is based on averaging 5 miles per day per person based on our experience collecting similar data for watershed analysis. Based on this assumption, approximately 6 person days are required to collect data for a 6 mi^2 sample unit with a 5 mi/mi^2 road density. Including one person-day for travel and three person-days for determining the %RSTAN and placement of site monumenting, we conclude that an average of 5 days is required for a two person team to collect the field data per 6 mi^2 sample area for the first sample, and an average of 3 days for subsequent samples.

Initial and subsequent data collection costs are listed per site, so the entire program cost can be estimated. Based on a minimum sample size of 50, the initial sample would cost approximately $476,900, and 6 person months of CMER staff time. Additional samples for obtaining an adequate %RSTAN range in the first-year sample, if necessary, would cost approximately $8,000 per site. A re-sample beginning at year 5 would cost approximately $350,000, assuming 3% inflation per year over the initial costs, less GIS time, less field time, and less time to set up the observer variability test. Budget estimates would be revised after the first year sample.

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[7] 3 in southwest Washington, 3 in southeast cascades, 1 in northeast Washington, and 3 in North Cascades.

Program Task	**Estimated Cost**
Start up Costs:	
1. Site selection & screening, landowner coordination (first sample only)	
a. 2 CMER staff at 2 months	
b. GIS analyst, 30 hrs @ $70/hr	$ 2,100
2. Data base development & coordination, (first sample only)	
1 scientist, 80 hrs @ $60/hr	$ 4,800
Sample Costs:	
3. Contract oversight & project coordination	
CMER staff, 2 months – per sample	
4. Supervising senior scientist, 300 hours @ $100/hr	$ 30,000/*sample*
5. Training of field crew & QA/QC, per sample	
a. 1 scientist, ~80 hrs training and prep @ $70/hr	$ 5,600/*sample*
b. 2 technicians 1 week @ $60/hr	$ 4,800/*sample*
6. Initial observer variability test, per sample	
1 scientist, 160 hours @ $70/hr	$ 11,200/*sample*
7. Post-sample observer variability test	
1 scientist, 80 hours @ $70/hr	$ 5,600/*sample*
8. Data analysis and report writing	
1 scientist, 1.5 months, at $70/hr	$ 16,800/*sample*
First Sample Unit Costs:	
9. First year data collection (50 samples, plus additional samples for %RSTAN, if necessary):	
a. GIS data acquisition; screening & post-field model runs	
GIS analyst: 2 days @ $70/hr	$ 1,120/site
b. Data collection:	
Field & office data, 2 technicians 1 week @ $60/hr	$ 4,800/site
Expenses: vehicles, per diem, supplies	$ 1,750/site
Equipment: data station & GPS contractor rental	$ 200/site
Site monument materials	$ 50/site

PART V RESULTS INTERPRETATION AND POTENTIAL ADAPTIVE MANAGEMENT

The road sub-basin scale effectiveness monitoring will provide information on the status of forest-road prism characteristics relative to road runoff and sediment production and delivery to surface waters beginning in 2006 (Table 5). It will provide an estimate of the trend in road attributes as rule implementation progresses toward completion. As information becomes available from subsequent sampling events, changes in the measures of road sediment delivery and hydraulic connectivity will be determined and estimates of the potential reduction upon full rule implementation can be refined.

The results of this first monitoring project will provide insights into the following:

1) Characteristics of the forest-road prism on FFR lands in Washington
2) Status of road standards implementation in 2006
3) Road run-off being delivered to streams
    a) Existing ratio of road length delivering to total stream length
    b) Difference between present ratio and target ratio
    c) Estimate of ratio upon full implementation of RMAP
4) Sediment delivery to surface waters by the existing forest road system
    a) Existing amount of estimated sediment being delivered per stream length
    b) Difference between present sediment delivery and target
    c) Estimate of amount of sediment delivery upon full implementation of RMAP.

The insights provided by the monitoring project into these issues will inform policy about the present impacts of the forest-road system upon public resources. Using this information, we can assess:

1) Additional road monitoring needs, and
2) Priorities assigned to other road-related monitoring projects.

This study could produce a range of results, and we provide guidance on how these results might be interpreted and used to guide future implementation of the monitoring plan and management decisions given the limitations of the modeling approach. Below are a few simplistic scenarios to illustrate some potential first-year results and appropriate responses.

Scenario 1: The first-year results show that the performance measures in the first sample are clearly above performance targets and that with increasing percentage of roads meeting standards, an appropriate decline to performance targets is shown. The status of attributes also indicates room for improvement in road conditions affecting sediment and hydrology. These initial results would be consistent with the 5 year RMAP planning window and the 15-year road rule implementation period. We expect that there is room for improvement in road attributes and performance measures results, and that our monitoring design is appropriately designed to detect these changes over the length of the monitoring program. The recommendation for this scenario is to stay the course and continue with periodic sampling to monitor these trends. Prior to investing in the second sample, we would evaluate the degree of change in the percentage of roads up to standard to determine if sufficient change has occurred to produce a significant or detectable change. We would also recommend moving ahead with validating the performance targets relative to resource impact.

Scenario 2: The first-year results show that the performance measures in the first sample are clearly above performance targets, and that no relationship is found between road attributes, the performance targets, and increasing percentage of roads meeting standards. This would be a troublesome result, as it suggests that the performance targets are unattainable (targets not met at high percent road standards), or performance targets or road standards are perhaps too high (targets met at low percent road standards). We would propose a study to analyze the factors contributing to these results, for example: disparity between landowner perception and actual length of road meeting standards, or unusual physical road or geographic attributes. Based on analysis of these results using existing project data, we could recommend continuing with the monitoring or moving ahead with well-focused compliance monitoring, model calibration, and performance target validation (relative to resource impact).

Scenario 3: The results show performance measures at or below the performance targets (based on confidence limits). This result suggests that road performance targets may be close to being achieved for a variety of reasons: a high percentage of roads already up to road standards in the sample; over-estimation of variance in the sample design; or the performance target is too high. Based on the results, we would recommend revision or adjustment of the monitoring design, and continuing with the next sample events to confirm findings, and propose to immediately implement performance target validation studies.

Scenario 4: The results are inconclusive, because the variance is too high to determine whether the performance measures are above or below the performance targets. We would re-evaluate the sample design to test if increasing the sample size by a reasonable quantity would decrease variance enough to provide a conclusive result. Based on this evaluation we could recommend 1) modifying the study by increasing the sample size or focusing the sample on a certain stratum (or strata) to reduce variance, 2) continuing the study to determine if variance decreases with time as a higher percentage of road standards are met, or 3) discontinuing the study in favor of compliance or another monitoring program.

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APPENDIX A: SITE SELECTION ROUTINE

Introduction

The study design proposes to sample the FFR road system within 60 sample units consisting of 6 mi^2 of FFR land. The purpose of this document is to present a consistent and objective method for delineating the FFR lands surrounding a randomly selected point to construct a polygon containing 6 mi^2 of FFR land.

Assumptions and Understandings

The delineation method uses a GIS set of algorithms to randomly select section corners within FFR and State forestlands and to identify and select six mi^2 of FRR lands contiguous to that point. The method assumes that FFR land tracts are available in GIS format and that ownership of these lands can be determined from county records.

Selection Method

The selection process involves three steps that are progressively more focused on land parcels. Each step is described here.

Step 1: Corner selection and FFR screen.

Step 1 selects possible sample areas and screens them for sufficient FFR land before the more labor-intensive parcel screen in step 2.

1. Randomly select section (or quarter-section) corners using the DNR dataset of surveyed section and quarter-section corners, which have been filtered by probable FFR and State forestlands. (The lands are not separated because of frequent land swaps between the State and private landowners with and without Habitat Conservation Plans.)

2. Outline the 16-section block centered on the selected corner and superimpose the FFR ownership map for the block.

3. Determine that at least 8 mi^2 of FFR land occurs within the block with a distribution that allows the selection of 24 ¼-sections within a 36 ¼-section portion of the block.

4. Discard the blocks that do not meet this criterion. Continue process until 75 blocks are available for the second screen

Step 2: Land-parcel screen.

The land-parcel screen uses ownership data and parcel maps from the county auditor to identify 24 ¼-sections of FFR land. Quarter sections are rejected if they contain a parcel with a non-forest use (i.e. residence, quarry, fire station, commercial, etc.); road, power line or railroad right-of-way is an acceptable non-forest use. A spiral-sampling plan is used to determine the sequence in which landownership within the ¼-sections is determined. The spiral begins in the ¼-section lying to the northwest of the selected corner and proceeds east and then south as shown in **Figure 1A**.

1. Obtain land ownership records and parcel maps for the accepted 16 mi^2 block from the appropriate county auditor.

2. Determine the land parcel boundaries and ownership around the selected section corners. Use the parcel data to determine the ownership in each ¼-section and eliminate probable non-FFR land. Sequentially add quarter sections according to rule listed below, to build a progressively larger polygon until it contains *at least* 24 (preferably 26) ¼-sections of 100% FFR land (more than 24 ¼-sections is desirable to allow for denial-of-access by some landowners – denial of access by one landowner in a ¼-section eliminates the entire ¼-section). In all likelihood the final polygon will contain inclusions of non-FFR land as shown in Figure 1B.

3. Continue the screen until the required number of sample areas per default region is obtained. Several additional (+10%) sample areas should be screened to provide a reserve for each default region to provide for the lost of a sample area because of land owner denial-of-access.

Rules

a. The selection spiral should be modified when the randomly selected corner falls on the edge of FFR land as in Figure 1C or in a corner of FFR land (Figure 1D) to avoid a priori rejection of the sample by excessive inclusion of non-FFR land resulting from the spiral sequencing pattern.

b. Each accepted sample area must contain six square miles of FFR land in quarter-section size blocks, that is, the sample area consists of 24 ¼-sections of 100 percent FFR forestland.

c. Quarter sections are rejected if they contain any parcel with a non-forest use (i.e. residence, quarry, fire station, commercial, etc.); road, power line or railroad right-of-way is an acceptable non-forest use, or if the forest landowner is operating under a HCP. e.g. DNR land on the Westside.

d. Sample areas are rejected when the total land area exceeds nine square miles that is, rejection occurs when the sample area would have to contain more than 12 rejected ¼-sections in order to achieve the desired 24 acceptable FFR ¼-sections

e. The acceptance of FFR ¼-sections should result in a coherent sample area; FFR ¼-sections may be rejected if their acceptance would result in

a) A ¼-section “FFR island” or a ¼-sections “FFR peninsula” that is surrounded by non-FFR ¼-sections, or

b) The inclusion of three or more non-FFR quarter sections within the sample area

Step 3: Contact Landowners

The landowner of each FFR parcel within the sample area should be contacted first by mail and then in person to obtain permission to access their roads and to conduct an interview about their road maintenance and abandonment plan. We anticipate that following steps will be included in this process.

1. Introductory letters to landowner organizations, i.e. Washington Forest Protection Association
2. Introductory letter to each landowner using parcel tax information for initial information
3. Follow-up may include a visit with the landowner, a second letter or phone call, or a mail-in questionnaire for the smaller landowner.

Discussion

The approach presented here has advantages and disadvantage. The advantages are the use of GIS framework to expedite sample area location, delineation, and screening and the objective, consistent, and reproducible method by which each sample unit is delineated. The preliminary selection of potential FFR land using the DNR FFR GIS layer saves time searching assessor records but the approach may falsely exclude some FFR parcels. This may not be a serious problem, because we anticipate the false exclusions will be limited to smaller parcels that are likely associated with non-FFR land.

The possible disadvantages are the irregular polygonal shape of the sample units. The buffer is built from quarter-section cells to increase the potential for the coincidence of land boundaries and sample-polygon boundaries. However, this cell size and the exclusion of cells with non-FFR land may give the sample area an irregular shape that some persons may find disquieting.

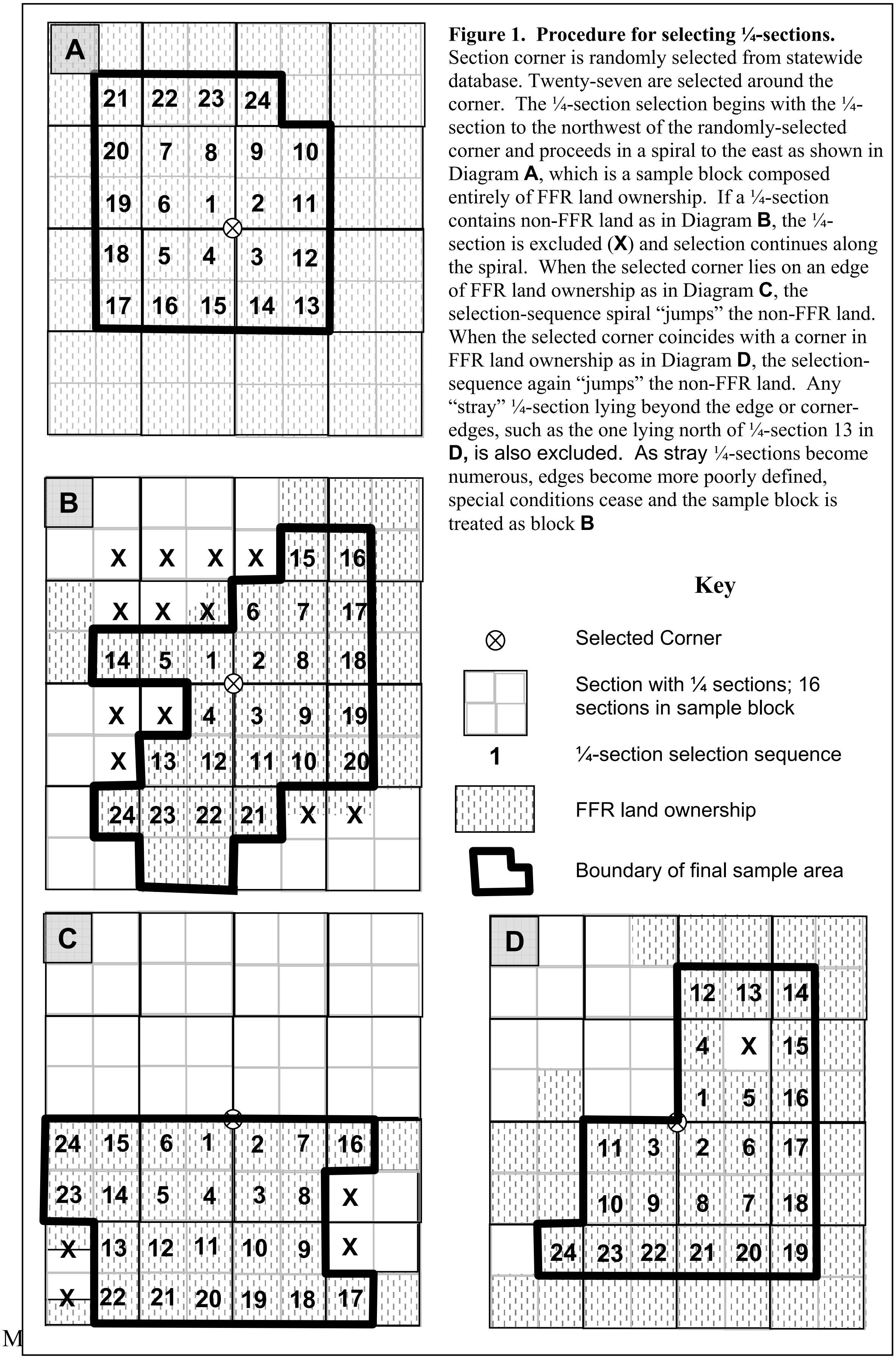

Figure 1. Procedure for selecting ¼-sections. Section corner is randomly selected from statewide database. Twenty-seven are selected around the corner. The ¼-section selection begins with the ¼-section to the northwest of the randomly-selected corner and proceeds in a spiral to the east as shown in Diagram **A**, which is a sample block composed entirely of FFR land ownership. If a ¼-section contains non-FFR land as in Diagram **B**, the ¼-section is excluded (**X**) and selection continues along the spiral. When the selected corner lies on an edge of FFR land ownership as in Diagram **C**, the selection-sequence spiral "jumps" the non-FFR land. When the selected corner coincides with a corner in FFR land ownership as in Diagram **D**, the selection-sequence again "jumps" the non-FFR land. Any "stray" ¼-section lying beyond the edge or corner-edges, such as the one lying north of ¼-section 13 in **D,** is also excluded. As stray ¼-sections become numerous, edges become more poorly defined, special conditions cease and the sample block is treated as block **B**

APPENDIX B: PERCENT ROAD STANDARDS EVALUATION

Introduction

Appendix B presents the method for estimating the road standards variable included in the sub-basin scale roads monitoring program. The methods described below are subject to revision or adjustment based on preliminary work to evaluate the feasibility of this approach.

Percent Road Standards

Percent RSTAN is a road-length weighted variable representing the degree to which roads in a sample area meet rule standards. The method used will depend in part on the data available from landowners. The %RSTAN measure could be reported by categories, which would acknowledge its source as an inaccurate estimate, or as a continuous value.

The simple approach is to have landowners review their roads included in the sample unit and estimate the degree to which they meet rule standards for water and sediment. The advantages to this approach are that it works well for the small forest landowners as maintenance records are not required, and implementation and communication with the landowner is transparent and intuitive. The disadvantage to this approach is the subjective evaluation by the landowner.

The more complicated approach to calculating %RSTAN requires maintenance records be available. We anticipate that many landowner RMAPs will contain the required level of specificity because of the detailed annual maintenance plans required by WAC 222-24-051(6) and (9). Also, we anticipate that by the time data collection occurs in 2005 and 2006 most roads for industrial forest landowners will be included in an RMAP because of the scheduling requirements in WAC 222-24-051(1) and (2). Moreover, we anticipate that more than 15% of the roads belonging to large landowners will be partially to completed maintained to road standards by the end of 2004 because WAC 222-24-050 requires that “Work performed toward meeting the standards must generally be *even flow* [emphasis added] over the 15-year period with priorities for achieving the most benefit to public resources early in the period.”

The number of road attributes used to calculate %RSTAN will vary with the road segment and the landowner’s maintenance plans for that road segment. For road segments requiring RMAP maintenance, the most complete and accurate estimation of %RSTAN is the length-weighted average percent completion of RMAP-specified modifications or existing compliance. The %RSTAN components could include:

- Length of road affected by modifications to drains -- culverts and other drainage features (D)
- Length of road resurfaced (S)
- Length of ditch improved (Di)
- Length of cutslope improved (C)
- Length of existing road that is rule compliant (R)
- Length of road affected by modification (L)

Using these factors and weighted by length of road affected, %RSTAN is calculated as

$$\%RSTAN = \frac{\{Ld(Dc/Dp) + Ls(Sc/Sp) + Ldi(Dic/Dip) + Lc(Cp/Cc) + Lr\}}{Ld + Ls + Ldi + Lc + Lr}$$

The subscript c and p refer to competed and proposed work respectively. %RSTAN calculated in this form does not distinguish between improvements that may substantially reduce sediment/water delivery, i.e. culvert placement, and those that may have only a minor affect, i.e. cutslope changes. The addition of weights could refine the accuracy of the estimate, or the factors could be reduced to those that substantially impact delivery, e.g. drainage and surfacing. In this form %RSTAN is a continuous variable that can be included in regression analyses with other variables.

The approach taken in the sub-basin monitoring program will depend in part on the results of the preliminary work on the feasibility of this approach. The feasibility study should provide the information to evaluate the degree to which landowner's have the necessary maintenance records required for the analysis and the amount of time required to acquire and analyze that data.