TYPE N/F RIPARIAN PRESCRIPTION MONITORING TO

EVALUATE THE EFFECTIVENESS OF FFR RIPARIAN PRESCRIPTIONS

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For: FFR Riparian Scientific Advisory Group

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INTRODUCTION

This document presents a strategy to evaluate the performance of the riparian management prescriptions recently adopted as Washington Forest Practices Rules (WFPB, 2001). It also presents proposed study designs for several individual projects identified in the strategy. This strategy, and the proposed projects that support it, have been prepared for the Timber, Fish and Wildlife (TFW) Cooperative Monitoring, Evaluation and Research Committee (CMER), which was established by the state Forest Practice Board to "conduct research, validation and effectiveness monitoring to facilitate achieving the resource objectives" and to "advance the science needed to support adaptive management" for state forest practices rules (WFPB, 2001).

The introduction section of this document provides a brief description of the riparian prescriptions and an overview of the scientific assumptions and uncertainties associated with the prescriptions. The second section presents a riparian monitoring strategy or framework to address these areas of uncertainty and provide information needed to conduct adaptive management. The remainder of the document consists of sections that present the study designs for several projects that are identified in the strategy. Other projects identified in the strategy will be developed and presented for review at a later date.

Background on the FFR Riparian Prescriptions

In the spring of 2000, the Washington Forest Practices Board adopted emergency rules designed to maintain and restore salmonid populations and to meet the requirements of the federal Clean Water Act (Washington Forest Practices Board, 2000). These rules were based on the recommendations of the Forests and Fish Report (FFR), the product of negotiations between the National Marine Fisheries Service, US Fish and Wildlife Service, US Environmental Protection Agency, timber landowners, state resource agencies, and some tribal and local governments (USFWS et al., 1999). A similar rule package was permanently adopted in May of 2001 (WPFB, 2001). The resource goals of FFR are to meet water quality standards, provide harvestable levels of fish, and to maintain viable populations of stream associated amphibians (SAAs). The riparian prescriptions are a key element of the FFR strategy to achieve these three goals. The FFR riparian prescriptions are designed to achieve the resource goals by maintaining important ecological functions provided by riparian forests, including LWD recruitment, shade to control stream temperature, sediment filtering/bank stability, and litter fall. These ecological functions are the basis of the functional objectives of the FFR riparian prescriptions:

- providing cool water (by maintaining shade, groundwater, flow and other watershed processes),
- providing complex in- and near-stream habitat (recruiting LWD and litter), and
- providing clean water and substrate (minimizing management-induced fine and coarse sediment input and protecting stream-bank integrity).

Some measurable performance targets have been adopted to provide a benchmark to evaluate effectiveness of FFR riparian prescriptions in meeting functional objectives (FFR, Schedule L1).

The FFR riparian prescriptions are designed to achieve the resource goals and functional objectives through a vegetative buffering strategy. The buffering strategy varies depending on whether the streams are fish-bearing (Type F) or non-fish-bearing (Type N), and whether they are on the east-side or west-side of Cascade Mountains. Within these divisions, the buffering requirements vary depending on site-specific factors. In some situations landowners can select different buffering options, and special provisions to reduce costs apply to small landowners.

Type F Riparian Prescriptions

The Type F riparian prescriptions establish Riparian Management Zones (RMZs) consisting of three bands parallel to the stream, a Core Zone nearest to the water, an Inner Zone, and an Outer Zone furthest from the water. The width of the zones varies, depending on the region, stream width, site productivity and timber habitat type. Timber harvest is not allowed within the Core Zone, and disturbance of vegetation is limited to road crossings and yarding corridors. Timber management is allowed within the Inner Zone, provided that leave tree and shade requirements are met. On the west-side (and the east-side High Elevation Zone), the stand remaining after harvest must be on a trajectory to meet the appropriate desired future stand condition (DFC) at age 140. The prescriptions for the west-side provide two options for harvest in the Inner Zone:

1. removal of the smallest trees throughout the inner zone (thinning from below), or
2. harvest working in from the outside of the inner zone (leave trees closest to water).

In the east-side Ponderosa Pine and Mixed Conifer Zones, thinning in the Inner Zone can occur when the stand reaches a threshold basal area. Post-harvest basal area must remain within a specified target range and a minimum number of leave-trees must be left. A minimum leave-tree requirement must be met in the Outer Zone, also. Other provisions allow for thinning of overstocked east-side RMZs. Both west-side and east-side Type F riparian prescriptions contain shade retention provisions designed to prevent summer water temperatures in adjacent fish-bearing streams from exceeding water quality standards. Landowners determine the amount of shade necessary to meet the water temperature standards using the temperature prediction methodology in the Forest Practices Board manual (WFPB, 2001) and leave enough trees within 75 feet of the stream to provide necessary shade. Trees in yarding corridors or road crossings are exempt from the shade requirement. In bull trout habitat management areas (the bull trout overlay), all available shade within 75 ft of the stream must be left.

Type N Riparian Prescriptions

The FFR prescriptions for non-fish-bearing (Type N) streams are designed to achieve the FFR goals (meeting water quality standards, maintaining viability of stream associated amphibians, and maintaining harvestable populations of fish in downstream Type F streams connected to the Type N stream network) and functional objectives related to LWD input, litter fall, shade/stream temperature and sediment input. The buffering strategy for Type N streams differs depending upon whether the stream has perennial flow (Type Np) or is seasonal (Type Ns). Leave trees are required along the perennial portions of the Type N stream network, but the prescription varies by region. On the west-side, a ‘clear-cut’ strategy is prescribed. Portions of riparian stands can be clear-cut to the stream, but other areas meeting a set of ‘sensitive site’ criteria are protected with 50 ft wide no-cut buffers. A minimum of 50% of the stream length is buffered. The distribution of buffered and harvested reaches will depend on the location of sensitive areas and other priority features. On the east-side, the ‘partial-cut’ strategy’ is the main harvest option. The partial-cut strategy allows thinning within 50 ft of a Type 4 stream, provided that the appropriate basal area requirement and leave tree requirements are met. In addition, landowners have the flexibility to choose a ‘clear-cut’ option or to clear-cut portions of a partial-cut unit, provided the clear-cut area does not exceed 30% of the stream length in the unit, and does not exceed 300 ft of continuous length. In addition, a two-sided no-harvest 50 ft buffer equal in length to the clear-cut portions of the unit must be left. A 30 ft wide equipment limitation zone on both perennial and seasonal streams, where use of yarding equipment is limited and soil disturbance and sediment delivery must be mitigated.

Overview of Uncertainties and FFR Riparian Adaptive Management

There is a substantial amount of uncertainty concerning the response of riparian stands to the FFR riparian management strategy, as well as whether the strategy will be successful in achieving FFR functional objectives and research goals. Some major uncertainties and assumptions in the FFR riparian prescriptions are identified in Table 1. An important goal of the FFR riparian monitoring strategy is to address, and reduce, major sources of uncertainty.

Table 1. FFR riparian management uncertainties, assumptions and research/monitoring issues.

Uncertainties	Assumptions	Effectiveness Questions	Validation Questions
1. Riparian Management Activity. The amount of riparian management activity occurring annually, the distribution of activity in different areas of the stand and the type of prescriptions being used is not currently being documented.	The scale and distribution of riparian management activity doesn't influence effectiveness.	How much FFR riparian management activity is occurring, which prescriptions are being used, and are there regional patterns?	
2. Buffer Integrity. There is uncertainty about mortality rates of leave trees following harvest of adjacent timber, thinning within the buffer and creation of yarding corridors.	Tree mortality rates following harvest will not increase enough to affect stand trajectory or function.	What are leave tree mortality rates in FFR buffers and what is the magnitude and duration of change in mortality associated with the FFR riparian prescriptions?	How does change in mortality rate affect functions?
3. Stand Trajectory. It is uncertain if riparian stands will respond as expected to thinning and develop towards their desired future condition target (west-side) or remain within appropriate ranges for their disturbance regimes (east-side).	Managed riparian stands will grow and develop as expected and achieve the desired conditions.	How do managed riparian stands develop and change over time, and what is the magnitude and duration of change in stand condition and trajectory associated with the FFR riparian prescriptions?	What are appropriate east- and west-side stand targets?
4. Riparian Functions. There is uncertainty about the magnitude and duration of change in shade, LWD recruitment, litter fall, soil disturbance following harvest, and whether the FFR performance targets will be achieved.	FFR buffers will provide levels of functions that meet FFR riparian functional objectives and performance targets.	What level of shade, LWD recruitment, litter fall and soil disturbance are associated with managed stands, what is the magnitude and duration of change in function associated with the FFR riparian prescriptions, and are performance targets met?	What level of function is needed to protect aquatic resources and what are appropriate functional performance targets?
5. Aquatic Resource Response. There is uncertainty about the response of aquatic resources to the riparian strategy and if FFR resource goals will be achieved (i.e. water quality standards are met, stream associated amphibian populations remain viable, and fish populations recover to harvestable levels).	The FFR riparian buffers will produce aquatic conditions that achieve the FFR resource goals for water quality, stream-associated amphibians and fish.	How do aquatic resource conditions respond to the FFR riparian management strategy and are water quality, stream-associated amphibian viability, fish habitat/population goals achieved?	What are the causal relationships between riparian management and aquatic resource response?
6. Alternative Prescriptions. There is uncertainty whether the current prescription strategy is the best approach, or whether other prescriptions would be more effective, in terms of both performance and cost.	FFR prescriptions are effective and efficient means of protecting aquatic resources.	How does cost and effectiveness of alternative prescriptions compare with FFR prescriptions?	

INTEGRATED SAMPLING STRATEGY

Addressing all of these major areas of uncertainty is beyond the scope of a single project, so an integrated strategy consisting of a series of projects is proposed. Figure 1 shows the areas of uncertainty, the projects proposed to address them, and the products applicable to adaptive management. Shaded areas indicate elements addressed by projects described in this document.

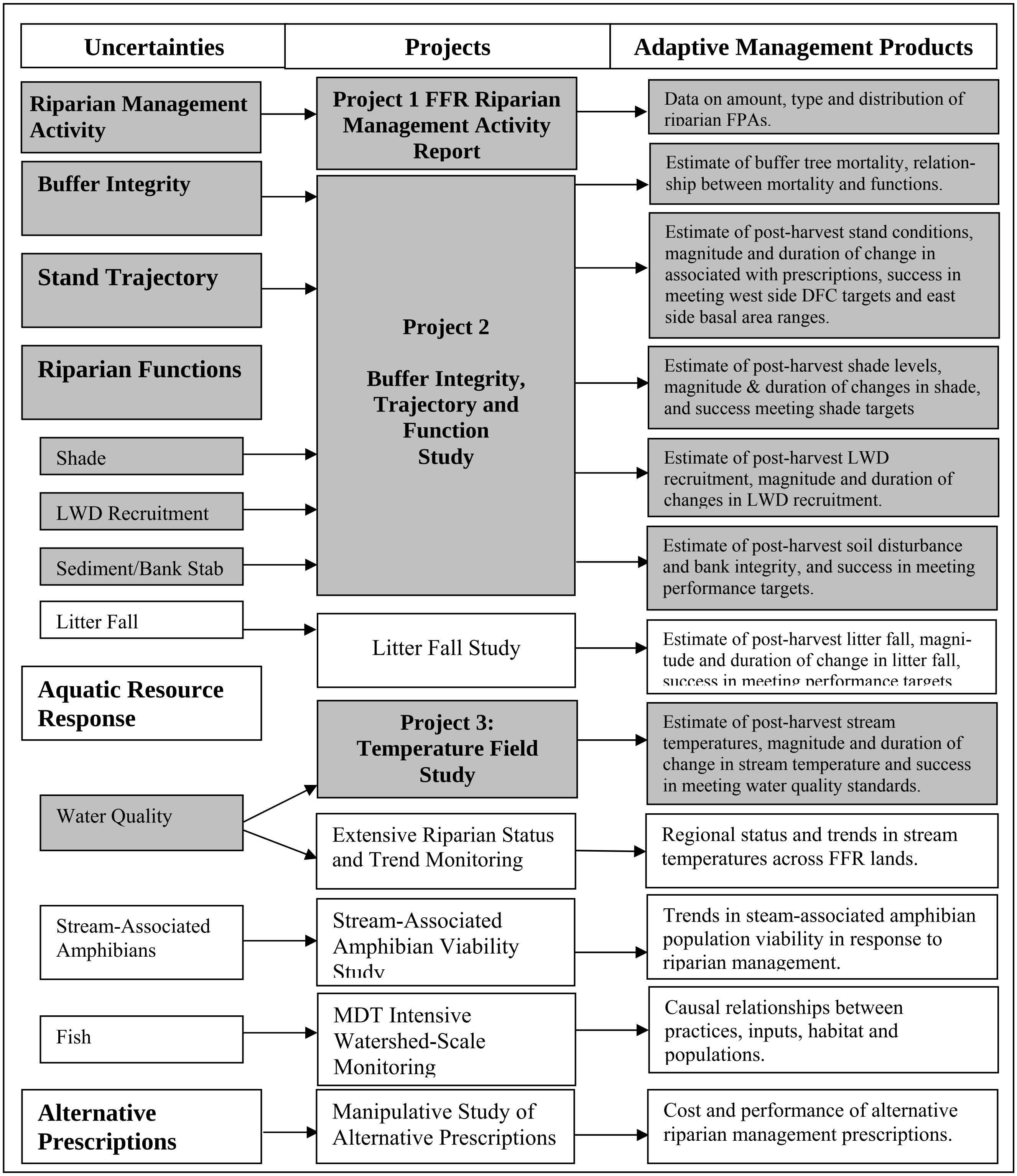

Figure 1. Projects and products to address uncertainties associated with FFR riparian strategy.

Project 1, riparian management activity report, (described in this document) is an office project designed to document FFR riparian management activity. It will address uncertainty about the level of activity, the type of prescriptions being used, and patterns in regional distribution.

Project 2, the buffer integrity, trajectory and function study (described in this document) is a combined remote sensing/field project designed to address questions concerning buffer tree mortality, stand development and trajectory, and changes in riparian functions including shade, LWD recruitment and soil disturbance. It will reduce short-term uncertainty associated with the FFR riparian prescriptions by evaluating whether buffers maintain their integrity, whether stands develop on the expected trajectory, how functions change in response to riparian management, and whether functional performance targets are met.

Project 3, stream temperature field study (described in this document), is a focused field study designed to address uncertainty concerning the response of stream temperature to the riparian management prescriptions, and to evaluate whether water quality standards are being met.

Other CMER studies will address the other areas of uncertainty identified (Table 1 and Figure 1). A briefing paper is being prepared to evaluate approaches to address litter fall issues. If an effectiveness monitoring approach is taken, a litter fall component may be added to Project 3. If validation research is needed, a separate research proposal will be developed. Status and trends in stream temperature and riparian stand condition on the landscape scales will be addressed by an extensive riparian monitoring project. A pilot project to test the proposed approach for documenting trends in stream temperature across FFR lands is underway (MDT, 2002). An amphibian viability study is proposed to address uncertainty about viability of stream-associated amphibians on FFR lands. Other intensive studies will be needed to address the response of fish habitat and populations to changes in inputs associated with the riparian prescriptions, including downstream effects in Type F streams from upstream management of Type N riparian areas. One approach to address the response of fish to changes in riparian management is the intensive watershed-scale monitoring project proposed by the monitoring design team (MDT 2002). If carefully designed, these water quality, stream associated amphibian and fish response studies will also provide data that can be used to validate or refine the function performance targets. As information on the performance of FFR prescriptions becomes available from all these projects, intensive manipulative studies will be designed and implemented to address the fifth area of uncertainty, the potential of alternative prescriptions to improve effectiveness and reduce cost. These studies will be used for two purposes: to test the effectiveness of alternative prescriptions in addressing situations where performance needs to be improved, and to test alternative prescriptions to identify management practices that are less costly or cumbersome to implement.

The remainder of this document presents study plans for three projects in the proposed strategy:
Project 1: Riparian Management Activity Report.
Project 2: Buffer Integrity, Trajectory and Function Study.
Project 3: Stream Temperature Field Study.

Linkages between these projects are illustrated in Figure 2. The FPARS database is a key link. It provides the pool of potential sites used to select a random sample for Project 2. Analysis of FPARS data in Project 1 will also provide context for interpreting effectiveness monitoring results and making inferences by documenting the frequency and distribution of riparian practices across the FFR landscape.

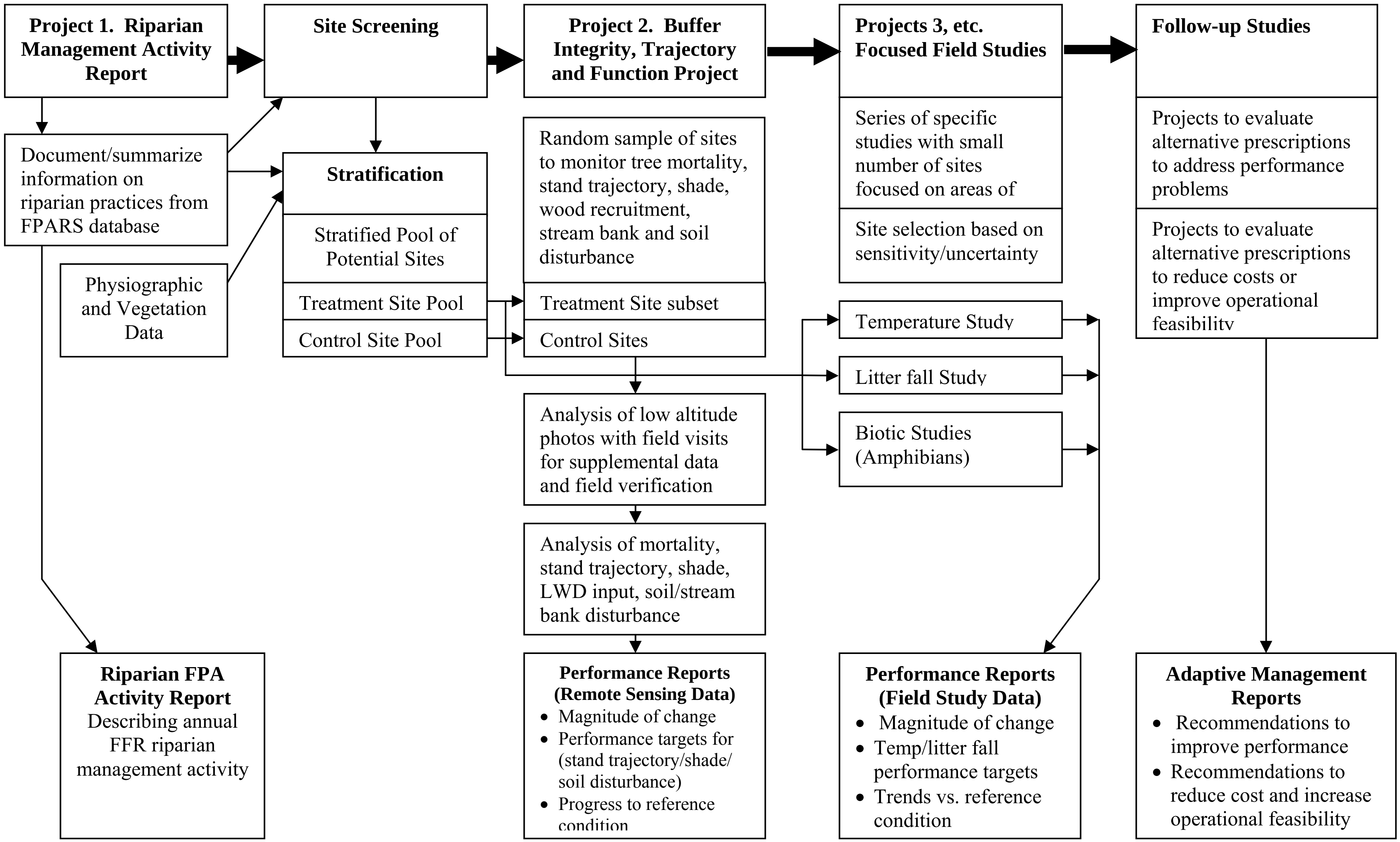

Figure 2. Integrated sampling strategy for monitoring FFR riparian prescriptions.

PROJECT 1. FFR RIPARIAN MANAGEMENT ACTIVITY REPORT

Objective

The purpose of this project is to document riparian management activity occurring on FFR lands. The project has two objectives:

1. Determine the total amount of riparian forest practice applications approved annually, determine the frequency that different types of prescriptions are being used, and identify regional patterns in activity levels and prescription options.
2. Create a pool of potential 'treatment sites' for evaluating riparian prescription effectiveness (Project 2).

In order to evaluate the potential effects of FFR riparian prescriptions (both positive and negative) on a landscape scale it is useful to document the number and acreage of forest practices applications for various prescription types and their distribution across different regions of the state. Currently there is no procedure or mechanism for assessing the amount of activity occurring under various prescriptions options. This leads to uncertainty concerning the magnitude of FFR riparian management and the preference of landowners for different riparian management options.

Critical Questions and Monitoring Metrics

This project will answer the critical question *"What is the extent and distribution of riparian management activity on FFR lands, which prescriptions are being used, and what are the site characteristics of the areas being managed?"*

The monitoring metrics are the annual number of riparian forest practice applications, sorted by stream type, prescription type, and DNR region (Table 2).

Table 2. Critical question and monitoring metrics for Objective 1.

Objective	Critical Question	Monitoring Metric	Analysis
Characterize FFR riparian management activity.	What is the extent and distribution of riparian management activity on FFR lands, which prescriptions are being used, and what are the site characteristics of the areas being managed?	The annual number of riparian FPAs by stream type, prescription type, and DNR region.	Monitoring Metric Estimation

Data Source and Analysis

This question will be answered by compiling data on riparian forest practices from the DNR Forest Practice Application Review System (FPARS) database and associated maps and tables. The project will be implemented in cooperation with DNR forest practices division staff responsible for maintaining FPARS. The FPARS database will be queried quarterly to identify FPAs adjacent to Type F or N streams that involve riparian management prescriptions. This will be done either by DNR or CMER staff. -The individual forest practice application is the unit of analysis. This data will be used to determine the total number of riparian Forest Practice Applications approved each year FPAs will be sorted by water type (Type F or N), prescription type (harvest option) and DNR region. This information will be assembled in a database that characterizes the types and locations of riparian management activities.

Products and Applications

Results of this analysis will be presented in an annual report that tracks trends in the number, type and distribution of FFR riparian management activity. The report will be produced by DNR, and/or CMER staff or a contractor. Information on the amount and distribution of FFR riparian management activity and the frequency with which various harvest options are selected by landowners will be useful in designing future riparian research and monitoring project and interpreting and extrapolating monitoring results.

A random number will also be assigned to each riparian forest practice application in order to produce a pool of potential monitoring sites for Project 2. The procedures for screening this random list of riparian practices to identify a set of riparian effectiveness monitoring is described in further detail in the section on site selection in the description of Project 2. A more detailed set of information on will be collected on a subset of randomly ordered sites during the screening process for Project 2 based on maps, worksheets and photos. This more detailed information will also be included in the annual report on riparian management activity.

PROJECT 2: BUFFER INTEGRITY, TRAJECTORY AND FUNCTION STUDY

Purpose

The purpose this project is to generate data needed to address uncertainties associated with the FFR riparian prescriptions related to buffer tree mortality, stand development and trajectory, and changes in riparian functions, i.e. levels of shade, woody debris recruitment, and soil and stream-bank disturbance. The project has five goals:

1. Evaluate the mortality rates of trees in FFR riparian buffers.
2. Evaluate riparian stand development and trajectory following application of the FFR prescriptions and determine if stands on trajectory to DFC (west-side) or are within the specified range (east-side).
3. Evaluate the effects of FFR riparian prescriptions on shade and determine if shade requirements specified in the forest practices rules are met.
4. Evaluate the effects of FFR riparian prescriptions on woody debris recruitment.
5. Evaluate the effects of FFR riparian prescriptions on soil disturbance and stream bank integrity, and determine if FFR performance targets are achieved.

It is proposed to accomplish these five goals in a single study rather than five separate studies because each requires a similar sampling strategy and site selection process. Consequently, significant savings can be achieved by integrating these efforts into one project to eliminate redundancy in site selection and data collection efforts.

Goals, Objectives and Critical Questions

This section discusses how each of the five goals will be accomplished. The discussion for each goal identifies a set of objectives, critical questions, hypotheses, monitoring metrics and analytical procedures.

Goal 1. Evaluate Mortality Rates of Trees in Riparian Buffers

This component of the study addresses uncertainty concerning the survival of leave trees in the riparian buffer. This is an important area of uncertainty because past research has indicated that leave trees in riparian buffers can suffer high rates of mortality following harvest of the adjacent stands in some situations due to wind-throw, damage incurred during harvest, and other factors (Andrus and Froelich, 1986; Sinton, 1996; Grizzel and Wolff, 1998; Grizzel et al., 2000). The magnitude of post-harvest mortality, and the processes that cause it, can vary depending on the region, site conditions, and stand type. Loss of buffer trees can impair riparian functions, reducing shade and long-term recruitment of LWD of sufficient size to provide channel and habitat-forming functions (Grizzel et al., 2000). Uncertainty is augmented by the fact that the designs of the FFR Type F and N prescriptions are new and untested, and the response of these buffers to mortality factors such as wind and edge effects across the highly variable conditions on FFR lands is unknown. The FFR riparian prescriptions do not incorporate specific procedures to identify sites sensitive to wind-throw or reduce wind-throw potential at sensitive sites. The FFR riparian strategy is based on the assumption that mortality rates following harvest will not increase to the extent that stand trajectory or riparian functions are adversely affected and that stands will remain relatively healthy and wind-firm.

Objectives

Uncertainties and assumptions related to buffer tree mortality will be addressed by accomplishing the following objectives:

1. Obtain an unbiased estimate of post-harvest buffer tree mortality in FFR riparian buffers.
2. Evaluate the magnitude and duration of post-harvest buffer tree mortality in FFR riparian buffers relative to un-harvested control sites.
3. Identify site or tree attributes that influence buffer tree mortality rates.
4. Estimate the effect of buffer tree mortality rates on stand condition, trajectory, shade, and woody debris recruitment.

A critical question has been framed for each objective. Table 3 lists the questions, along with the analytic approach and data required. Question 1.1 provides an estimate of variability in mortality rates associated with FFR riparian prescriptions using post-harvest data from treatment sites. Question 1.2 provides an estimate of the magnitude and duration of changes in tree mortality relative to untreated control sites using a treatment-control design. Question 1.3 identifies relationships between tree mortality rates and tree and site attributes using covariate data from study sites. Question 1.4 examines relationships between buffer tree mortality rates and the stand trajectory or level of riparian functions using data and analyses described for goals 2-4.

Table 3. Critical questions, analytic approach and data required to evaluate buffer tree mortality.

Critical Question	Analytic Approach	Data Requirements
1.1. What are the mortality rates for trees in riparian buffers following application of the FFR riparian prescriptions?	Metric estimation. Estimate leave tree mortality rates for FFR riparian buffers and calculate descriptive statistics for each stratum sampled.	Post-harvest treatment site tree mortality data.
1.2. What is the magnitude and duration of change in mortality rates associated with the FFR riparian prescriptions compared to untreated control sites?	Hypothesis testing. Use paired sample test to test H_o= There is not a significant difference in tree mortality rate between riparian buffers and untreated control sites.	Tree mortality data from treatment and control sites for the post harvest sampling intervals.
1.3. What site or tree attributes influence buffer tree mortality rates?	Exploratory Covariate Analysis. Use regression or graphical analysis to identify relationships between site and tree attributes and mortality rates.	Post harvest treatment site tree mortality data and site and tree covariate data.
1.4. How does buffer tree mortality rate affect stand condition, stand trajectory, shade and woody debris recruitment levels and probability of achieving performance targets.	Regression Analysis/Hypothesis Testing. Use regression analysis evaluate relationships between tree mortality rates and stand attributes, shade and woody debris recruitment rates. Use a two-sample t test to test the hypothesis H_o= there is not a significant difference in tree mortality between sites meeting performance targets and those that do not.	Post harvest treatment site tree mortality rates and data on stand attributes and trajectory, shade levels and targets, and woody debris recruitment rates.

Monitoring Metrics

The following tree mortality rate monitoring metrics will be used in these analyses:

1. Percent mortality in trees/acre per sampling interval
2. Percent mortality in trees/acre/year per sampling interval
3. Cumulative percent mortality in trees/acre/year over post-harvest period
4. Percent mortality in basal area/acre per sampling interval
5. Percent mortality in basal area/acre/year per sampling interval
6. Cumulative percent mortality in basal area/acre/year for post-harvest period

Monitoring metric 1, percent mortality in trees/acre per sampling period will be estimated for each treatment and control site for each post harvest sampling interval by totaling the number of trees that died or are missing from the site since the previous sampling event, dividing them by the total number of live trees at the beginning of the sampling interval, and dividing by the plot area in acres. Monitoring metric 2, percent mortality in trees/acre/year per sampling period will be calculated by dividing metric 1 by the number of years since the previous sampling event. Monitoring metric 3, the cumulative post harvest percent mortality/acre/year will be calculated by totaling the number of trees that have died for all post-harvest sampling intervals, dividing by the total number of live trees immediately after harvest, dividing by the plot acreage, and dividing by the number of years since the previous sampling event.

Monitoring metric 4, percent mortality in basal area/acre per sampling period will be estimated for each treatment and control site for each post harvest sampling interval by totaling the basal area of trees that died or are missing from the site since the previous sampling event, dividing them by the sum of the that number plus the basal area of live trees at the end of the sampling interval, and dividing by the plot area in acres. Monitoring metric 5, percent mortality in basal area/acre/year per sampling period will be calculated by dividing metric 4 by the number of years since the previous sampling event. Monitoring metric 6, the cumulative post harvest percent mortality in basal area/acre/year will be calculated by totaling the basal area of trees that have died in all post-harvest sampling intervals, dividing by the sum of that number plus the basal area of live trees at the current sampling event, dividing by the plot acreage, and dividing by the number of years since the previous sampling event.

Analytic Procedures

Question 1.1. Question 1.1 will be answered using post-harvest data from treatment sites where the riparian prescriptions are applied to estimate the monitoring metrics following each sampling event at each site. The mean values for each monitoring metric will be calculated for each sampling stratum, along with the standard deviation and the 95% confidence interval around the mean. Mortality rates from different sampling intervals will be examined to identify patterns in post-harvest mortality rates over time.

Question 1.2. Question 1.2 will be answered using post-harvest data on tree mortality rates from treatment sites where the riparian prescriptions are applied as well as matching data for the same time period from untreated control sites. Hypothesis 1.1 will be tested beginning with data collected during the survey conducted two years post harvest. For strata where it was possible to pair each treatment site with a control site, the difference in each tree mortality rate monitoring metric *(m)* between the treatment and control pair will be estimated as:

$$\lambda = m_{treatment} - m_{control}\,.$$

A paired sample test (or its nonparametric equivalent if appropriate) will be used to test the one-sided null hypothesis:

$$H_o : \overline{\lambda} \le 0,$$

$$H_A : \overline{\lambda} > 0,$$

For strata where it was not possible to pair all treatment sites with a control site, a two sample t-test (or its nonparametric equivalent if appropriate) will be used to test the hypothesis that there is no difference in the mean *m* between the sample of treatment sites and the sample of control sites. The one-sided null hypothesis tested will be:

$$H_o : \overline{m}_{treatment} \leq \overline{m}_{control},$$
$$H_A : \overline{m}_{treatment} > \overline{m}_{control}.$$

If there is a significant difference in tree mortality rates between the treatment and control site populations for any stratum, the difference between the means will be computed to determine the magnitude of the effect. By repeating the procedure for each sampling interval, the duration of the effect will be determined and variation in the magnitude of change over time will be documented.

Question 1.3. Exploratory regression analysis will be done to evaluate potential relationships between site level mortality rates and various continuous site attribute covariates identified in Table 4. Graphical analysis will be done for categorical covariates. To evaluate potential relationships between individual tree characteristics and mortality rates, exploratory regression analysis (or graphical analysis) will be used to examine attributes associated with individual trees such as species, canopy class, distance from edge of stream or buffer, etc. These procedures will be used to identify potential relationships of interest. This information can be used to build hypotheses for further testing and to design follow-up studies.

Question 1.4. Determining the effect of tree mortality rates on stand condition, trajectory and function is a critical step in interpreting the significance of any changes observed. This question will be answered by comparing data on post-harvest tree mortality rates at treatment sites (monitoring metrics 1-6 above) with data on changes in stand condition and stand trajectory performance targets obtained from goal 2, data on shade levels and achievement of shade requirements obtained from goal 3, and data on woody debris recruitment obtained from the analysis for goal 4. Regression analysis will be used to evaluate the strength of relationships between tree mortality rates and stand condition metrics and post-harvest shade levels. Future woody debris recruitment rates and characteristics will be modeled using FVS and RAIS to estimate the effects of observed stand mortality on woody debris recruitment. The effect of buffer tree mortality on the ability of stands to meet performance targets will be done in a series of separate tests for the DFC performance target, east-side basal area ranges, and shade requirement targets. Data from Type F sites on the west-side or east-side high elevation zone will be used to test the effect of tree mortality on the ability of stands to remain on trajectory to meet DFC performance targets. Data from Type F sites in the east-side Ponderosa Pine or Mixed Conifer Timber Habitat types will be used to test the effect of tree mortality on maintaining stands within east-side basal area ranges. Data from all sites will be used to determine if shade requirements are being met. In each analysis, sites will be sorted into two categories, those that meet performance targets and those that do not. Then a two-sample t-test (or the non-parametric equivalent) will be used to test whether there is a significant difference in the mean tree mortality metrics, *m*, between the sites that meet the performance target and those that do not. A two-sample t-test with a one-sided alternative hypothesis will be used to test:

$$H_o : \overline{m}_{on-t\arg et} = \overline{m}_{off-t\arg et}.$$
$$H_A : \overline{m}_{off-t\arg et} < \overline{m}_{on-t\arg et}.$$

If the null hypothesis is not rejected at alpha = 0.10, a power analysis will be done to determine the size of the differences for the test parameters necessary to be detected with power ≥ 0.80.

Table 4. List of site-level covariates.

Covariate	Data	Variable Type	Source	Stream Type	Objective				
					Buffer Tree Mort-ality	Stand Traj-ectory	Shade	Wood Recruit-ment	Soil Distur-bance
Management Covariates									
Regulatory RMZ width	Minimum required width of core and inner zone (ft)	Categorical	FPA[7]	F	X	X	X	X	X
RMZ width actual	Mean width of core & inner zone (ft)	Continuous	LAP[8]	F	X	X	X	X	X
Inner zone harvest option	Thin below, Leave trees close to water, no cut	Categorical	FPA	F	X	X	X	X	X
Basal area target	Regulatory target (ft^2/acre)	Categorical	FPA	F	X	X	X	X	
Yarding corridor	Percentage of stream length	Continuous	LAP	F	X	X	X	X	X
Bull trout overlay	Yes-No	Categorical	FPA	F	X	X	X	X	
Type N Harvest	Partial-cut, Clear-cut	Categorical	FPA	N	X	X	X	X	X
Percent of stream length buffered	Percentage of stream length	Continuous	LAP	N	X	X	X	X	
Yarding method	Skyline, highlead, rubber-tired skidder, tractor, helicopter	Categorical	FPA	all	X	X	X	X	X
RMZ length	Stream length (ft)	Continuous	LAP	all	X	X			
Physical/Biological Covariates									
Dominant species	Species with greatest basal area	Categorical	LAP	all	X	X	X	X	
Percent conifer	Percentage of conifer basal area	Continuous		all	X	X	X	X	
Mean basal area	Mean basal area/acre	Continuous	Calc	all	X	X	X	X	
Density	TPA, relative density	Continuous	LAP	all	X	X	X	X	X
Stand Age	<80, 80-120, 120-200, >200	Categorical	Field	all	X	X	X	X	
Landform	Floodplain, low terrace, high terrace, hill-slope [1]	Categorical	LAP	all	X	X	X	X	X
Physiographic region	EPA Level III eco-regions [2,3]	Categorical	GIS	all	X	X	X	X	X
Aspect	North, East, South, West	Categorical	LAP	all	X	X	X	X	
Elevation	Elevation of plot	Continuous	GIS	all	X	X	X	X	
Hill-slope gradient	Percent slope	Continuous	LAP	all	X	X	X	X	X
Precipitation	State precipitation isohyetals [4]	Categorical	GIS	all	X	X	X	X	X
Geology group	19,from WDNR geology units [5]	Continuous	GIS	all	X	X			X
Channel width	Mean bankfull width	Continuous	LAP	all	X	X	X	X	
Channel type	6 types [6]	Categorical	Field	all	X				
Channel gradient	Mean channel gradient	Continuous	LAP	all	X				
Valley form (confinement)	Ratio of channel to valley width	Continuous	LAP	all	X	X	X	X	X
Site Index (field)	Estimated height at age 100	Continuous	Field	all	X	X	X	X	
Surficial material	State soil mapping unit	Categorical	GIS	all	X	X			X
Soil Depth	Inches, from state soil survey	Continuous	GIS	all	X	X			X

[1]Rot, 1995; [2] Omernik and Gallant, 1986; [3] Pater et al., 1997; [4] Miller, J. et al. 1973; [5] Sasich, 1998; [6] Montgomery and Buffington, 1993, 1997; [7] FPA=Forest Practice Application; [8] LAP = Low altitude aerial photography

Goal 2. Riparian Stand Development and Trajectory

This component addresses the high level of uncertainty concerning riparian stand growth and development trajectory following application of the FFR riparian prescriptions. Much of this uncertainty is due to the fact that past research has focused on upland stands. Limited research on riparian systems indicates that riparian stands are typically more dynamic and complex that adjacent uplands, due to variability in site conditions and a higher frequency of disturbance and a more complex set of disturbance agents (Agee, 1988). Riparian stand structure and disturbance regime varies with factors such as stream size and landform (Agee, 1988; Rot et al., 2000). Disturbance processes create and alter habitats, creating a patchwork of disturbance-related habitats and triggering a complex forest community response that can be difficult to predict (Agee, 1988). Gregory (1997) maintains that:

> *"one of the major limits of current riparian management is the lack of information on the structure and stand dynamics of riparian forests… almost all considerations of riparian forest dynamics- regeneration, growth, survival, mortality, snag development, downed wood delivery, community succession and rates of succession- are based on assumptions derived from upslope forests".*

The effect of FFR riparian prescriptions on stand growth and development are largely based on model projections and professional judgment (Fairweather, 2001; Schuett-Hames, 2002). This issue is important because the FFR Type F riparian strategy prescribes thinning in the inner zone to increase tree growth rates, favor conifer species, and create stands that emulate mature stand conditions (west-side DFC) or are similar to stands historically associated with natural disturbance regimes (east-side). The west-side DFC targets and east-side basal area ranges have been established to measure effectiveness in achieving these goals. The potential effects of the various Type N riparian management strategies on stand development are also unknown.

Objectives

The uncertainties and assumptions related to stand development and trajectory will be addressed by accomplishing the following objectives:

1. Obtain an unbiased estimate of post-harvest stand characteristics in FFR riparian buffers and monitor changes over time following application of the prescriptions.
2. Evaluate the duration and magnitude of post-harvest changes in stand attributes associated with the prescriptions relative to un-harvested control sites.
3. Determine the proportion of west-side Type F treatment sites (and east-side high elevation sites) that remaining on trajectory to meet DFC basal area performance targets over time.
4. Determine the proportion of east-side Type F treatment sites that remain within east-side basal area ranges over time.
5. Identify site and stand attributes that influence stand condition and trajectory.

A critical question has been framed for each objective. Table 5 lists the questions, along with the analytic approach and data required. Question 2.1 provides an estimate of variability in stand conditions associated with FFR riparian prescriptions using post-harvest data from treatment sites. Question 2.2 provides an estimate of the magnitude and duration of changes in stand condition associated with the prescription treatments relative to untreated control sites using a treatment-control design. Question 2.3 and 2.4 estimate the proportion of treatment sites meeting DFC performance targets and east-side basal area ranges, respectively. Question 2.5 identifies relationships between stand condition and site attributes using covariate data from study sites.

Table 5. Critical questions, analytic approach and data required to evaluate changes in riparian stand development and trajectory in FFR riparian buffers.

Critical Question	Analytic Approach	Data Requirements
2.1. What are the characteristics and trajectories of riparian stands following application of the FFR riparian prescriptions?	Metric estimation. Estimate stand condition metrics for FFR riparian buffers and calculate descriptive statistics for each stratum sampled.	Treatment site stand data from post-harvest sampling events.
2.2. What is the magnitude and duration of change in riparian stand attributes following application of the FFR riparian prescriptions compared to untreated control sites?	Hypothesis testing. H_o= There is not a significant difference for the change over time in stand composition, basal area, density, percent conifer, dominant tree species, height, and quadratic mean diameter between riparian buffers and untreated control sites.	Treatment and control site stand attribute data from post- harvest sampling events.
2.3. What proportion of sites meet the west-side (and east-side high elevation) riparian DFC performance targets for Type F streams?	Metric estimation. The percentage of sites meeting the west-side (and east-side high elevation) riparian DFC performance targets for Type F streams.	Post harvest treatment site stand data and updated DFC model projections (west-side/ eastside HEZ).
2.4. What proportion of east-side treatment sites meets the east-side riparian stand condition ranges for Type F streams?	Metric estimation. The percentage of east-side treatment sites meeting the east-side disturbance regime basal area ranges for Type F streams.	Post harvest treatment site basal area data (eastside).
2.5 What site attributes influence stand development and trajectory?	Exploratory Covariate Analysis. Use regression or graphical analysis to identify relationships between stand development/trajectory monitoring metrics and site attribute covariates.	Post harvest treatment site stand data and site covariate data.

Monitoring Metrics

The following stand condition monitoring metrics will be used in these analyses:

1. Basal area per acre (live conifer, live hardwood, live total, snags)
2. Mean tree diameter (live conifer, live hardwood, live total, snags)
3. Quadratic mean diameter of trees (live conifer, live hardwood, live total, snags)
4. Density in trees/acre (live conifer, live hardwood, live total, snags)
5. Percentage of live conifer (basal area and trees per acre)
6. Dominant tree species (basal area)
7. Mean overstory tree height
8. Percentage of west-side Type F sites on trajectory to meet DFC basal area targets
9. Percentage of east-side Type F sites remaining within specified basal area ranges

In order to calculate basal area, diameter and quadratic mean diameter, the diameter at breast height (DBH) for individual trees must be known. Since this parameter cannot be measured directly from aerial photos, the DBH for each tree will be estimated using species-specific regression equations developed for each site. The equations will correlate field DBH measurements collected at field verification plots, with photo measurements of tree height and crown area (Grotefendt and Pickford, nd). This procedure worked well for predicting DBH in old-growth forests in southeast Alaska, and is expected to perform better for second growth stands (R. Grotefendt, personal communication). Once tree diameter estimates are available, the basal area (BA) of each tree ≥ 4 in will be calculated using the formula: BA (ft^2) = 0.005454

dbh^2 (in). Then the trees for each site will be sorted into four groups: live conifers, live hardwoods, all live trees, and all snags.

Monitoring metric 1, basal area per acre, will be calculated for each of the four groups by summing the basal area of all trees in the group and dividing by the total plot acreage. Basal area per acre will also be calculated by zone (core, inner, and outer) for Type F prescriptions.

Metric 2, mean diameter ($\overline{dbh}$) will be calculated by summing the diameters of all trees in the group and dividing by the total number of trees. Metric 3, quadratic mean diameter (QMD) will be calculated using the following formula:

$$\text{QMD} = \sqrt{\frac{\overline{BA}}{0.005454}}\ .$$

Metric 4, density in trees per acre (TPA), will be calculated by tallying the number of trees in each group and dividing by the total plot acreage. Metric 5a, percentage of conifer by basal area, will be calculated by dividing live conifer basal area/acre by total live basal area/acre. Metric 5b, percentage of conifer by trees/acre will be calculated by dividing live conifer trees/acre by total live trees/acre. Metric 6, dominant tree species, will be determined by summing basal area by species and identifying the species with the greatest basal area. Metric 7, mean overstory tree height, will be calculated by averaging the height measurements of live trees in the dominant and co-dominant size classes.

Metric 8, percentage of Type F sites on trajectory to meet DFC basal area targets, will be estimated for each post-harvest sampling interval using data from Type F treatment sites on the west-side or the east-side high elevation zone. Sites will be analyzed by prescription region (west-side or east-side high elevation zone) and site class category (I, II, III, IV, or V). Using a standard model (FVS), the basal area at 140 years will be predicted for each treatment site. The predicted basal area for each site will then be compared to the DFC target value for basal area in the forest practices rules (WFPB, 2001).

Metric 9, percentage of east-side Type F sites within specified basal area ranges, will be estimated for each post-harvest sampling interval using data from Type F treatment sites in the east-side mixed conifer and ponderosa pine timber habitat types. Sites will be sorted by timber habitat type and site index category (mixed conifer sites only). The basal area for each treatment site will be calculated and compared to the east-side basal area target ranges in the forest practices rules (WFPB, 2001).

Analytic Procedures

Question 2.1. Question 2.1 will be answered using post-harvest data on stand condition (monitoring metrics 1-7) from treatment sites where the riparian prescriptions are applied to estimate post-harvest mortality rates. The mean values for each monitoring metric will be calculated for each sampling stratum, along with the standard deviation and the 95% confidence interval around the mean. Differences in stand condition monitoring metrics between different sampling intervals following harvest will be examined to identify patterns of change over time.

Question 2.2. Question 2.2 will be answered using post-harvest data on stand condition metrics from treatment sites where the riparian prescriptions are applied as well as matching data for the same time period from untreated control sites. Hypothesis 2.2 will be tested for each post-harvest sampling interval using data on monitoring metrics 1-7 from treatment and control sites analyzed by sampling strata. For each monitoring metric, *c*, change in *c* from the previous sample period and from the pre-harvest condition will be estimated as:

$$\Delta c = c_{t+1} - c_t$$

For strata where it is possible to pair each treatment site with a control site, a paired sample test (or its nonparametric equivalent if appropriate) will be used to test the one-sided null hypothesis:

$$H_o : \Delta c_{treatment} - \Delta c_{control} \le 0,$$
$$H_A : \Delta c_{treatment} - \Delta c_{control} > 0.$$

For strata where it was not possible to pair all treatment sites with a control site, a two sample t-test (or its nonparametric equivalent if appropriate) will be used to test the hypothesis that there is no difference in the mean change in *c* between the sample of treatment sites and the sample of control sites. The one-sided null hypothesis tested will be:

$$H_o : \overline{\Delta} c_{treatment} \le \overline{\Delta} c_{control},$$
$$H_A : \overline{\Delta} c_{treatment} > \overline{\Delta} c_{control}.$$

If there is a significant difference between the treatment and control site populations for any stand condition metric, the difference in means will be computed to determine the magnitude of the effect. By repeating the procedure at each sampling interval, the duration of the effect will be determined and variation in the magnitude of change over time will be documented.

Question 2.3. This question will be answered by estimating the percentage of sites (*p*) in each stratum that meet or exceed the DFC performance target (monitoring metric 8) for each sampling interval. A 95% confidence interval for *p* will be estimated using methods in Fleiss (1981). Selected site, buffer layout, and stand covariates (Table 4) will be used to characterize the subset of treatment sites where performance targets were not achieved and contrast them with treatment sites where performance targets were achieved. This information can be used to direct and design follow-up studies on sites which consistently fail to meet performance standards.

Question 2.4. This question will be answered by estimating the percentage of sites (*p*) in each stratum that are within the east-side basal area target ranges (metric 9) for each sampling interval. A 95% confidence interval for *p* will be estimated using methods in Fleiss (1981). Data on site, buffer layout, and stand covariates (Table 4) will be used to characterize the subset of treatment sites where the target ranges were not achieved and contrast them with treatment sites where performance targets were achieved. This information can be used to direct and design follow-up studies on sites which consistently fail to meet performance standards.

Question 2.5. Exploratory regression analysis will be done to evaluate potential relationships between stand condition monitoring metrics and various continuous site attribute covariates identified in Table 4. Graphical analysis will be done for categorical covariates. These procedures will be used to identify potential relationships of interest. This information can be used to build hypotheses for further testing and to design follow-up studies.

Goal 3. Evaluate Changes in Shade

This component addresses uncertainty concerning changes in shade levels following timber harvest. The FFR forest practices rules include target shade requirements for harvest units adjacent to Type F streams for the purpose of retaining shade necessary to maintain stream temperatures within state water quality criteria. The shade requirements are based on empirical relationships between shade and stream temperature and vary by region, elevation and the water quality classification of the stream (Sullivan et al., 1990). The Type F strategy is based on the assumption that: 1) the temperature prediction model accurately determines the shade needed to meet water quality standards; 2) leave trees will survive following timber harvest and continue to provide shade over time; and 3) removing trees from yarding corridors or road-stream crossings will not reduce shade below the shade requirements. However, there is uncertainty about the amount of shade actually provide by different prescription options and buffer designs (particularly sites with yarding corridors or patch buffers) and how shade levels are affected by factors such as tree mortality. The FFR approach for shade on Type N streams is based on the assumption that the west-side patch buffer strategy and the east-side partial-cut strategy will provide adequate shade to achieve the state water quality criteria. However, there is uncertainty about the validity of these assumptions since neither the patch-buffer system (clear-cut strategy) or the thinned buffer system (partial-cut strategy) have been modeled or tested.

There has not been systematic research or monitoring on shade levels following harvest under Washington's forest practice rules. Research on changes in shade following harvest under Oregon's riparian prescriptions indicated that canopy cover (shade) left following harvest varied regionally and decreased (and became more variable) following harvest (Allen and Dent, 2001). Change in shade was greatest on small streams, and was minimal on large streams (Dent, 2001).

Objectives

The uncertainties and assumptions related to riparian shade levels will be addressed by accomplishing the following objectives:

1. Obtain an unbiased estimate of post-harvest shade levels in FFR riparian buffers and monitor changes over time following application of the prescriptions.
2. Evaluate the duration and magnitude of post-harvest changes in shade at treatment sites relative to untreated control sites.
3. Determine the proportion of treatment sites managed under the riparian prescriptions that meet the shade requirements in the Forest Practices Board manual over time.
4. Identify site and stand attributes that influence shade levels.

A critical question has been framed for each objective. Table 6 lists the questions, along with the analytic approach and data required. Question 3.1 provides an estimate of variability in shade levels associated with FFR riparian prescriptions using post-harvest data from treatment sites. Question 3.2 provides an estimate of the magnitude and duration of changes in shade levels associated with the prescription treatments relative to untreated control sites using a treatment-control design. Question 3.3 estimates the proportion of treatment sites meeting forest practices rule shade requirements. Question 3.4 identifies relationships between shade levels and site attributes using covariate data from study sites.

Table 6. Critical questions, analytic approach and data required to evaluate changes in shade in FFR riparian buffers.

Critical Question	Analytic Approach	Data Requirements
3.1. What shade levels are provided by riparian stands following application of the FFR riparian prescriptions?	Metric estimation. Estimate shade conditions associated with FFR riparian buffers. Calculate descriptive statistics for each stratum sampled.	Post-harvest treatment site canopy closure data.
3.2. What is the magnitude and duration of change in riparian shade following application of the FFR riparian prescriptions compared to untreated control sites?	Hypothesis testing. H_o= There is not a significant difference for the change over time in canopy closure between riparian buffers and untreated control sites.	Post-harvest canopy closure data from treatment and control sites.
3.3. What proportion of sites meet the shade requirements specified in the forest practices board manual?	Metric estimation. The percentage of sites meeting the forest practices board manual shade requirements.	Post harvest treatment site canopy closure data.
3.4. What site attributes influence riparian shade levels?	Exploratory Covariate Analysis. Use regression or graphical analysis to identify relationships between shade monitoring metrics and site attribute covariates.	Post harvest treatment shade monitoring metrics and site covariate data.

Monitoring Metrics

The following shade monitoring metrics will be used in these analyses:

1. Mean percent canopy closure
2. Percentage of sites meeting forest practice board shade requirements

Monitoring metric 1, the mean percent canopy closure, will be calculated for each site at each sampling event by averaging canopy closure readings taken in the steam adjacent to the site. At Type N sites treated with the clear-cut strategy, mean canopy closure measurements will also be calculated separately for buffered and un-buffered areas.

Monitoring metric 2, percentage of sites meeting forest practices shade requirements, will be determined by calculating the 95% confidence interval around the mean canopy closure value for each treatment site after each sampling event. When the minimum shade requirement value specified in the forest practices rules is above the upper limit of the 95% confidence interval around the mean, the site will be considered as not having met the performance target. The percentage of sites that meet or exceed the shade requirement (p) will be calculated by dividing sites that meet or exceed the shade requirement by the total number of sites in the stratum.

Analytic Procedures

Question 3.1. Question 3.1 will be answered using post-harvest canopy closure data (monitoring metric 1) from treatment sites where the riparian prescriptions are applied. For each sampling stratum, mean canopy closure for all sites will be calculated for each sampling interval, along with the standard deviation and the 95% confidence interval around the mean. Canopy closure estimates from different sampling intervals following harvest will be examined to identify patterns over time.

Question 3.2. Question 3.2 will be answered by comparing the change in shade at treatment sites where the riparian prescriptions are applied with matching data from untreated control sites in the same stratum. The comparison will be repeated for each post-harvest sampling interval. Change in percent canopy closure s from the previous sample period will be estimated as:

$$\Delta s = s_{t+1} - s_t$$

For strata where it is possible to pair each treatment site with a control site, a paired sample test (or its nonparametric equivalent if appropriate) will be used to test the one-sided null hypothesis:

$$H_o : \Delta s_{treatment} - \Delta s_{control} \leq 0,$$
$$H_A : \Delta s_{treatment} - \Delta s_{control} > 0.$$

For strata where it was not possible to pair all treatment sites with a control site, a two sample t-test (or its nonparametric equivalent if appropriate) will be used to test the hypothesis that there is no difference in the mean change in s between the sample of treatment sites and the sample of control sites. The one-sided null hypothesis tested will be:

$$H_o : \overline{\Delta} s_{treatment} \leq \overline{\Delta} s_{control},$$
$$H_A : \overline{\Delta} s_{treatment} > \overline{\Delta} s_{control}.$$

If there is a significant difference in mean percent canopy closure between the treatment and control site populations, the difference in means will be computed to determine the magnitude of the effect. By repeating the procedure at each sampling interval, the duration of the effect will be determined and variation in the magnitude of change over time will be documented.

Question 3.3. This question will be answered by estimating monitoring metric 2, the percentage of sites (p) in each stratum that meet or exceed the shade requirements, for each post-harvest sampling interval. A 95% confidence interval for p will be estimated using methods in Fleiss (1981).

Question 3.4. Exploratory regression analysis will be done to evaluate potential relationships between site level shade monitoring metrics and various continuous site attribute covariates identified in Table 4. Graphical analysis will be done for categorical covariates. These procedures will be used to identify potential relationships of interest. This information can be used to build hypotheses for further testing and to design follow-up studies. Interpretation of shade data will be enhanced by data from the stream temperature field study (Project 4) and the extensive riparian monitoring project discussed in the section “integrated riparian monitoring strategy” above.

Goal 4. Evaluate Changes in Woody Debris Recruitment

This component addresses uncertainty concerning the effect of riparian prescriptions on woody debris recruitment to adjacent stream channels. Widespread harvest of riparian stands in over the past 100 years has altered the age and composition of many riparian stands, decreasing the size and abundance of wood in stream channels and changing its composition (Bilby and Ward, 1991; McHenry et al., 1998; Beechie et al., 2000; Rot et al., 2000). As a result, riparian stands on managed timber land typically consist of trees less than 80 years of age with stems too small to provide woody debris of functional size (Beechie et al., 2000; Grizzel et al., 2000). Adjacent stream channels are often depleted in wood (Bilby and Ward, 1991; Ralph et al., 1994; McHenry et al., 1998; Rot et al., 2000). Consequently, a major objective of many riparian management strategies in the Pacific Northwest is to increase recruitment of wood of functional size to stream channels to increase habitat and cover and promote recovery of salmonid stocks (Beechie et al., 2000). Two approaches have been proposed to address this issue, leaving strips of trees along streams to provide wood recruitment (Murphy and Koski, 1989) and thinning riparian stands to stimulate more rapid height and diameter growth, reducing the time needed to produce functional wood (Rainville et al., 1985; Berg, 1997; Beechie et al., 2000). The FFR prescriptions employ both strategies. Buffer widths and leave tree requirements have been increased adjacent to fish-bearing streams and thinning is allowed in the inner zone of RMZs to increase diameter growth, reducing the time needed to produce wood of functional size and stands characteristic of mature stands (west-side DFC) or natural disturbance regimes (east-side). The Type N patch and partial cut buffer strategies provide a source of woody debris recruitment to headwater streams.

There are many scientific uncertainties about the effect of the various FFR prescriptions on the woody debris recruitment rates and the type, size and functionality of wood recruited. The recruitment potential of the stand over time, i.e. the number of trees capable of providing functional wood to the channel (of sufficient height to reach the channel with sufficient diameter to function) and the woody debris recruitment rate are affected by many variables. Buffer width, stand density, composition, growth rate (site productivity), and mortality rates and processes all affect the potential of the stand to provide wood as it develops through time, while factors such as mortality rates and processes, fall direction and distance to the stream affect actual recruitment rates (Harmon et al., 1986). For example, species composition and mortality processes and rates are known to vary widely by region, with wind throw prevalent along the coast and in the Cascades, while insect and disease are more prevalent further east (Harmon et al., 1986).

The FFR riparian prescriptions will be applied across a landscape with many different stand types and variable physiographic and climatic conditions which will influence woody debris recruitment rates and processes. The FFR prescriptions are based on the assumption that riparian stands managed under the Type F prescriptions will develop into stands similar to mature forests (west-side) or stands characteristic of natural disturbance regimes (east-side). In both cases, it is assumed that the rate of wood recruitment, and the size and type of material recruited, will be similar to that provided by natural riparian stands and should provide functions and habitat similar to that of unmanaged mature forests. The assumption for stands managed under the Type N prescriptions is that both the clear-cut or partial cut strategies will provide adequate wood recruitment to provide channel functions (sediment/nutrient routing and habitat) within the Type N network and will export enough wood to Type F streams to maintain habitat necessary to produce harvestable populations of fish.

Objectives

The uncertainties and assumptions related to woody debris recruitment will be addressed by accomplishing the following objectives:

1. Obtain an unbiased estimate of post-harvest woody debris recruitment potential and rates for FFR riparian buffers and monitor changes in those attributes over time following application of the prescriptions.
2. Evaluate the duration and magnitude of post-harvest changes in woody debris recruitment potential and rates at treatment sites relative to untreated control sites.
3. Identify site and stand attributes that influence woody debris recruitment.

A critical question has been framed for each objective. Table 7 lists the questions, along with the analytic approach and data required. Question 4.1 provides an estimate of variability in woody debris recruitment associated with FFR riparian prescriptions using post-harvest data from treatment sites. Question 4.2 provides an estimate of the magnitude and duration of changes in woody debris recruitment associated with the prescription treatments relative to untreated control sites using a treatment-control design. Question 4.3 identifies relationships between woody debris recruitment and site attributes using covariate data from study sites.

Table 7. Critical questions, analytic approach and data required to evaluate changes in woody debris recruitment in FFR riparian buffers.

Critical Question	Analytic Approach	Data Requirements
4.1. What are woody debris recruitment rates, processes and recruitment potential associated with riparian stands following application of FFR riparian prescriptions?	Metric estimation. Estimate woody debris recruitment rates, processes and potential for FFR riparian buffers. Calculate descriptive statistics for each stratum sampled.	Post-harvest treatment site woody debris recruitment data.
4.2. What is the magnitude and duration of change in woody debris recruitment rates, processes and potential following application of the FFR riparian prescriptions, compared to untreated control sites?	Hypothesis testing. H_o= There is not a significant difference for the change over time in woody debris recruitment potential, rates, and processes between riparian buffers and untreated control sites.	Post harvest woody debris recruitment data from treatment and control sites.
4.3. What site and stand attributes influence the woody debris recruitment monitoring metrics?	Exploratory Covariate Analysis. Use regression or graphical analysis to identify relationships between woody debris recruitment monitoring metrics and site attribute covariates.	Post harvest treatment woody debris recruitment monitoring metrics and site covariate data.

Monitoring Metrics

The following woody debris recruitment monitoring metrics will be used in these analyses:

1. Stems per acre potentially capable of recruitment
2. Volume of wood per acre potentially capable of recruitment
3. Number of woody debris pieces recruited/stream length/year by sampling interval
4. Cumulative number of woody debris pieces recruited/stream length over post-harvest period
5. Volume of woody debris recruited/meter of stream length/year by sampling interval
6. Cumulative volume of woody debris pieces recruited/stream length over post-harvest period
7. Mean piece diameter of recruited woody debris
8. Mean piece volume of recruited woody debris
9. Percentage of recruited woody debris pieces by recruitment process
10. Volume of recruited woody debris pieces by recruitment process

Monitoring metric 1, stems per acre potentially capable of recruitment, will be calculated by subtracting the slope distance to the channel from the tree height. Any trees with positive values will be counted as capable of recruitment. Metric 2, volume of wood potentially capable of recruitment, will be calculated using tree height, diameter at breast height, and the relevant tree taper equation for the species to estimate the volume of wood in the tree above a height equal to the slope distance to the channel.

Metric 3, the number of woody debris pieces recruited/stream length/year for the sampling inteval, will be calculated by summing the number of pieces recruited to the bankfull channel since the previous sampling event, dividing by the stream length of the plot, and dividing by years since the previous sampling event. Metric 4, the cumulative number of woody debris pieces recruited/stream length over the post-harvest period, will be calculated by summing the pieces recruited for all post-harvest sampling periods and dividing by the plot stream length.

Metric 5, the volume of woody debris recruited/stream length/year, will be determined by calculating the volume of wood intruding into the bankfull channel for each piece that has recruited during the sampling interval (length times cross-sectional area), summing the volumes, dividing by the stream length of the plot, and dividing by years since the previous sampling event. Metric 6, the cumulative volume of woody debris pieces recruited/stream length over post-harvest period, will be calculated by summing the volume of woody debris recruited for all post-harvest sampling periods and dividing by the stream length of the plot.

Mean piece diameter (metric 7) and mean piece volume (metric 8) will be calculated by summing the mean diameters and volumes, respectively, of all pieces recruited during each sampling period and dividing by the total number of pieces. Metric 9, percentage of pieces by recruitment class, will be calculated by summing the number the debris pieces for each recruitment process and dividing them by the total. Metric 10, volume of pieces by recruitment process, will be calculated by summing the volume of debris pieces associated with each recruitment process and dividing by the total.

Analytic Procedures

Question 4.1. Question 4.1 will be answered using data for each of the woody debris recruitment monitoring metrics from treatment sites where the riparian prescriptions are applied. For each sampling stratum, each metric will be calculated after each sampling event, along with the standard deviation and the 95% confidence interval around the mean. Estimates from different sampling intervals following harvest will be examined to identify patterns in woody debris recruitment rates and other metrics over time.

Question 4.2. Question 4.2 will be answered using post-harvest data on woody debris recruitment monitoring metrics from treatment sites where the riparian prescriptions are applied as well as matching data for the same time period from untreated control sites. Hypothesis 4.2 will be tested for each sampling strata at each post-harvest sampling interval. For any woody debris recruitment monitoring metric (w), change in w from the previous sample period and from the pre-harvest condition will be estimated as:

$$\Delta w = w_{t+1} - w_t \, .$$

For strata where it was possible to pair each treatment site with a control site, a paired sample test (or its nonparametric equivalent if appropriate) will be used to test the one-sided null hypothesis:

$$H_o : \Delta w_{treatment} - \Delta w_{control} \leq 0,$$
$$H_A : \Delta w_{treatment} - \Delta w_{control} > 0.$$

For strata where it was not possible to pair all treatment sites with a control site, a two sample t-test (or its nonparametric equivalent if appropriate) will be used to test the hypothesis that there is no difference in the mean change in *c* between the sample of treatment sites and the sample of control sites. The one-sided null hypothesis tested will be:

$$H_o : \overline{\Delta} w_{treatment} \leq \overline{\Delta} w_{control},$$
$$H_A : \overline{\Delta} w_{treatment} > \overline{\Delta} w_{control}.$$

If there is a significant difference between the treatment and control site populations, the difference in means will be computed to determine the magnitude of the effect. By repeating the procedure at each sampling interval, the duration of the effect will be determined and variation in the magnitude of change over time will be documented.

<u>Question 4.3</u>. Exploratory regression analysis will be done to evaluate potential relationships between woody debris recruitment monitoring metrics and various continuous site attribute covariates identified in Table 4. Graphical analysis will be done for categorical covariates. These procedures will be used to identify potential relationships of interest. This information can be used to build hypotheses for further testing and to design follow-up studies.

<u>Goal 5. Soil and Stream-Bank Disturbance</u>

This component addresses uncertainty concerning the effectiveness of the FFR riparian prescriptions in meeting performance targets for soil disturbance and stream-bank integrity. Schedule L-1 establishes performance targets for disturbance of stream-banks adjacent to harvest units and for disturbance of soil within riparian areas. The sediment performance target for the Type F riparian prescriptions is intended to prevent disturbance to stream-banks and prevent soil disturbance that delivers sediment to the stream channel. The sediment target for the Type N riparian prescriptions is intended to prevent stream-bank disturbance, to limit soil disturbance to less than 10% of area within 30 ft of the stream (the equipment limitation zone), and to prevent delivery of sediment to the stream channel.

The FFR prescriptions are based on the assumption that restrictions on harvest within the core zone adjacent to Type F streams and restrictions on use of yarding equipment within the 30 ft equipment limitation zone on Type N streams will protect stream-banks and prevent sediment delivery to stream channels. However, there is uncertainty about the level of disturbance associated with yarding corridors across stream channels and the effectiveness of the equipment limitation zones for preventing soil disturbance and sediment delivery in terrain vulnerable to erosion. Past research on the effectiveness of riparian management zones (RMZ) in preventing soil disturbance concluded that riparian buffers were typically effective in preventing sediment delivery if they were not yarded across, however, in some cases site-specific factors, such as steep inner gorge slopes, cable yarding corridors and use of skidders reduced their effectiveness (Rashin et al., 1999). Soil and stream-bank disturbance levels were higher on headwater streams without buffers, where disturbance was often observed in close proximity to stream channels, leading to sediment delivery (Rashin et al., 1999).

Objectives

The uncertainties and assumptions related to stream-bank and soil disturbance will be addressed by accomplishing the following objectives:

1. Obtain an unbiased estimate of post-harvest management-related soil and stream-bank disturbance in FFR riparian buffers and monitor changes in those attributes over time following application of the prescriptions.
2. Determine the proportion Type F riparian prescription treatment sites that meet the soil/stream-bank disturbance performance targets.
3. Determine the proportion of Type N riparian prescription treatment sites that meet the soil/stream-bank disturbance performance targets.
4. Identify site and stand attributes that influence soil and stream-bank disturbance.

A critical question has been framed for each objective. Table 8 lists the questions, along with the analytic approach and data required. Question 5.1 provides an estimate of variability in management-related soil and stream-bank disturbance associated with FFR riparian prescriptions using post-harvest data from treatment sites. Question 5.2 estimates the proportion of Type F treatment sites meeting soil and stream-bank disturbance performance targets. Question 5.3 estimates the proportion of Type N treatment sites meeting soil and stream-bank disturbance performance targets. Question 5.4 identifies relationships between management-related soil and stream-bank disturbance and site attributes using covariate data from study sites.

Table 8. Critical questions, analytic approach and data required to evaluate changes management-related soil and stream-bank disturbance in FFR riparian buffers.

Critical Question	**Analytic Approach**	**Data Requirements**
5.1. What levels of management-related soil and stream-bank disturbance are observed where FFR riparian prescriptions have been applied?	<u>Metric estimation</u>. Estimate management related soil and stream-bank disturbance levels at sites with FFR riparian buffers. Calculate descriptive statistics for each stratum sampled.	Post-harvest treatment site soil/stream-bank disturbance data.
5.2. What proportion of Type F sites achieve the FFR soil/stream-bank disturbance performance targets?	<u>Metric estimation</u>. The percentage of sites meeting the Type F soil/stream-bank disturbance performance targets.	Post harvest Type F treatment site soil/stream-bank disturbance data.
5.3. What proportion of Type N sites achieve the FFR soil/stream-bank disturbance performance targets?	<u>Metric estimation</u>. The percentage of sites meeting the Type F soil/stream-bank disturbance performance targets.	Post harvest Type N treatment site soil/stream-bank disturbance data.
5.4. What site and stand attributes influence soil/stream-bank disturbance monitoring metrics?	<u>Exploratory Covariate Analysis</u>. Use regression or graphical analysis to identify relationships between soil/stream-bank disturbance monitoring metrics and site attribute covariates.	Post-harvest treatment site soil/stream-bank disturbance data and site covariate data.

Monitoring Metrics

The following soil and stream-bank disturbance monitoring metrics will be used in the analyses:

1. Number of management-related stream-bank disturbance features/stream length
2. Total number of management-related soil disturbance features/stream length
3. Number of management-related soil disturbance features that deliver sediment/stream length
4. Percentage of equipment limitation zone with management-related soil disturbance
5. Percent of Type F treatment sites achieving soil/stream-bank disturbance performance targets
6. Percent of Type N treatment sites achieving soil/stream-bank disturbance performance targets

Monitoring metric 1 will be calculated for each site by tallying the number of management-related stream-bank disturbance features within the plot following harvest and dividing by the stream length of the plot. Metric 2 will be calculated for each site by tallying the number of management-related soil-disturbance features within equipment limitation zone (Type N streams) or the core zone (Type F streams) following harvest and dividing by the stream length of the plot. Metric 3 will be calculated using a separate tally of soil disturbance features that deliver sediment to the stream channel and dividing by the plot stream length. To determine the percentage of the equipment limitation zone with management-related soil disturbance (metric 4), the surface area of each individual management-related soil disturbance feature within the Type N equipment limitation zone will be calculated by multiplying its mean width by the length. Total surface area of exposed soil in the equipment limitation zone will be calculated summing the areas of the individual features. The percentage of area with soil disturbance will be calculated by dividing the area of soil disturbance by the total equipment limitation zone area.

Metric 5, the percentage of Type F sites achieving soil/stream-bank disturbance performance targets, will be estimated using treatment site data from the first post-harvest sampling event. Sites which have no management-related stream-bank disturbance features and no management-related soil disturbance features that deliver sediment will be considered to meet the Type F performance target. The number of sites in each stratum that meet the target will then be divided by the total number of sites in the stratum. Metric 6, the percentage of Type N sites achieving soil/stream-bank disturbance performance targets, will be estimated using treatment site data from the first post-harvest sampling event. Sites which have no management-related stream-bank disturbance features (metric 1) and less than 10% soil disturbance in the equipment limitation zone will be considered to meet the Type N performance target. The number of sites in each stratum that meet the target will be divided by the total number of sites in the stratum.

Analytic Procedures

Question 5.1. Question 5.1 will be answered using post-harvest data on the soil and stream-bank disturbance monitoring metrics from treatment sites where the riparian prescriptions are applied. For each sampling stratum, the mean for all sites will be calculated for each sampling interval, along with the standard deviation and the 95% confidence interval around the mean.

Question 5.2. Question 5.2 will be answered using post-treatment data for monitoring metric 5 from Type F treatment sites sorted by sampling strata. The percentage of sites (p) in each stratum that meet or exceed the performance target will be estimated for each sampling interval. A 95% confidence interval for p will be estimated using methods in Fleiss (1981).

Question 5.3. Question 5.3 will be answered using post-treatment data for monitoring metric 6 from Type N treatment sites sorted by sampling strata. The percentage of sites (*p*) in each stratum that meet or exceed the performance target will be estimated for each sampling interval. A 95% confidence interval for *p* will be estimated using methods in Fleiss (1981).

Question 5.4. Exploratory regression analysis will be done to evaluate potential relationships between the soil and stream-bank disturbance metrics and various continuous site attribute covariates identified in Table 4. Graphical analysis will be done for categorical covariates. These procedures will be used to identify potential relationships of interest. This information can be used to build hypotheses for further testing and to design follow-up studies.

Overview of Analytic Approaches

The critical questions identified in the analytic procedures sections above incorporate two approaches for evaluating the effects and performance of the riparian prescriptions:

1. Treatment-control. Comparison of the magnitude and duration of change resulting from application of the prescriptions relative to untreated control sites;
2. Performance target comparison. Comparing post-harvest conditions relative to FFR performance targets.

A third approach, comparison of post treatment conditions with an unmanaged reference condition, may be incorporated at a future date when reference condition data becomes available.

Each of these approaches is discussed below.

Treatment-Control Approach

A site-scale approach for evaluating effectiveness is to compare the changes that occur at treatment sites where the prescriptions are applied with changes at untreated control sites. The critical questions concerning the magnitude and duration of change at treatment sites relative to untreated control sites will be answered by testing hypotheses that compare sites where the treatments were applied with unmanaged control sites. Testing these hypotheses requires data obtained from the two populations, a treatment population consisting of riparian stands where the FFR prescriptions were applied and a control population consisting of stands with similar vegetation, geomorphology and climate where no treatment will be applied during the study period. Control sites will not be managed during the study period and will likely have a similar past management history to the treatment sites, consequently they are not necessarily ‘natural’ or ‘unmanaged’ stands. Comparing the magnitude and direction of change during the post-harvest period at treatment sites to changes observed at control sites during the same period will allow changes associated with the treatment to be isolated and distinguished from changes associated with factors other than the prescriptions such as inter-annual fluctuations in climate. The change in values for the monitoring metrics between the pre-harvest sampling point and each post-harvest sampling interval (and between each post-harvest sampling intervals) will be estimated for each site. The duration of change will be determined by tracking trends in the magnitude of differences between treatment and control sites over time. Statistical testing of matched pairs of similar treatment and control sites is the preferred analytic approach because it provides greater control over potential sources of variability associated with site and stand covariates. Consequently, an attempt will be made to match each treatment site with a paired control site which is similar in age, and has similar stand characteristics and site conditions. The changes at treatment sites will be compared with changes at matched control sites using a paired sample t-test. When it is not possible to find a matching control for each treatment site, a two-sample t-test will be used to compare the total sample of control and treatment sites for the stratum.

Performance Target Comparison

The critical questions concerning the ability of treatment sites to meet performance targets will be answered by comparing post-harvest values for the monitoring metrics against numeric performance targets for those parameters adopted by the FFR Policy Committee. Performance targets for stream temperature, woody debris recruitment, litter fall, soil disturbance, and in-channel indicators have been adopted by the FFR Policy Committee as measurable criteria to evaluate progress and success in achieving FFR resource (functional) objectives (FFR, Schedule L-1). Although many of the current targets are considered “preliminary”, and other targets are under development, the performance targets represent the approach sanctioned by the FFR Policy Committee for evaluating the performance of the FFR riparian prescriptions.

The procedure for performance target comparison requires post-harvest data from the treatment population of riparian stands where the FFR prescriptions were applied. Treatment sites will be sampled at intervals following harvest. Each individual site will be evaluated relative to the performance target at each sampling interval and the percentage of sites meeting the performance targets in each stratum will be estimated. A 95% confidence interval for this percentage will be estimated. The characteristics of treatment sites that do not meet the performance standards will be compared to the characteristics of the treatment sites that met the standards to identify site attribute variables associated with sites that fail to achieve performance targets.

Treatment-Reference Condition

A third approach for evaluating performance is to compare the range of stand and functional conditions across a group of sites where the prescriptions are applied with the range of conditions associated with riparian stands in unmanaged ecosystems (the reference condition). This information is relevant for adaptive management because the FFR management approach for west-side riparian stands is to emulate unmanaged mature riparian stands (DFC), and the FFR management objective for east-side stands to emulate the range of conditions associated with natural, pre-European disturbance regimes. Comparing the range of conditions in managed stands over time with the range of reference conditions in unmanaged riparian stands would provide a better understanding of the performance of FFR riparian management practices in emulating unmanaged riparian ecosystems. By repeating the comparison over time, trends can be identified, making it possible to determine whether, and at what rate, conditions at treatment sites are moving towards the reference condition. A similar approach has been proposed as part of the FFR Monitoring Design Team extensive riparian monitoring project (MDT, 2002). This approach is not included in the current proposal because of logistic difficulties and expense. There appears to be a limited and patchy distribution of potential reference sites in western Washington, and it is questionable whether any true ‘unmanaged’ reference sites can be found in drier east-side forests due to widespread fire suppression, which has altered the condition of forests associated with more frequent natural fire regimes. However, if data characterizing west-side riparian reference conditions is developed for the MDT extensive riparian monitoring, it will be possible to use it for comparison purposes at a future date.

Sampling Strategy

This section discusses the strategy for identifying sampling sites and collecting the data necessary to conduct the analyses described in the preceding sections.

Stratification Approach

Due to the variability in riparian vegetation and site conditions across the forest lands of Washington State, a corresponding level of variability in the response of riparian stands to the FFR riparian prescriptions is anticipated. The purpose of stratification is to define sampling strata that will reduce within stratum variability in the monitoring metrics. Since the number of stratification attributes selected will directly affect the number of strata to be sampled, stratification is limited to a few key attributes that are expected to exert a strong influence on variability in the metrics of interest, e.g. tree mortality rate; stand composition, density, and basal area; shade; and wood recruitment rate. The monitoring metrics for Project 2 are related to characteristics of riparian stands and their management, rather than stream channel characteristics. Consequently, sites will be stratified on the basis of vegetation and prescription strategy should be most effective in compartmentalizing variability in stand response, reducing within-stratum variability. For this reason, a stratification system based on prescription strategy and forest vegetation zone is proposed. Each stratification attribute is discussed below.

Forest zone. Forest vegetation zones are broad areas of similar macro-climate in which one forest series is prevalent. The boundaries between zones reflect primarily temperature and moisture gradients that influence the competitive advantages of different forest series (Franklin and Dyrness, 1988). Forest zone is a useful parameter for stratifying stand response because it represents the dominant tree species present, the climatic conditions and the dominant disturbance regimes. For example, tree mortality rates and processes differ by forest zone. Wind is the dominant tree mortality agent in Sitka Spruce Zone forests, accounting for 70% of stem mortality. The influence of wind drops to 17-47% of mortality in the Western Hemlock Zone forests in the Cascade Range, and less than 20% in ponderosa pine and mixed conifer forests. In contrast, insects and diseases accounted for 40% of mortality in ponderosa pine (Harmon et al., 1986). Likewise, Agee (1994) noted differences in fire disturbance regimes and fire-related mortality patterns between different climax forest zones in eastern Washington. In addition, factors such as growth rates and successional patterns would be expected to differ for between forest zones due to differences in the dominant plant associations.

A system of eight forest zones is proposed (Figure 3), based on Franklin and Dyrness (1988), Agee (1994) and Cassidy et al. (1997), including:

- Western Hemlock (west-side)
- Sitka Spruce (west-side)
- Silver Fir/Mountain Hemlock (west-side)
- Puget Sound Douglas-fir (west-side)
- Subalpline Fir (east-side)
- Ponderosa Pine (east-side)
- Interior Douglas-fir/Grand Fir (east-side)
- Interior Western Hemlock/Redcedar (east-side)

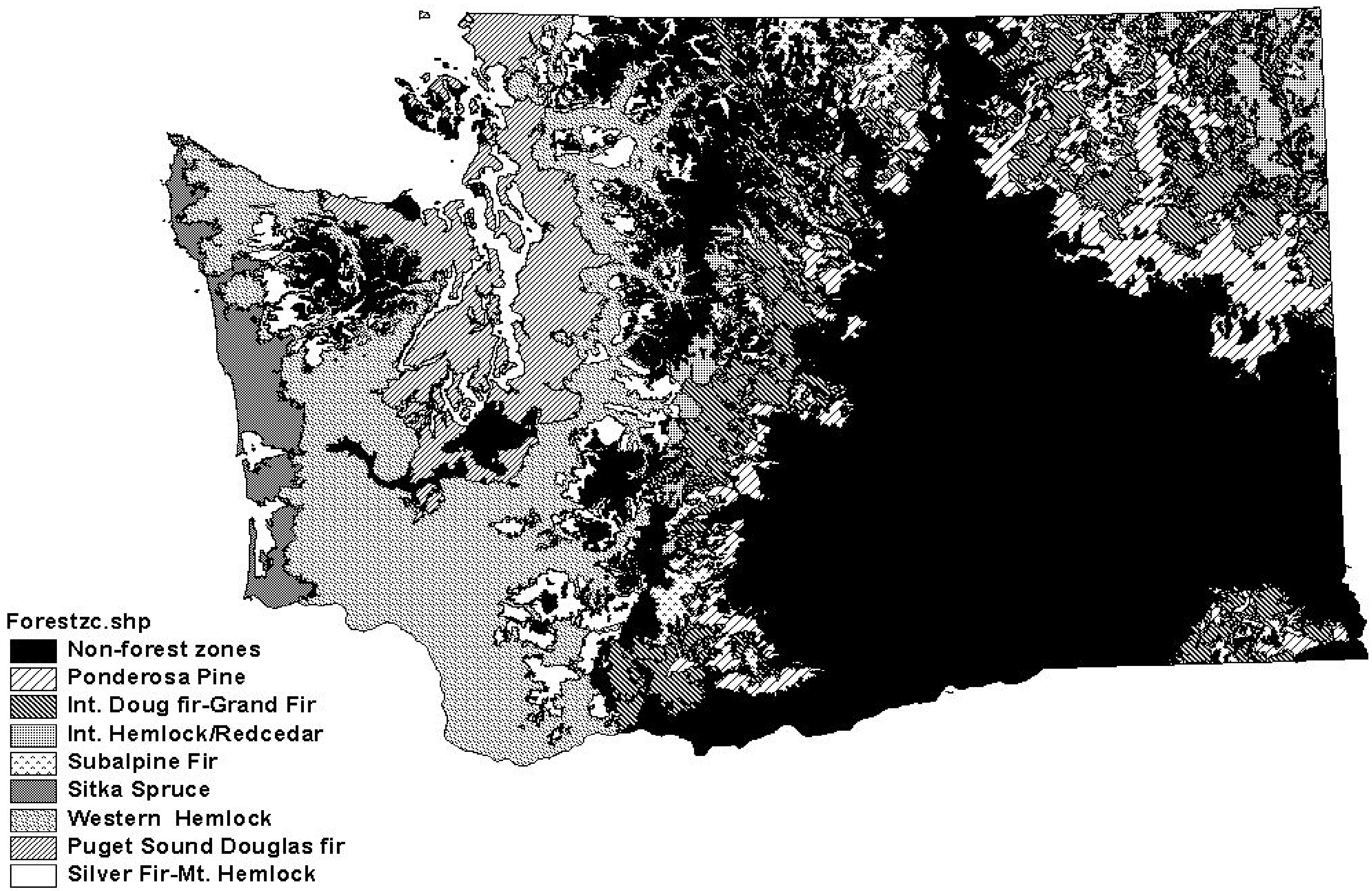

Figure 3. Map of forest vegetation zones.

Prescription strategy. The FFR riparian strategy applies two fundamentally different approaches to Type F and Type N streams. Type F streams receive a continuous buffer with a no-cut core zone and a partial cut inner zone. In contrast, the Type N prescriptions are fundamentally different from the Type F prescriptions, employing a patch buffer approach to protecting sensitive areas, or a partial cut approach (east-side only). Consequently, Type F and Type N sites will be sampled separately to constrain differences in response due to application of the different prescription strategies.

Distribution of FFR Riparian Area by Sampling Strata

Combining prescription type and forest zone yields eight west-side strata and eight east-side strata. Table 9 shows the percentage of stream length on FFR lands in the west-side strata. This estimate was developed using GIS data. Land managed under FFR rules were estimated using landownership and land cover data. To approximate the area where the Type F and Type N prescriptions would be applied, streams on FFR lands were sorted into two categories, fish-bearing streams (Type 1-3 waters) and non-fish-bearing streams (Type 4 and 5) using pre-FFR water type data from the DNR hydro layer.

Table 9. Proportion of west-side streams on FFR lands by water type and forest zone.

Forest Zone	**% of total west-side FFR riparian area by forest zone**	**% of west-side Type 1-3 FFR riparian area by forest zone**	**% of west-side Type 4-5 riparian area by forest zone**	**Type 1- 3 as % of total west-side riparian area**	**Type 4-5 as percent of total west-side riparian area**
Western Hemlock	72.6 %	70.9 %	73.2 %	16.7 %	56.0 %
Sitka Spruce	14.3 %	19.2 %	12.8 %	4.5 %	9.8 %
Silver Fir/Mt. Hemlock	9.9 %	4.7 %	11.5 %	1.1 %	8.8 %
Puget Sound Douglas-fir	2.8 %	4.7 %	2.2 %	1.1 %	1.7 %
Other	0.4 %	0.5 %	0.3 %	0.1 %	0.3 %
Total	100 %	100 %	100 %	23.5 %	76.5 %

Approximately 23.5% of streams on west-side FFR lands are Type 1-3 waters (fish-bearing) and 76.5% are Type 4-5 (non-fish-bearing). The majority (72. 6%) of streams on west-side FFR land are in the Western Hemlock zone, (72.6% of Type 1-3, and 70.9% of Type 4-5). The Sitka Spruce zone, located along the coast, has the second-largest amount of FFR streams with 14.3 % of the total (19.2 % of Type 1-3 and 12.8 % of the Type 4-5). About 10% of the total occurs in the Silver Fir/Mountain Hemlock zone at higher elevations in the Cascades and Olympics. This zone has less than 5 % of the Type 1-3 and over 10 % of Type 4-5 streams, likely due to a higher proportion of headwater streams at higher elevations. The Puget Sound Douglas-fir zone has less than 5 % of the total.

Table 10 shows the percentage of riparian area on FFR lands in each east-side stratum. Approximately 19.2 % of east-side streams on FFR lands are Type 1-3, while over 80% are Type 4-5. The Interior Douglas-fir/Grand Fir zone, located at intermediate elevations on Cascades, Okanogan Highlands and Blue Mountains, contains over 50% of the streams on potential FFR land on the east-side, with 43.9% of type 1-3 and 52.4 % of Type 4-5. The Ponderosa Pine zone, located at lower elevations, has the second largest share (34.3%) of east-side FFR streams, with 39.6 % of the Type 1-3 and 33.1 % of the Type 4-5 streams. The Interior Western Hemlock/

Redcedar zone, located in moist portions of the Selkirk and eastern Cascade Mountains, has 11.5% of the FFR streams. The Subalpine Fir and Silver Fir/Mt. Hemlock zones have less than 5% of FFR east-side streams, due to the limited amount high elevation land in private ownership.

Table 10. Proportion of east-side streams on FFR lands by Water Type and Forest Zone strata.

Forest Zone (east-side)	% of total east-side FFR riparian area by forest zone	% of east-side Type 1-3 FFR riparian area by forest zone	% of east-side Type 4-5 riparian area by forest zone	Type 1- 3 as % of total east-side riparian area	Type 4-5 as percent of total east-side riparian area
Interior Douglas-fir/Grand Fir	50.8%	43.9%	52.4%	8.4%	42.4%
Ponderosa Pine	34.3%	39.6%	33.1%	7.6%	26.7%
Interior W. Hemlock/Redcedar	11.5%	13.6%	11.0%	2.6%	8.9%
Subalpine Fir	3.2%	2.8%	3.3%	0.5%	2.7%
Silver Fir/Mountain Hemlock	0.2%	0.2%	0.1%	0.0%	0.1%
Total	100.0%	100.0%	100.0%	19.2%	80.8%

Table 11 combines data from the both the west-side and east-side to provide a statewide perspective. Statewide, 22.4 % of FFR streams are Type 1-3, while 77.6 % are Type 4-5. The west-side Western Hemlock Zone has 54.4% of the FFR streams statewide, followed by the Interior Douglas-fir/Grand Fir zone (13%0), Sitka Spruce zone (10.7%), Ponderosa Pine zone (8.7%) and Silver Fir/Mountain Hemlock zone (7.4%). The other three zones all had less than 3% of the FFR streams.

Table 11. Proportion of streams on FFR lands (statewide) by water type and forest zone strata.

Forest Zone (statewide)	% of total statewide FFR riparian area by forest zone	% of statewide Type 1-3 FFR riparian area by forest zone	% of statewide Type 4-5 riparian area by forest zone	Type 1- 3 as % of total statewide riparian area	Type 4-5 as percent of total statewide riparian area
Western Hemlock	54.4%	55.7%	54.0%	12.5%	41.9%
Interior Douglas-fir/Grand Fir	13.0%	9.6%	13.9%	2.1%	10.8%
Sitka Spruce	10.7%	15.1%	9.4%	3.4%	7.3%
Ponderosa Pine	8.7%	8.6%	8.8%	1.9%	6.8%
Silver Fir/Mountain Hemlock	7.4%	3.8%	8.5%	0.8%	6.6%
Int. W. Hemlock/Redcedar	2.9%	3.0%	2.9%	0.7%	2.3%
Puget Sound Douglas-fir	2.1%	3.7%	1.6%	0.8%	1.2%
Subalpine Fir	0.8%	0.6%	0.9%	0.1%	0.7%
Total	100.0%	100.0%	100.0%	22.4%	77.6%

Based on these distributions, it appears that sampling eight of the 16 strata cover the vast majority of streams on FFR lands. Sampling the west-side Western Hemlock and Sitka Spruce zones would cover nearly 90% of the FFR streams on the west-side, while sampling the Interior Douglas-fir/Grand Fir and Ponderosa Pine zones on the east-side would cover about 85% of east-side FFR streams.

Sample Size

The analytic procedure proposed to test hypotheses is a paired sample test of differences between treatment and control sites, however there is no available treatment-control data for a power analysis. Consequently, an initial sample size estimate was developed by examining existing data sets to assess variability in post-harvest tree mortality, an important monitoring metric. This analysis was done using data on the percentage of post-harvest mortality from several studies, including a study of TFW-era Riparian Leave Areas (RLA) at 40 sites on Type 4 (non-fish-bearing) streams in the North Cascades (Grizzel and Wolff, 1998), a study of watershed analysis riparian buffers at 10 sites on fish bearing streams in the North Cascades eco-region (Grizzel et al., 2000), and a study of TFW buffers by the Quinault Tribe (Mobbs and Jones, 1995). These data are summarized in (Table 12). This analysis indicated that post-harvest tree mortality was quite variable, both among sites within the same study, and between different studies. Mean mortality ranged from 33.8% for RLAs in the North Cascades to 5.6% for TFW buffers on fish bearing streams in the Quinault area. Three of these data sets had between 35 and 40 samples. Examination of these data indicated that a sample of this size appeared reasonable for the type of analysis proposed.

Table 12. Mortality rates for riparian buffer trees from previous western Washington studies.

Study	Stream Type	n	Mean % Mortality	Stand Dev.	Range
NC Riparian Leave Areas	Non-fish-bearing	40	33.8%	21.7%	2-92%
NC Watershed Analysis Buffers	Fish-bearing	10	23.8%	15.6%	4.6-60.5%
Quinault 1990 TFW buffers	Fish-bearing	38	5.6%	10.7%	0.0-54.8
Quinault 1990 TFW buffers	Non-fish-bearing	4	8.0%	3.9%	4.3-12.3
Quinault 1991 TFW buffers	Fish-bearing	38	5.6%	6.8%	0.0-25.9
Quinault 1991 TFW buffers	Non-fish-bearing	8	11.5%	10.9%	0.0-27.2

Site Selection

Two types of sites are needed for this project: treatment sites, where the FFR riparian prescriptions are applied, and control sites that have similar conditions to the treatment sites but will not have a harvest treatment applied. The following sections describe the process for selecting both.

Treatment Site Selection

The population of DNR-approved forest practice applications (FPAs) involving riparian harvest will be used as the sample frame for selecting a sample of treatment sites. All approved FPAs are listed in DNR's Forest Practice Application Review System (FPARS) database. Each year a new round of sampling is initiated, the FPARS database will be queried on May 15 to identify all riparian applications approved in the past 12 months. The FPAs on this list will then be screened and sorted in a three-step process, first using the limited data in the FPAR database, followed by more intensive screening using scanned harvest maps and worksheets, and finally information from landowners.

Step 1. FPA level classification and screening. Information in the FPARS database will be used to create a table that contains the FPAs with the application number, approval date, harvest type, and legal description. Each FPA will be assigned a random number that is used to order them for further screening.

Step 2. Segment level screening. The second step involves manual screening of FPAs using scanned maps and worksheets. This will be done by working down the randomly ordered list for each stratum FPA by FPA until an adequate number of suitable sites have been identified.

First, the legal description on the FPA will be compared with a look-up table to determine if the FPA is within the forest zone for which sites are being selected. Then the map and worksheets for each FPA will be reviewed to verify that the FPA includes a riparian prescription for the prescription type (F or N) being sampled.

The next step is to identify suitable riparian sampling segments from the FPA map. Each riparian sampling segment (RSS) consists of a contiguous stream reach with a uniform stream type and buffer layout, not interrupted by a stream confluence. To help control for the confounding effect of other types of prescriptions, portions of the stream with channel migration zones (CMZs) or areas where mass wasting prescriptions are applied will be excluded from the sample. Stream reaches with stream adjacent roads will be excluded because the pre-existing impact from the road would add variability that confounds evaluation of the riparian prescription. One-sided riparian buffers will also be excluded from the initial sample based on the rationale that the future management of the other side of these buffers is an unknown and unpredictable source of confounding variability. Each RSS will also be screened for a minimum buffer length of 100m to reduce the confounding influence of edge effects and must be located at least 50 m from the edge of the adjacent harvest unit. An individual FPA may have more than one RSS. In these cases all suitable RSSs on the FPA will be identified, and one will be randomly selected. The others will be discarded to maintain independence between samples.

The third step in the screening process involves contacting the landowner for additional information on segments that pass screening. The landowner will be contacted to determine if the harvest timing is compatible with the sampling schedule. The timeframe for harvesting the unit is critical. Only units harvested between April 1-July 31 will be accepted. This will exclude units cut before or during the winter storm season (mortality could occur before they can be sampled), and ensure that trees are cut before the ‘post harvest flight’ on or around August 1.

Control Site Selection

Once a set of suitable treatment sites has been identified, the next step in the process is to identify a set of matching control sites. To minimize variability in the monitoring metrics due to differences in site attributes, control sites should be a similar as possible to the treatment sites. To accomplish this, each individual treatment site will be matched with a similar control site using the attributes and criteria in Table 13. The first step in this process is to create a profile of each treatment site by determining values for each attribute using information from various sources including the FPA, GIS layers, topo maps, aerial photos and landowner interviews.

Table 13. Criteria for selecting paired control sites.

Attribute	Categories	Control Site Criteria	Source
Stream type	F, N	Same as treatment	GIS
Forest zone	8 zones (see stratification above)	Same as treatment	GIS
Elevation	Continuous variable	Within 500 ft elev	GIS
Geology	Glacial, Igneous, Metamorphic, Sedimentary	Same as treatment	GIS
Stand Age	Continuous variable	Within 10 years	GIS/inventory data
Stream Aspect	Continuous variable	Within 45 deg.	Topo map
Stand type	Conifer, Mixed	Same as treatment	Aerial photo
Dominant species	Tree Species	Same as treatment	Aerial photo
Density class or TPA	Dense, Sparse or Trees per acre	Same as treatment	Aerial photo
Channel gradient	Deposition (<4%), Transport (4-20%), Source (>20%)	Same as treatment	GIS/Topo map
Valley form	Confined; Moderate, Unconfined	Same as treatment	Aerial Photo

Once a profile is available for each treatment site, the second step is to conduct a search to identify possible matching control sites. First, potential control sites will be screened using GIS attributes including stream type, forest zone, elevation, geology, and stand age to identify a subset of potentially suitable matches. The second step is identify a subset of the potentially suitable matches that are in close proximity to the treatment site (e.g. within the same WAU) for more intensive screening. These sites will then be screened for the remaining attributes (stream aspect, stand type, dominant tree species, density, channel gradient, and valley form) using topo maps and aerial photos. The suitable control site closest to the treatment site will be selected as the matching pair.

It is anticipated that many control sites with second-growth vegetation will be needed (since most harvest sites are now second growth). Control sites must not be managed during the study period. The most likely sources of control sites include land with second-growth riparian stands that are not slated for harvest in the near future, such as USFS riparian reserves, DNR HCP lands, small landowner reserves, natural resource conservation areas, municipal watersheds, or State Parks.

Data Sources and Sampling Methods

The data needed to calculate the monitoring metrics and site covariates will be obtained from a combination of sources, including low-altitude aerial photography, field surveys, GIS coverages and maps. The following section identifies the sources of data and the data collection methods for this project.

Sampling Frequency

The sampling intervals will be based on the harvest schedule of the treatment site. Each pair will be sampled prior to harvest, immediately after harvest (within 3 months), and at year 2. At that point a decision will be made on whether to continue monitoring. Sampling could continue beyond year 2 at more infrequent intervals (e.g year 5, 10, 20) to obtain a longer term perspective on stand development and woody debris recruitment (Table 14).

Table 14. Sampling schedule for treatment and control sites (need for 5 and 10 year sampling events, shaded, will be determined after evaluation of results a year 2).

	Pre-Harvest	Post-Harvest				
		<3 mo	2yr	5yr	10yr	Etc.
Aerial Photography	X	X	X	X	X	X
Field Verification/QA		X				
Shade		X				
Soil/Stream Bank Disturbance		X				

Photogrammetry Data

Measurements taken from low altitude aerial photography have been used successfully to generate data for studies of riparian stands and in-channel woody debris (Grotefendt et al., 1996; Martin et al., 1998). Interpretation of low altitude photography, with field verification, will be used to collect the data needed to calculate many of the monitoring metrics related to mortality of leave trees in riparian buffers, riparian stand condition and trajectory, and woody debris recruitment. In addition, aerial photography can be used to collect data on a number of stand attribute covariates (Table 4). The lower cost for data collection with low altitude photography relative to field surveys will make it feasible to increase the sample size, sampling a larger number of randomly selected forest practice applications than would be possible with field surveys and to include a sub-set of control sites. A large sample size will be helpful in dealing with expected variability associated with variation in site conditions and in buffer design and layout. It will also make it feasible to survey each segment in its entirety, allowing a more precise estimate of the monitoring metrics than could be obtained by sub-sampling.

Low-altitude photos will be shot at a scale of 1:6000. Photo negatives will be scanned using a high-resolution scanner to create digital images. Three-dimensional stereo images will be viewed on a computer monitor and photo analysis software will be used to collect data from the photos. Individual trees will be identified and located on GIS. The entire RMZ on both sides of the riparian sampling segment will be surveyed.

Data on individual trees that will be collected from aerial photographs include:

- tree count
- tree species
- tree crown area
- tree height
- tree condition (live, dead, damaged, missing)
- tree location (distance from stream)

Data on down woody debris that will be collected from aerial photographs include:

- piece count
- piece length
- piece diameter
- piece location and intersection with stream channel
- direction of fall
- recruitment process

Data on site attributes that will be collected from aerial photographs include:

- stream centerline
- bankfull channel location and width
- valley width
- stream gradient
- hillslope gradient
- aspect
- landform
- RMZ length and area
- stream length in yarding corridor
- stream length buffered (Type N)

Once the sites and schedule are determined, a flight will be contracted to generate low-altitude stereo photos of the sites after harvest occurs. Each treatment and control sites pair will be photographed on the same schedule in order to produce a paired treatment-control data set for each sampling event. Follow-up flights for the subsequent sampling intervals will occur on the appropriate calendar year. Control sites will be sampled on the same schedule as treatment sites.

Field Data

Field surveys will be used for two purposes including;

- To provide field verification and quality assurance for aerial photo interpretation
- To collect supplemental data that cannot be obtained from aerial photos
- To produce correction factors or correlations for aerial photo interpretation

Field Verification. A field verification visit will take place after harvest. A variety of tree and woody debris data will be collected to verify the accuracy of photo interpretation. Stand data will be collected at two sets of plots established at two randomly selected transects along the stream in the riparian sampling unit. The boundary of each plot will extend for 10 m parallel to the stream. The other plot boundary will extend out at a right angle from the edge of the bankfull channel one site potential tree height (to the boundary of the outer zone). Plot corner points will be marked on the ground so they are visible in the low-altitude photos. Tree and woody debris data will be collected using the methods described in Roorbach et al. (2002). Data on trees and snags include species, diameter at breast height, condition, canopy class, landform, decay class (snags), crown type, and distance from bankfull channel edge. Increment cores to determine age will be taken from a sub-sample of trees by canopy class. Data will also be collected on woody debris. Terrestrial down woody debris in the plots will be documented using methods in Roorbach et al. (2002) to produce data on wood type, orientation, location relative to channel, diameter, piece length, decay class, recruitment class, and mortality agent. Data on large woody debris in the channel adjacent to the plot will be collected using the methods in Schuett-Hames et al. (1999a).

Supplemental Data. Several other pieces of supplemental data will be collected during the post-harvest field visit, including:

- Canopy closure data (goal 3)
- Soil/stream bank disturbance features (goal 5)

Data on canopy closure will be taken at 75 ft intervals along the centerline of the bankfull channel using a spherical densitometer, as described in Schuett-Hames et al. (1999b). In addition, a hemispherical photo will be taken at each transect as described in Allen and Dent (2001).

Data on stream bank disturbance will be collected by walking along the edge of the channel. Any stream-bank disturbance features caused by harvest or yarding activity will be noted and a photograph will be taken. A measurement will be made of the total length of bank disturbed and the associated management activity will be recorded. Data on soil disturbance within the core zone of Type F RMZs or 30 foot Equipment Limitation Zone on Type N streams will be determined by visually inspecting the area. Any soil erosion features associated with harvest or yarding will be noted, the distance from the bankfull channel will be measured, and a photograph will be taken. A measurement will be taken of the length and average width, the associated management activity will be noted, and the potential for sediment delivery will be noted. Follow-up visits will be made in the early spring to sites with a significant number of soil disturbance features to determine the number and percentage of features with evidence of sediment delivery to the channel.

Office, Mapping, GIS Data

A brief description of the office, mapping, GIS data acquisition procedures for each attribute follows.

Regulatory RMZ widths. Riparian Management Zone widths are determined by forest practice regulations and are based on whether the site is in eastern or western Washington, whether the stream is fish-bearing or not, the productivity of the site, and the width of the stream (Washington Forest Practices Board, 2001). RMZ widths are supplied by landowners in forest practice applications and will be confirmed in the field.

Inner zone harvest option (Type F streams). Two options for inner zone harvest include thinning from below or concentrating leave trees on the stream side of the zone. Harvest option is identified by the landowner in forest practice applications.

Basal area target. Basal area targets are supplied in the worksheet associated with the forest practice applications.

Bull trout overlay. Whether a sites falls under jurisdiction of the bull trout overlay is identified in forest practice applications.

Type N Harvest option. In west-side forests and in the east-side High Elevation Zone, a clear-cut strategy with patches of buffer strips is prescribed. In other east-side forest zones, landowners have the option of a partial-cut, or a clear-cut with buffer strip leave requirements. Harvest options along type Np streams are identified in forest practice applications.

Yarding method. Yarding methods include ground cable, highlead, skyline, shovel, rubber tired skidder, tracked skidder, animal, helicopter or balloon. Information on whether yarding corridors (paths cut through a riparian management zone for cable logging) will be placed in the core zone will be noted. Harvest equipment (cable or ground based) is identified by landowners in forest practice applications.

Physiographic region. The physiographic region is determined from a GIS coverage of the EPA level III eco-region map (Omernik and Gallant, 1986).

Elevation. Site elevation will be taken from USGS topographic maps or the USGS digital elevation model GIS coverage.

Precipitation. Annual precipitation levels will be gathered from a GIS layer for statewide precipitation isohyetals (Miller et al., 1973).

Geology group. Sites will be classified into one of twenty different groups, based on a GIS coverage of lithologic divisions and WDNR geology units (Sasich, 1998).

Soil Mapping Unit and Soil Depth. This information will be taken from the state soil survey coverage.

Quality Assurance

Photogrammetry

Two methods will be used to ensure the accuracy and quality of measurements taken from aerial photos will occur in two ways. First, an independent observer will repeat measurements on at least one set of photos each year. Comparison of the results from two observers will be used to establish the range of variability in photo measurements, identify discrepancies in methods and interpretation that contribute to different results, and to recommend ways of reducing discrepancies and improving accuracy.

The second method will involve comparing field surveys and photogrammetry results for the field plots. This comparison will be used to identify the range of variability and error associated with photogrammetry, and may identify recommendations for improving or refining photography or interpretation techniques. It may also be possible to derive correction factors to adjust photogrammetry data to compensate for features that are difficult to detect on aerial photos (e.g. understory trees).

Field Surveys

The quality assurance strategy for field surveys including the riparian stand survey, LWD survey, canopy closure measurements and soil/stream bank disturbance measurements will consist of three elements including training, quality assurance surveys and data error checking. CMER staff will provide training to field crews in the application of the methods prior to commencing field work. Once crews begin work, a well-trained independent survey team will perform a replicate survey at one site during the first week of data collection. Data from the replicate surveys will be used to identify the level of variability between the survey team and the QA team, and to identify discrepancies due to incorrect application of the field methods. This information will be used to develop any appropriate recommendations for improving the field team's application of the methods, and a subsequent QA visit will be done if needed. Finally, as data is received from the field crews, it will error-checked to identify missing or questionable values.

Implementation

A great deal of flexibility is gained by breaking out the sampling effort by strata. Project costs and workload can be controlled by staggering the date when sampling is initiated in the various strata, and by determining how many of the 16 sampling strata should be sampled. Since only four of the strata contain 67% of the stream length on FFR lands, and eight contain over 85%, economy can be gained by focusing sampling effort initially in strata that represent the largest proportion of the stream length.

Two scenarios are presented below as examples possible implementation strategies. The first scenario (Table 15) begins by sampling one stratum from each of four categories: west-side Type F, a west-side Type N, an east-side Type F and an east-side Type N. The stratum with the largest proportion of FFR stream length in each category has been selected, so 67% of statewide FFR stream length would be covered. Each stratum is assumed to include a total of 70 sites, 35 treatment sites and 35 control sites. The schedule in Table 15 takes each of the four strata through the pre-harvest, immediate post-harvest and two year post-harvest sampling intervals. At that time a decision will be made as to whether to continue with further sampling. The cost of the project is $364,000 per strata for a total of 1,486,000 through year two post harvest. Each additional sampling event (e.g. 5 year, 10 year, etc) will added approximately $556,000 to the total project cost.

Table 15. Four strata sampling scenario.

	2003	**2004**	**2005**	**2006**	**2007**	**2008**	**Total**
West-side Type F Western Hemlock	$225,000		$139,000			Begin year 5 sampling cycle (if needed)	$364,000
West-side Type N Western Hemlock		$225,000		$139,000			$364,000
East-side Type F Doug-fir/Grand Fir			$225,000		$139,000		$364,000
East-side Type N Doug-fir/Grand Fir				$225,000		$139,000	$364,000
Equipment	$30,000						$30,000
Total	$255,000	$225,000	364,000	$364,000	$139,000	$139,000	$1,486,000

The second scenario (Table 16) would initiate sampling in eight strata (half of the total number) during the first four years, including two each in the west-side Type F, west-side Type N, east-side Type F and east-side Type N categories. The strata with the largest proportion of FFR stream length in each category has been selected, so over 85% of FFR stream length would be covered. Each strata is assumed to include a total of 70 sites, 35 treatment and 35 control. The schedule in Table 16 takes each of the strata through the pre-harvest, immediate post-harvest and two year post-harvest sampling intervals. At that time a decision will be made as to whether to continue with further sampling. The cost of the project is $364,000 per strata for a total of 2,942,000. Each additional sampling event (e.g. 5 year, 10 year, etc) will added approximately $1,110,000 to the total project cost.

Table 16. Eight strata sampling scenario.

Strata	2003	2004	2005	2006	2007	2008	Total
West-side Type F Western Hemlock	$225,000		$139,000			Begin year 5 sampling cycle (if needed)	$364,000
West-side Type N Western Hemlock	$225,000		$139,000			Begin year 5 sampling cycle (if needed)	$364,000
East-side Type F Doug-fir/Grand Fir		$225,000		$139,000			$364,000
East-side Type F Doug-fir/Grand Fir		$225,000		$139,000			$364,000
West-side Type F Sitka Spruce			$225,000		$139,000		$364,000
West-side Type N Sitka Spruce k			$225,000		$139,000		$364,000
East-side Type F Ponderosa Pine				$225,000		$139,000	$364,000
East-side Type N Ponderosa Pine				$225,000		$139,000	$364,000
Equipment	$30,000						$30,000
Total	$480,000	$450,000	$728,000	$728,000	$278,000	$278,000	$2,942,000

Structure and Organization

The proposed scenario for implementation of the project would involve a number of different parties.

Project oversight. The CMER Riparian Scientific Advisory Group (RSAG), or a sub-group appointed by RSAG, will be responsible for providing direction and guidance, overseeing implementation and making decisions regarding implementation of the project.

Project management. CMER staff will be responsible for managing the implementation of the project, enduring that tasks are completed on schedule and according to specifications, and reporting back to RSAG on progress and for guidance as needed.

Contract administration. The DNR adaptive management administrator and contract specialist will be responsible for generating contracts necessary to implement the project, approving work, and processing invoices and payments.

Site selection. Site selection and screening will be the responsibility of the CMER study implementation coordinator and CMER staff.

Photogrammetry. The photogrammetry section of DNRs engineering department will be contracted to obtain and process low-altitude photography. Data collection from photography will be done by a DNR photogrammetrist and CMER staff.

Field surveys. Field survey work will be done by a combination of CMER staff, DOE staff, and contractors. The mix of staff and contractor effort will depend upon the workload (i.e. number of strata sampled) at any given time.

Quality assurance. Implementation of quality assurance will be the responsibility of CMER staff. Actual quality assurance surveys may be contracted in some cases.

Data management. Data error-checking, processing and archiving will be the responsibility of CMER staff. Data management will be done according to guidelines in the CMER standards and procedures manual.

Data analysis. Data analysis will be done by NWIFC biometricians, and CMER/DOE staff, following procedures described in the study plan. Draft results will be reviewed by RSAG and CMER.

Report Preparation. Project progress reports will be prepared annually by CMER staff, DOE staff and NWIFC biometricians.

Technical Review. Technical review of project results will be done by the Scientific Review Committee.

Schedule

Table 17 shows the sequence and timing of data collection and analysis tasks.

Table 17. Annual data collection and analysis task list and schedule.

Task	Party	May	Jun	July	Aug	Sept	Oct	Nov	Dec	Jan	Feb	Mar
Site selection	CMER staff FIC											
Flight plan/contract	DNR											
Ground control	DNR & CMER staff											
Aerial photo flight	DOT or contractor											
Scanning	DOT or contractor											
Aerial triangulation	DNR or contractor											
Photo interpretation	DNR &/or CMER staff											
Field data collection	Contractors/CMER staff											
Quality assurance	CMER staff											
Data analysis	CMER staff, NWIFC											

PROJECT 3. STREAM TEMPERATURE FIELD STUDY

Purpose

The purpose of the stream temperature field study is to evaluate the response of stream temperature to the FFR riparian prescriptions and determine if water quality criteria are met. The riparian prescriptions are based on the assumption that designing Type F harvest units to meet the shade requirements in the forest practices rules and buffering portions of the Type N network, the state water quality criteria for stream temperature will be met. There is uncertainty about the response of stream temperature in Type F waters where yarding corridors cut through the core zone (up to 20% of the buffer length), or where leave tree mortality occurs, particularly in smaller, low elevation streams with limited groundwater input. There is also great uncertainty about temperature response of Type N stream reaches with alternating clear cut and buffer patches.

Objective

The objective of this study is to estimate the magnitude and duration of the effect of riparian harvest on stream temperature. There are several critical questions embedded within this objective (Table 18).

Table 18. Critical questions and analytic approaches to evaluate stream temperature response to FFR riparian buffers.

Critical Question	Analytic Approach	Data Requirements
3.1 *Site-Specific effects*-What is the change in stream temperature at a given treatment stream reach after harvest? Does the difference persist through time?	Hypothesis testing. H_o=The difference in water temperature between upstream and downstream sites pre-harvest= the difference post-harvest.	Comparison of upstream vs downstream water temperature pre-vs. post-harvest (repeated sampling may be necessary).
3.2. *Overall effect*-What is the mean stream temperature response to harvest across all sampling units relative to unharvested control sites?	Hypothesis testing. H_o= The mean temperature change at harvested units=mean change at unharvested units.	Comparison of stream temperature response at harvested units to unharvested sites.
3.3 *Exploratory analysis*-Are there site characteristics that could be used to indicate where the current rules are under- or over-protective?	Covariate Analysis. Identify relationship of site attributes with magnitude and direction of change after harvest.	Exploratory regression and graphical analysis.
3.4. *Compliance with WQ standards*-What is the proportion of treatment units meeting water quality standards pre- and post-harvest?	Metric estimation. The percentage of sites meeting state water quality criteria for stream temperature.	Comparison of post harvest treatment site stream temperature data with water quality criteria.

Study Design

The intent is to estimate the effect of harvest on water temperature in Type Np and Type F streams: 1) at each harvested site, relative to upstream temperature; and 2) to estimate the mean effect across all monitored harvest sites, relative to a set of control (unharvested) sites. Water temperature will be monitored at the upper and lower end of each harvest unit with at least one, or preferably two, years of pre-harvest data and two years post- harvest. To test for effects of harvest on water temperature at each site, the upstream site will serve as control site and post-harvest changes in downstream temperature will be evaluated relative to the control.

In order to estimate the mean effect of harvest on stream temperature, each treatment site will be paired with an unharvested control site with similar topographic, stream channel, and riparian stand characteristics. The control site will have no management within the RMZ and will be surrounded by a 100 ft buffer on both sides and the outer edge. If control sites cannot be paired with treatment sites, then control sites will be randomly chosen from a pool of unharvested sites similar to the treatment sites. Control sites typically will be second-growth forest and will not be harvested during the study period. Likely sources of control sites include industrial timberland and Department of Natural Resources land but may include USFS riparian reserves, small landowner reserves, natural resource conservation areas, municipal watersheds, or State Parks. Potential control sites near each treatment site will be solicited from land managers and assessed via aerial photos, mapping information, and site visits. Data on the pre-harvest stand characteristics will be taken from the photos and combined with other GIS and map attribute data (Table 19) to produce a ‘profile’ of each treatment site and used to match with a suitable control sites.

Table 19. Criteria for selecting paired control sites.

Attribute	**Categories**	**Control Site Criteria**	**Comment**
Stream type	F, N	Same as treatment	GIS
Forest zone	8 zones (see stratification above)	Same as treatment	GIS
Elevation	Continuous variable	Within 500 ft elev	GIS
Geology	Geo-groups	Same	GIS
Stand age	Continuous variable	Within 10 years	GIS/inventory data
Stream aspect	Continuous variable	Within 45 deg.	Topo map
Stand type	Conifer, mixed	Same as treatment	Aerial photo
Dominant species	Tree species	Same as treatment	Aerial photo
Density class or TPA	Dense, sparse, trees per acre	Same as treatment	Aerial photo
Channel gradient	Deposition (<4%); transport(4-20%), source(>20%)	Same as treatment	GIS/Topo map
Valley form	Confined; moderate, unconfined	Same as treatment	Aerial Photo
Eco-region	Eight forested eco-regions	Same as treatment	GIS

Two possible configurations will be used to produce paired treatment-control site replicates for Type F streams. The first option is to locate treatment and control sites on adjacent stream reaches. Each treatment-control replicate consists of a downstream harvest unit site with an adjacent upstream control site that will not be harvested. Both harvest and control sites will be a minimum of 1000 ft long (parallel to the stream). Consequently, the total length for needed for a one treatment-control pair is 2000 ft along the stream. The second option is to locate treatment and control sites on separate streams. This design requires two streams in close proximity, with similar riparian stands (both type and age) and stream channels of similar basin area, width, gradient, geology, elevation, aspect and valley landform. Only the second option will be used for Type N streams because the entire Np stream length will be studied.

Statistical testing of matched pairs of treatment and control sites is the preferred analytical approach. However, if it is not possible to find a matching control for each treatment site, an alternative analytic approach will be used to compare the total sample of control and treatment sites for the stratum (analogous to a paired t test vs two sample t test).

Site Selection

With respect to stream temperature, the riparian buffer's primary function is to provide adequate shade. However, other factors do influence stream temperature and its response to harvest, including air temperature and stream size (Adams and Sullivan, 1989). The influence of riparian vegetation on stream temperature is greatest in smaller streams, because adjacent trees more effectively shade narrower channels and smaller water bodies are more responsive to changes in solar radiation inputs because of the smaller water volume. Because water temperature is correlated to air temperature, high stream temperatures should be more likely at lower elevation, where mean air temperature is higher. We propose to begin testing the effectiveness of riparian harvest rules in low-elevation, low gradient streams (Table 20). The results will indicate the need for testing additional streams using different site criteria. If water temperature standards are met in these sensitive waters, then other less sensitive sites may not need to be tested.

From within each of the sampling groups, potential treatment sites will be identified by asking landowners to identify harvest units 1-2 years in advance of the harvest date (for pre-harvest monitoring). Potential sites will be screened for membership in the proposed sampling groups in Table 20 and matched with control sites, as described above, until the desired sample size is met. Sites with multiple prescriptions or with portions of the stream with channel migration zone buffers (CMZs), mass wasting buffers, stream adjacent roads, or one-sided riparian buffers will be excluded.

Table 20. Stream temperature sampling groups.

Sampling Group	Elevation	Channel Width	Gradient	Treatment
Type F- West-side	<1500 ft	10 ft	< 4%	Two-sided RMZ with yarding corridors
Type F- East-side	<3000 ft	15 ft	< 4%	Two-sided RMZ with yarding corridors
Type N- West-side	<1500 ft	10 ft	< 4%	Two-sided patch cut buffer
Type N- East-side	<3000 ft	15 ft	< 4%	Two-sided patch cut/partial cut buffer

Data Collection

Because the buffering strategy for west-side Type N streams (sensitive site buffers but otherwise buffer is discontinuous along stream) and east-side Type N streams (partial cut vs. clear-cut strategy) is fundamentally different than the Type F (continuous buffers of variable width), the Type N monitoring design will differ from the typical upstream vs. downstream model used for the Type F streams.

For Type F buffers temperature recorders will be deployed in the stream at the lower boundary of the harvest unit and at approximately 50 meters above the upper boundary following TFW guidelines (Schuett-Hames, 1999b). The upper thermistor is placed above the boundary to minimize the effects of the harvest on stream temperature at the upstream site. Shade measurement will be collected at the downstream site and at 50 m intervals for 300 m upstream. Monitors will be deployed by June 1or as early as practicable and retrieved after September 15th each year. The harvested stream reach should be at least 300 m long. Simultaneously, thermistors will be deployed in the control site at the same distance interval as the harvested site.

Rules for west-side Type N streams require buffers on the reach adjacent to the Type F junction and certain sensitive sites, including the perennial initiation point (PIP). A patchwork of clear-cut and buffer may be allowed on the remaining stream, (depending upon stream length) with at least 50% of the total stream length buffered. Therefore, harvest units will encompass most or all of the Type Np stream and, preferably, most of the Np basin. Thermistors will be installed at the edge of the PIP buffer, above the Type F junction, at the approximate upstream end of the Type F junction buffer, and at regular intervals along the entire Type Np stream. The lowest thermistor represents the overall effect of harvest on stream temperature, the PIP buffer thermistor acts as a control for the site-scale analysis, and the others will construct a longitudinal profile of temperature response. After harvest, additional thermistors will be installed at the edges of the patch buffer, to construct an after harvest temperature profile to correlate with the buffer configuration.

Rules for east-side Type N streams allow for a partial cut along the entire stream length or a clear cut along part of the stream or some combination of these within the same harvest unit. Pre-harvest, thermistors will be deployed above and at the lower end of the harvest unit, at 100m intervals throughout the unit, and just above the Type F junction. Post-harvest, these will be supplemented with thermistors at any clear-cut edges within the harvest unit.

In addition to water temperature, air temperature will be recorded within the riparian buffer near the uppermost stream thermistor on each site. Many of the variables listed in Table 14 will be measured during site selection. In addition, riparian shade, length of the stream in yarding corridors, length in clear cut, partial cut and buffer, and channel geometry and gradient will be measured. Monitoring will continue for two years post harvest and possibly longer if necessary to determine time for recovery from harvest impacts.

Quality Assurance

Quality Assurance for stream temperature and field measurements will consist of:

1) training,
2) thermistor check,
3) observational quality assurance visit, and
4) data error check.

Field personnel will receive training in the survey procedures in Schuett-Hames et al. (1999b). All thermographs used in the project will be checked for accuracy across a range of temperatures from 0 C to 20 C by submersing in an ice bath prior to installation and comparing the thermistor with a thermometer of known accuracy as the bath warms to room temperature. A quality assurance survey will be conducted during each crew's first week of field work (Pleus, 1994). Downloaded data will be error-checked following procedures in Schuett-Hames et al. (1999b).

Data Analysis

Data analysis will be conducted at two scales:

1) the site-specific (individual harvest unit) scale to estimate the effects at that site; and

2) across all harvested sites for the average effect due to harvest.

<u>Site specific evaluation</u>

At this scale the analysis will test for changes in daily maximum, minimum, and mean stream temperature after harvest. Changes in the treatment reach from pre- to post-harvest will be assessed with multiple linear regression. Using the model below, we can control for water temperature as it leaves the control reach and account for typical seasonal variation in water temperature, unrelated to harvest.

$T_{trmt} = b_0 + b_1 * T_{control} + b_2 * \sin(time) + b_3 * \cos(time)$

Where,

T_{trmt} = temperature at the treatment site,

$T_{control}$= temperature at the control site,

Sin(time) and cos(time)=terms to account for seasonal variation in water temperature,

B_0, b_1, b_2, and b_3 are the regression coefficients.

Because serially collected (time series) data are often auto-correlated and this violates the assumption of independent observations, seasonality terms will be included in the model and the interval between observations may need to increase (Helsel and Hirsch, 1992). Using daily maximum temperature data from several small, perennial streams in Washington state (Weyerhaeuser Co, unpublished data.), a combination of seasonal functions and reduction in the sampling frequency to twice weekly reduced autocorrelation to an acceptable level.

Changes in treatment water temperature will be assessed by comparing the pre- vs. post-harvest slope and y-intercept of the treatment temperature vs. control temperature regression line.

The specific hypotheses tested will be:

1) $H_{0\text{-y-intercept}}$: $B_{0\ \text{pre-harvest}} = B_{0\ \text{post-harvest}}$ (The pre- and post-harvest regression lines have different y-intercepts).

2) $H_{0\text{-slope}}$: $B_{1\ \text{pre-harvest}} = B_{1\ \text{post-harvest}}$ (The pre- and post-harvest regression lines have different slopes).

If either of these hypotheses is rejected, then significant post-harvest changes in water temperature have occurred. However, the rejection of $H_{0\text{-y-intercept}}$ must be interpreted with caution. By definition, differences in the y-intercept are evaluated at x (control reach water temperature) = 0, requiring extrapolation well beyond the expected range of x values. Instead, the y-intercept will be evaluated at the lower range of measured control reach temperature by constructing confidence bands about the regression lines.

Using the same data, Figure 4 shows the post-harvest changes in treatment reach water temperature (decreases in the y-intercept and slope of the treatment vs. control line) as the vegetation regenerates following harvest. In this case no pre-harvest data were available and second and third year following harvest are being compared with immediately after harvest, but the technique is same.

A power analysis was done using these data to estimate the minimum detectable change in temperature between years. The linear model described above with twice per week sampling was used and the variance of the regression residuals was calculated for each of seven sites and three years each. The minimum detectable difference was calculated as:

$$\Delta T = (2s^2 / \sqrt{n})(t_{1-\alpha/2} + t_{1-\beta})$$

Where ΔT = detectable change,

s^2= variance of residuals,

n= sample size,

α= 0.05,
β= 0.05.

Estimates of ΔT ranged from 0.1 to 1.7 C (n= 21), with median and mean values of 0.3 and 0.4 C, respectively. The mean and median values are well within the range of expected change and are near the operational limits of the temperature monitors.

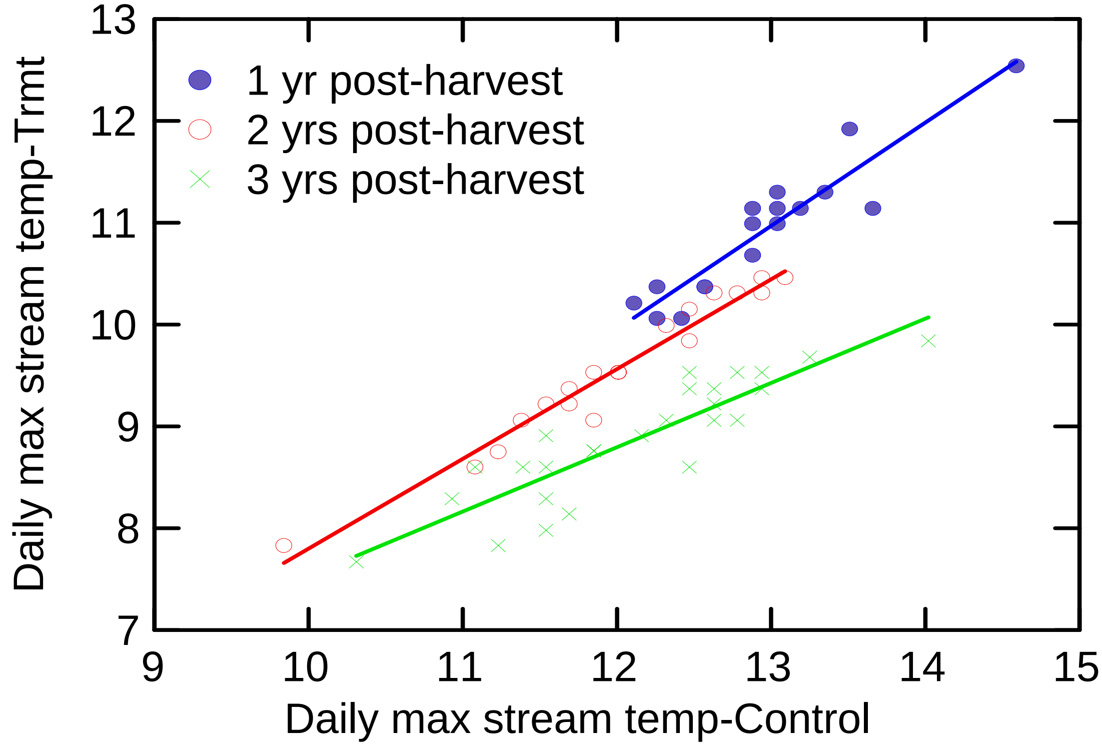

Figure 4. Changes in post-harvest temperature in treatment reaches vs. control reaches.

Evaluation of the overall effectiveness

This will test the mean temperature response at harvested sites vs. at control sites. Variables to be tested include the maximum 7-day average of daily maxima and maximum 7-day mean stream temperature. Temperature response first will be evaluated using an analysis of variance (ANOVA) with the difference in stream temperature between the control and treatment reaches as the dependent variable and harvest as the treatment. The hypothesis:

H_0: Δpre= Δpost,

where Δpre = Control-Harvested reach before harvest and

Δpost= Control-Harvested reach after harvest,

will be tested. However, this analytical approach may be lacking in power if the sites and harvest strategies differ. There are a wide range of harvest options that may affect steam temperature to varying degrees. In addition, the pool of potential sites is determined by the landowner, based largely on economic and silvicultural considerations. Other factors can also affect stream temperature, including elevation, aspect, shade, stream depth, air temperature, and ambient stream temperature above the harvested reach. If the sites differ with respect to these covariates, then 'noise' in the data could mask the impact of harvest. To address this, regression analysis will be used to relate post-harvest changes in stream temperature at harvested sites to site-specific conditions. This exploratory analysis should identify sources of variability in the data due to unavoidable differences in the sites selected. If these sources of variability can be identified, they may be built into the buffer strategy or used to direct further research.

Comparison of pre- and post-harvest data with water quality standards will follow the guidelines used by the Department of Ecology.

Implementation

The uncertainty surrounding the effects of harvest is greatest in Type N streams. However, because the range of harvest options is greater on east-side Type N streams, initially, only west-side Type N streams will be targeted.

The paucity of comparable data makes estimating sample size difficult. Because sites must be selected opportunistically from available harvest units rather than harvesting on sites selected for specific characteristics, the study may not be able to control for some factors that will influence the outcome. As a result, the *post hoc* regression analysis may be necessary to differentiate between harvest impacts and between site variability requiring a relatively large sample size. A sample size of 20 treatment-control site pairs was chosen as a reasonable compromise.

Budget

The budget estimate (Table 21) assumes that CMER staff and agency staff will select sites. The statistical analyses and reports will be done either by agency staff or will be contracted out at a later date. The budget figures include data collection, data QA, and equipment costs. The annual deliverables include: all data in specified electronic formats, field data forms, and a progress report.

Table 21. Annual cost estimates for west-side Type N riparian effectiveness monitoring. Budget includes 20 treatment-control site pairs with two years pre- and post-harvest monitoring.

2002	2003	2004	2005	Total
$126,000	$45,000	$83,000	$45,000	$298,000

Structure and Organization

The proposed scenario for implementation of the project would involve a number of different parties.

Project oversight. CMERs Riparian Scientific Advisory Group (RSAG), or a sub-group appointed by RSAG, will be responsible for providing direction and guidance, overseeing implementation and making decisions regarding implementation of the project.

Project management. CMER or agency staff will be responsible for managing the implementation of the project, ensuring that tasks are completed on schedule and according to specifications, and reporting back to RSAG on progress and for guidance as needed.

Contract administration. The DNR adaptive management administrator and contract specialist will be responsible for generating contracts necessary to implement the project, approving work, and processing invoices and payments.

Site selection. Site selection and screening will be the responsibility of the CMER study implementation coordinator and CMER staff.

Field surveys. Field survey work may be done by a combination of CMER staff, DOE staff, and contractors.

Quality assurance. Implementation of quality assurance will be the responsibility of CMER staff. Actual quality assurance surveys may be contracted in some cases.

Data management. Data error-checking, processing and archiving will be the responsibility of CMER staff. Data management will be done according to guidelines in the CMER standards and procedures manual.

Data analysis. Data analysis will be done by NWIFC biometricians, and CMER/DOE staff, following procedures in the study plan. Draft results will be reviewed by RSAG and CMER.

Report Preparation. Project progress reports will be prepared annually by CMER staff, DOE staff and NWIFC biometricians.

Technical Review. Technical review of project results will be done by the Scientific Review Committee.

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