A REVIEW OF EFFECTIVENESS EVALUATIONS EXAMINING FOREST PRACTICES AND WATER QUALITY

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July 2003

FOREWARD

This project was carried out during a co-op work term by Perry Hystad, a fourth year Geography student at the University of Victoria. The project was sponsored by Forest Practices Branch, Ministry of Forests, to support the development and implementation of a program to evaluate the effectiveness of forest practices legislation at protecting the water value during forest and range activities.

Any views expressed in the report do not necessarily represent the views of the Branch or the Ministry of Forests.

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1.0 INTRODUCTION

The purpose of this project was to examine how jurisdictions other than British Columbia have evaluated the effectiveness of forest practices that are designed to protect water quality, or that may influence water quality, quantity, and timing of flows. The aspects of these projects that were of specific interest were:

- the forest practices examined
- the criteria which had to be met to determine if a practice was effective
- how sites were selected
- the variables measured, or observed
- how the data was analysed
- the results of the evaluation
- any recommendations made as a result of the evaluation.

This report summarises the findings for each of these project aspects, and provides other information found to be of interest. In Appendix A, a summary is provided of each evaluation project included in the report.

The information gained through this research on effectiveness evaluations will be used to aid in the creation of an effectiveness evaluation program for BC, one component of which will evaluate the effectiveness of forest practices at protecting water quality. Appropriate methods for evaluation elements such as site selection, sample size, monitoring techniques and effectiveness criteria can then be incorporated in the planning process of a management practices effectiveness evaluation.

2.0 EFFECTIVENESS MONITORING

Forestry activities such as harvesting, road building and silviculture have the potential to impact water resources if they are not carried out in a manner that prevents or minimizes the introduction of sedement, chemicals and pathogens into the the stream. The impacts of forest management activities on the environment are (a) not easily traceable to any discreet facility, (b) induced by natural processes such as precipitation, and (c) best controlled using BMPs (NCASI, 1988). A “best management practice” (BMP) can be defined as a practice or combination of practices that are thought to be the most effective method to reducing the amount of pollution from non-point sources. Examples of forestry BMPs are stream management zones (SMZs), and maximum allowable gradients for logging roads and skid trails.

Effectiveness monitoring is used to determine whether the plans or practices implemented are actually meeting their desired outcomes; that is, are they effective in reducing pollution and environmental degradation? Effectiveness evaluations of silvicultural nonpoint source control programs have traditionally been based on control technology monitoring (BMPs) rather than direct monitoring of water quality and comparison to water quality standards (NCASI, 1988). This has led to effectiveness evaluations based on qualitative surveys or audits rather than quantitative analysis. This

report will examine the advantages and disadvantages of both qualitative and quantitative based effectiveness evaluation projects.

To evaluate the effectiveness of BMPs accurately it is important to also evaluate if practice were carried out properly (implementation monitoring), and whether the desired conditions actually provide for protection of natural conditions (validation monitoring). The primary focus of this report, however, is on effectiveness monitoring.

3.0 DEVELOPING A MONITORING PLAN

A written monitoring plan is a necessary tool for conducting a successful monitoring program. A monitoring plan should explain the overall objectives of the project, the materials and individuals required, and the methodologies needed to reach the desired goals. This report will briefly cover what a monitoring project's study objective should incorporate and what an "ideal" BMP effectiveness study should accomplish. This will be followed by an in-depth analysis of monitoring parameters (e.g. sampling location, sample variables, and timeframes) that have been used in existing BMP effectiveness evaluations.

4.0 MONITORING OBJECTIVES

The fundamental step in developing a monitoring plan is to determine the goals and objective of the program. In the past, numerous monitoring projects have not fully considered this aspect of the design process, resulting in data collection efforts that led to little useful information for decision making (Macdonald et al., 1991). Monitoring program objectives must convey what data will be gathered and how the resulting data will be used. Vague statements will lead to monitoring programs that produce too little or too much data, thereby failing to meet the data needs or exceeding budget requirements.

For each objective, a number of issues should be identified that encompass a series of site-specific monitoring and research issues, watershed scale monitoring issues, and specific research questions. These issues will break each monitoring objective into smaller, more manageable areas. This presents a focus for developing testable hypotheses and designing efficient sampling programs that will provide the information desired.

There was a noticeable pattern to the objectives established for the BMP projects reviewed. The objectives are guided by the philosophy that effectiveness monitoring programs should be a practical management tool designed to: (1) provide answers to specific questions about the effectiveness of forest practices in protecting aquatic resources; (2) document trends in the conditions of aquatic resources in managed forest watersheds; and (3) produce information that identifies why practices are or are not effective.

Jackson (2002) describes the ideal BMP effectiveness study as one which would:

- produce high-resolution data capable of detecting small changes (allow confident determination of 10% change)
- allow calculations of daily, seasonal, and annual pollutant loads
- encompass the range and mode of operational behaviour (i.e. show variability in pollutant loads from apparently similar sites)
- quantify marginal benefits in the degrees of BMP implementation (e.g. value of increasing SMZ width by 30 feet)
- quantify relative pollutant contributions from different sources (i.e. how much sediment originates on roads compared to natural erosion sites)
- relate pollutant loading/stream alteration to biological response (e.g. increased sediment delivery caused an increase/decrease in macroinvertebrate abundance and diversity).

It is extremely rare that any monitoring program answers all of these questions, especially those dealing with the variability of natural systems. Because of the inherent difficulties in monitoring environmental conditions, it is pivotal to define precisely the monitoring questions and develop a specific framework to achieve the projects goals.

5.0 PROJECT DESIGN

The level of monitoring and monitoring strategy must be appropriate to the objectives of the monitoring program. Four major levels of monitoring have been determined that are used for evaluating the effectiveness of forestry BMPs in meeting water quality goals: BMP I, II, III, and IV.

- BMP effectiveness I uses empirical observations and a limited amount of qualitative data to evaluate BMP effectiveness. This method is highly subjective and relies on professional judgement. This method requires experienced personnel to judge whether BMPs are effective in protecting water quality.
- BMP effectiveness II depends largely on qualitative data and limited quantitative data for analysis leading to the evaluation of effectiveness.
- BMP Effectiveness III relies predominantly on quantitative data, with additional qualitative data for detailed analysis to evaluate effectiveness.
- BMP Effectiveness IV relies on quantitative data, with some qualitative data for detailed analysis to evaluate effectiveness, to establish water-quality criteria, goals, or cause and effect. This level of monitoring is usually associated with research (USDA, 1990).

Low level monitoring (BMP effectiveness I and II) identifies high-level needs and has the potential to extend high-level monitoring information. High level monitoring (BMP effectiveness III, and IV) develops information that supports or validates decisions made in low-level monitoring (USDA, 1990). Any wide-ranging BMP effectiveness evaluation should be composed of complementary low level and high level monitoring strategies.

5.1 Sample Size

Sample size is a function of the desired level of precision subject to the cost constraints of the project. In a recent BMP implementation and effectiveness study carried out for the State of Minnesota, it was determined that a statewide sample of 120 sites per year would provide adequate representation of desired categories for onsite audits. Given the logistics and cost, a sample size greater than this was unrealistic. It is important that sample size is determined with help from statisticians, who are involved from the onset of the project.

The cost of monitoring BMP effectiveness is very high, especially when instream monitoring is required, and is usually the primary constraint to sample size. The cost for one BMP effectiveness study in Florida was $290,000 over a 1.5-year study period. In the US, those States with regulatory BMP programs invest $500,000 to $750,000 per state in compliance checks annually (Ellefson et al., 2001). A recent estimate of the price to run a long-term, modern, continuous sampling station was quoted at $30,000 per year. From these estimates it is obvious that sample size will be influenced largely by budget constraints. Below, Table 1 indicates the methods currently being used in the United States to evaluate BMP effectiveness by State (note the low number of water sampling).

Table 1. State BMP effectiveness monitoring (Stuart, 2000).

Effectiveness Monitoring	**Number of States Performing Activity**
Number of states involved in monitoring	17
Visual observation of sediment delivery	14
Visual observation of impairment	14
Water sampling	2
Biological sampling	3
Research	3

5.2 Study Type

The selection of different test sites will parallel different study techniques. To document the magnitude of change resulting from the implementation of BMPs, numerous monitoring techniques can be used. The advantages and disadvantages of certain monitoring techniques will be based on a number of environmental variables, and the desired monitoring information. It should be noted that for many of the experimental designs the time period required to observe BMP related impacts will depend upon how large of a change is actually being made. For example, a 30 percent reduction in concentration will take longer to observe above the variability of a natural system, than will a 90 percent reduction (Spooner et al, 1985). The following are definitions of common study designs used to determine BMP effectiveness:

- Up-down – Upstream and downstream comparisons of monitored parameters.
- BACI Up-Down – Before and after treatment and upstream-downstream comparisons of monitored parameters.

- Paired – Paired watersheds to establish quantifiable relationships between monitoring parameters.
- X-Land – Cross landscape comparisons with replication of watersheds and monitoring parameters.
- BACI – Before and after comparisons of sets of small watersheds and their associated, monitoring data.
- Process Studies – Based on measuring, mapping, and monitoring the factors that contribute to the water quality impacts of interest.
- Stats-GIS – Based on regressions, cluster analysis, or ordination analysis of water quality metrics and land use characteristics.
- NAWQA – Based on USGS National Water-Quality Assessment procedures (e.g. stratified sampling techniques).

Table 2 summarises these study designs and their applicability to certain project goals.

Table 2. Study designs and project goals (Jackson, 2002).

	Study Design Type							
GOALS	Up-down	BACI up-down	Paired	x-land	BACI	Process Studies	Stats-GIS	NWQA
High resolution	limited	limited	Yes	No	Maybe	Yes	Maybe	Yes
Daily, seasonal, annual loads	Limited	Limited	Yes	No	Prob. no	Yes	Prob. no	Yes
Range and mode	Possible	Possible	No	Yes	Possible	Possible	No	No
Marginal benefit	No	No	No	Yes	Yes	Yes	No	No
Relative loading	No	No	No	No	Possible	Possible	No	No
Channel morphology	Yes	Yes	Yes	Yes	Yes	No	No	No
Biological response	Partial	Partial	Partial	Partial	Partial	Possible	No	No
Timeframe	Quick	2-3 years	Long to quick	2-3 years	Variable	Variable	Variable	Variable
Stream size	Small	Small	Small	Variable	Small	Small	Any	Any

Paired and nested (up-down) watershed approaches are the most appropriate methods when trying to evaluate the impact or benefit of BMPs at the watershed scale (Spooner et al., 1985). The key advantage to these two methods is that they incorporate climatic variation from year to year and variation between watersheds in a statistically accountable fashion, providing there is a sufficient calibration period.

If data cannot be collected for the calibration period, a multiple-watershed design should be used. This method uses multiple watersheds in a region, some with BMP implementation and others without. By monitoring numerous watersheds, the true variability between watersheds is considered. The results from this type of study design can therefore be transferred to other watersheds in the region.

Ambient water quality information can also be used in determining BMP effectiveness. BC has a significant number of ambient water quality monitoring stations that have the potential to be incorporated into a provincial BMP effectiveness evaluation. The problem with using ambient water quality data is that changes in water quality are very difficult to associate with land-use activity. A study design based on ambient water quality data would have to be accompanied by qualitative site surveys and site specific research projects.

5.3 Site Selection:

The process of site selection is a function of water resource type, monitoring objectives, and data analysis plans (USEPA, 1997). The selection of the appropriate site or sites for monitoring depends largely on the desired objective of the project. The scale of the project will also determine the geographical and temporal constraints for site selection. Generally, three geographic scales are considered when selecting the appropriate sites. The first is the sample point, which provides representative data to a specific area. The second is the reach approach, which uses multiple sites to reflect the conditions and trends for a certain portion of a stream. The third geographical scale is the basin scale. This scale uses multiple reaches to reflect trends throughout a watershed.

Individual study locations are also broken into site types:

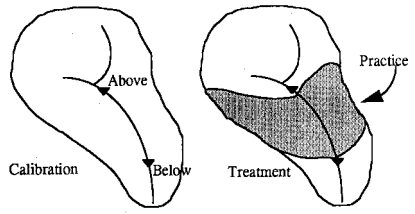
- Study Sites are selected to answer very specific questions. These can include those questions about the effects of certain forestry BMPs.
- Reference sites reflect the best available conditions present within a specific stream, watershed basin or ecoregion. A realistic reference site usually represents the best attainable conditions. Ideally more than one reference site will be used for studies that include several variables.
- Randomly selected sites are chosen completely at random to attain a sample that is most representative of the natural environment. In most cases, random sites are grouped, or stratified, according to certain factors such as ecoregion or stream order (USEPA, 1997).

The larger BMP evaluations, such as those completed by California, Washington, and Oregon State, utilised either a random sampling design or a stratified random sampling design to select an unbiased representative sample. Usually projects of this magnitude involve qualitative descriptions of areas chosen at random. These study locations ranged from specific watershed groups to individual Timer Harvest Plans (THPs), and were stratified based on such aspects as georegion or mass failure probability.

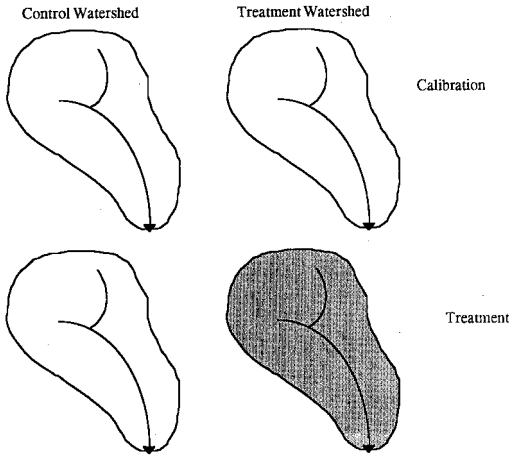
5.4 Monitoring Stations

Once a general study area has been selected, individual monitoring site locations must be determined. While the major consideration for monitoring location is based on study design, additional considerations, such as local physiographic features and site accessibility, must be incorporated.

The two monitoring designs that are most effective in evaluating BMPs are the nested and paired watershed designs. These are indicated below in Figure 1, with the triangles indicating the relative location of monitoring sites (USEPA, 1997).



A) Nested Paired Watershed Study Design



B) Paired Watershed Study Design

Figure 1. Monitoring locations for nested and paired watershed study design.

Sediment sampling sites should be located in sink areas as determined by intensive surveys, reconnaissance surveys, and historical data of the region. When conducting specific evaluations of BMPs, the monitoring site should be located immediately downstream of the activity of interest. The easiest place to obtain this information may be a few hundred feet downstream of the activity; however, this would not provide a representative sample because the likelihood of capturing other supplementary influences is very high. The location for a sediment sampling site should also be chosen by considering the sediment mechanics and the hydrological characteristics of the waterbody (USEPA, 1975).

Temperature is a parameter that requires extra consideration when planning monitoring locations. Some of the additional considerations unique to stream temperature include:

- Install temperature recorders at sites with turbulence and mixing, such as riffles, runs, or cascades.
- Install temperature recorders toward the lowest point of the channel bed (thalweg) where possible.
- Ensure temperature recorder will be submerged in low flow periods.

- Shade temperature recorder.

Figure 2 shows the locations for monitoring temperature responses to forest harvesting (OWEB, 1997). Note site one and four are located 1000 feet upstream and downstream of the harvest block to act as control reaches.

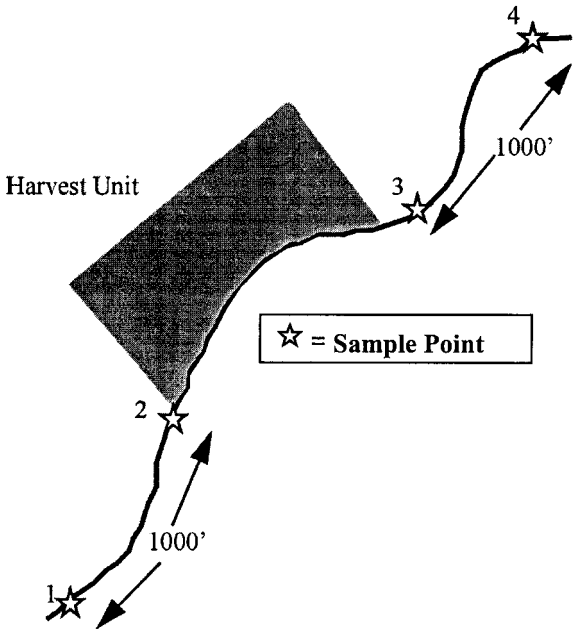


Figure 2. Monitoring locations to determine stream temperature response to land-use.

In general, individual monitoring locations will be a function of the local geomorphology of each region. However, several guidelines for establishing site locations for physical and chemical water column sampling should be incorporated into a monitoring design framework:

- Sites should be located at representative locations in mainstem rivers. These sites can be used to characterise the overall quality of the area's surface waters and will provide water quality baselines against which progress can be measured.
- Sites should be located in water quality limited areas. Sites in water quality limited areas can be used to evaluate the overall pollution control strategy and BMP system effectiveness.
- Sites should be located upstream and downstream from representative land use areas. These sites can be used to compare the relative effects of pollution sources and morphologic zones on water quality and document baseline water quality conditions.
- Sites should be located to measure the input and output of nutrients and other pertinent substances into and from waterbodies. This information can be used to establish cause-and-effect relationships, identify problem areas, and indicate appropriate corrective measures.
- River sections monitored should be smooth, straight, accessible and uniform in depth, and at least 100 meters upstream of a confluence (USEPA, 1997).

The following table indicates the general locations of monitoring stations used in the reports analysed. Appendix A will provide a more thorough description of monitoring methodologies.

Table 3. Location of monitoring stations.

PROJECT TITLE	MONITORING LOCATION
Effectiveness of Silvicultural Streamside Management Zones in the Sand-Clay Hills of Mississippi.	-Upstream/downstream locations corresponding to harvest boundaries. -60 m sampling reach.
California Hillslope Monitoring Program: Monitoring Results from 1996 through 1998.	-Randomly selected site surveys.
Effectiveness of Riparian Management Areas and Hardwood Conversions In Maintaining Stream Temperature.	-Upstream/downstream locations corresponding to harvest boundaries. -500 or 1000 feet downstream of harvest unit.
Harvest Effects on Riparian Function and Structure Under Current Oregon Forest Practice Rules.	-Randomly selected distances from bottom of harvest unit.
Evaluating the Effectiveness of Maryland's Best Management Practices for Forest Harvest Operations.	-Lowermost reach of study watersheds.
Evaluating Management Practices for Reducing Sediment Production from Forest Roads.	-Bottom location of each road plot. -Road surface flow and berm flow.
Using Stream Bioassessment to Monitor Best Management Practice Effectiveness.	- Upstream/downstream locations corresponding to harvest boundaries. -Sites representative of higher slope and soil erodibility conditions.
The Effects of Roading, Harvesting and Forest Regeneration on Streamwater Turbidity Levels in a Moist Eucalypt Forest.	-Lowermost reach of study watersheds.
Effectiveness of Washington's Forest Practice Riparian Management Zone Regulations for Protection of Stream Temperature	-Upstream/downstream portion of RMZ boundaries.
South Dakota Silviculture Best Management Practices Audit: Project Final Report.	-Randomly selected site surveys.
Alaska Sediment BMPs Evaluation	-Twenty feet downstream of culvert outlet.
Effectiveness of Vegetation in Erosion Control from Forest Road Sideslopes	-Lowermost cutslope and fillslope locations.
Effects of Logging on Macroinvertebrates in Streams With and Without Buffer Strips	-Upper, lower and middle reaches of watershed.
Results of Voluntary Forest Management Practice Guidelines to Protect Water Quality in the South-eastern US: An Example from South Carolina.	-Lowermost reach of study watersheds.
Effects of Best Management Practices on forest Streamwater Quality In Eastern Kentucky	-Lowermost reach of study watersheds.
Hydrologic Impacts of logging an Appalachian Watershed Using West Virginia's Best Management Practices	-Lowermost reach of study watersheds.

5.5 Monitoring Variables

Forestry activities have the potential to influence a number of environmental variables. For this reason, forestry monitoring guidelines have been expanded beyond traditional

monitoring methods (i.e. temperature, turbidity) to evaluate and review a wider range of parameters. These parameters can be grouped into the following major categories:

- Physical and chemical constituents (temperature, pH, conductivity, nitrogen, phosphorus, dissolved oxygen, pesticides).
- Flow characteristics (size, timing and peak flows, low flow, and water yield).
- Sediment (bedload, suspended sediment, turbidity).
- Channel characteristics (cross section, width-depth ration, pool parameters, thalweg profile habitat units, bedload material, bank stability, etc.).
- Riparian characteristics (riparian canopy opening, riparian vegetation).
- Aquatic organism (bacteria, algae, macro-invertebrates, fish).

There are many variables that can be monitored to evaluate the effectiveness of forestry BMPs in protecting the quality of water resources. Table 4 highlights the variables monitored in the effectiveness evaluations examined in this report.

Table 4. Variables monitored.

PROJECT TITLE	VARIABLES MONITORED
Effectiveness of Silvicultural Streamside Management Zones in the Sand-Clay Hills of Mississippi.	- Electrical conductivity, DO, pH, temperature, turbidity. - Bank height/width, % canopy cover, % vegetation cover on bank, and stability. - Macroinvertebrates, fish diversity, species richness and diversity.
California Hillslope Monitoring Program: Monitoring Results from 1996 through 1998.	- Qualitative survey of specific BMPs with potential to influence water quality.
Effectiveness of Riparian Management Areas and Hardwood Conversions In Maintaining Stream Temperature.	- Stream temperature. - Stream flow, aspect, elevation, gradient, thalweg depth, wetted and bankfull width, substrate, buffer width, harvest unit length, and cover.
Harvest Effects on Riparian Function and Structure Under Current Oregon Forest Practice Rules.	- Percent stream cover and shade. - Buffer tree dbh, distance from stream, degree of lean, percent slope, and species. - Stream gradient, stream orientation, dominant substrate, and wetted/bankfull channel width.
Evaluating the Effectiveness of Maryland's Best Management Practices for Forest Harvest Operations.	- Stream stage and discharge. - Total suspended sediment. - Temperature. - Benthic macroinvertebrates, primary/secondary instream habitat, and riparian zone habitat.
Evaluating Management Practices for Reducing Sediment Production from Forest Roads.	- Continuous flow and volume. - Total suspended sediment. - Rainfall and traffic information.
Using Stream Bioassessment to Monitor Best Management Practice Effectiveness.	- Benthic macroinvertebrates. - Dissolve oxygen, pH, conductivity, temperature, total suspended solids, turbidity, colour, nutrients, and coliform bacteria. - Substrate type and availability, water velocity, habitat smothering, and riparian conditions.
The Effects of Roading, Harvesting and Forest Regeneration on Streamwater Turbidity Levels in a Moist Eucalypt Forest.	- Turbidity. - Discharge.

Effectiveness of Washington's Forest Practice Riparian Management Zone Regulations for Protection of Stream Temperature	- Temperature, and discharge. - Riparian shade levels. - RMZ length, gradient, distance from divide, stream depth, bankfull stream width, RMZ width, and tree count information.
South Dakota Silviculture Best Management Practices Audit: Project Final Report.	- Qualitative survey of specific BMPs (road design, surface drainage, construction, maintenance, timber harvesting, SMZ, etc.).
Alaska Sediment BMPs Evaluation	- Turbidity and precipitation. - Road condition survey (length of ditch erosion, frequency of functional cross drains per mile, damaged road drainage structures, area of un-vegetated road cut slopes).
Effectiveness of Vegetation in Erosion Control from Forest Road Sideslopes	- Suspended sediment, and precipitation. - Inspections of ground cover conditions.
Effects of Logging on Macroinvertebrates in Streams With and Without Buffer Strips	- Benthic macroinvertebrates. - Riffle complexes.
Results of Voluntary Forest Management Practice Guidelines to Protect Water Quality in the South-eastern US: An Example from South Carolina.	- Stream discharge. - Dissolve oxygen, pH, conductivity, temperature, total suspended solids, turbidity, colour, nutrients, and coliform bacteria.
Effects of Best Management Practices on Forest Streamwater Quality In Eastern Kentucky	- Flow data, suspended sediment. - Specific conductivity, total alkalinity, pH, numerous chemical properties. - Temperature.
Hydrologic Impacts of logging an Appalachian Watershed Using West Virginia's Best Management Practices	- Flow data and temperature. - Major ions, pH, calcium, magnesium, potassium, nitrate, and sulphate.

5.6 Monitoring Timeframe

The monitoring timeframe is vital to the statistical significance of any conclusions resulting from a monitoring project. A monitoring timeframe incorporates how long the actual program will be carried out for, and the specific timing of onsite monitoring. These schedules will be based on objectives, budgets, and the statistical significance desired in the results. Statisticians should be involved from the onset of a monitoring project to ensure sufficient data is collected for interpretation. Below is a review of the monitoring timeframes from completed effectiveness evaluations.

Table 5. Summary of monitoring timeframes for effectiveness evaluations.

PROJECT TITLE	MONITORING TIMEFRAME
Effectiveness of Silvicultural Streamside Management Zones in the Sand-Clay Hills of Mississippi.	-Study conducted over duration of 1999-2000. -Stream chemistry sampled monthly, for 4 months pre/post harvesting. -Habitat and macroinvertebrate parameters measured at monthly intervals.
California Hillslope Monitoring Program: Monitoring Results from 1996 through 1998.	-Site surveys conducted from 1996-1998 -Qualitative one time site surveys.
Effectiveness of Riparian Management Areas and Hardwood Conversions In Maintaining Stream Temperature.	-Monitoring July through September 1995. -Temperature data collected every 48 minutes. -Qualitative analysis of physical and vegetative data throughout duration of monitoring project.
Harvest Effects on Riparian Function and Structure	-40 pre-harvesting site surveys measuring shade and

Under Current Oregon Forest Practice Rules.	cover in 1994. -25 plots revisited after harvesting.
Evaluating the Effectiveness of Maryland's Best Management Practices for Forest Harvest Operations.	-Monitoring from August 1995 to July 1999. -Stage measured continuously at 15-minute intervals. -Biweekly grab samples of water quality. -Temperature measured at 20-minute intervals throughout growing season. -Benthic macroinvertebrates measured on three occasions throughout growing season.
Evaluating Management Practices for Reducing Sediment Production from Forest Roads.	-Two water samples per rainfall event for each non-continuous plot. -One water sample per rainfall event in continuous plots.
Using Stream Bioassessment to Monitor Best Management Practice Effectiveness.	-Bioassessment and water chemistry grab sampling carried out for pre-harvest conditions, Feb. 1996, and post harvest conditions, Feb. 1997.
The Effects of Roading, Harvesting and Forest Regeneration on Streamwater Turbidity Levels in a Moist Eucalypt Forest.	-Samples taken for 7 pre-treatment and 8 post-treatment years (1976-1991). -Turbidity and water chemistry collected for all storm events for the duration of 3-hours per event.
Effectiveness of Washington's Forest Practice Riparian Management Zone Regulations for Protection of Stream Temperature	-Monitoring during summer of 1990. -Temperature data summarised every hour for max/min and mean values based on 5-second hydrographs.
South Dakota Silviculture Best Management Practices Audit: Project Final Report.	- Qualitative one time site surveys conducted in 2001.
Alaska Sediment BMPs Evaluation	-Monitoring occurred throughout 1999. -Turbidity sampling occurred 3, 42 and 49 hours after structure installation. -Qualitative surveys of road erosion sources throughout installation and post-installation period.
Effectiveness of Vegetation in Erosion Control from Forest Road Sideslopes	-Monitoring duration from 1995-1999. -Four year study period. -Sediment tanks collected every one to twelve weeks depending on time required to fill. -18 inspections of ground cover spaced equally throughout 4-year study.
Effects of Logging on Macroinvertebrates in Streams With and Without Buffer Strips	-57 monitoring stations monitored from May 3 to Sept. 13, 1975. -8 benthic macroinvertebrates samples for each station, spaced evenly throughout monitoring period.
Results of Voluntary Forest Management Practice Guidelines to Protect Water Quality in the South-eastern US: An Example from South Carolina.	-Flow rates averaged hourly. -Water quality parameters determined for one stormflow and two baseflow conditions each month.
Effects of Best Management Practices on forest Streamwater Quality In Eastern Kentucky	-Streamflow measured continuously 18 months prior to harvesting. -Suspended sediment collected every 6 hours. -Weekly water quality grab samples. -Sampling ran Feb. 1982 to Feb. 1993.
Hydrologic Impacts of logging an Appalachian Watershed Using West Virginia's Best Management Practices	-Weekly sampling of water quality. -May1 to April 30th water year. -Suspended sediment collected during storm events. -Weekly min/max temperature reading.

Projects with excellent spatial design, but a poor monitoring timeframe, will result in water quality data that cannot be correlated to land-use practices. An excellent example of such a program is given below.

Beginning is 1981, the Georgia Environmental Protection Division conducted a three year monitoring study of several forestry activities. The objectives of this study included: (1) determining the quality of undisturbed streams and water affected by various nonpoint sources, (2) identifying water quality changes associated with land activities, and (3) determining whether these changes impaired or inhibited beneficial use of water (Mikelson, 1984). The cost of this project was around $250,000.

Clusters of streams located in major physiographic regions and representing various land use activities were identified for monitoring. Five streams with pending commercial forest activities were selected and monitored before and after harvesting. For each stream, data was collected on the basin characteristics and land-use activities, stream biology, water quality, and aquatic and riparian vegetation. Water samples were collected on a semi-monthly basis, and metals and organic compounds were collected on a quarterly schedule.

The decision to use an extensive but infrequent sample schedule to collect biological and water quality indicators was based on previous "urban" nonpoint assessments done throughout the United States. The infrequent collection of water quality samples proved to be ineffective in indicating impacts to forest stream systems. It is important to realise that forestry activities, as contrasted with agriculture, appear to exert a temporary, rather than continuing effect on the environment (Mikelson, 1984).

This assessment clearly demonstrates that infrequent collection of water quality samples for analysis, of before and after stream conditions, is inadequate to assess stream quality impacts as they relate to forestry activity.

6.0 EFFECTIVENESS CRITERIA

The single most important factor when identifying monitoring variables is to establish which variables are likely to be the most sensitive indicators of potential change or trends given the objective of the program (http://srmwww.gov.bc.ca/risc/pubs/aquatic/design/index.htm). Effectiveness criteria can then be based on these variables and the water quality standards that are to be upheld, or the information gained through qualitative analysis of on-site conditions.

Monitoring programs based on subjective interpretation of impacts are increasingly becoming the basis for effectiveness evaluations. The variability throughout natural environments, in geologic conditions, climate, hydrology, and vegetation, require traditional monitoring methods that involve complex monitoring designs, sophisticated equipment, and extremely high costs. Even with the best possible monitoring system it is sometimes impossible to connect water quality changes to land use impacts.

BMP monitoring, using qualitative data usually consists of field audits and visual evaluations of the applications, and are based on professional judgement. The drawbacks to qualitatively based BMP evaluations include: the time and training required by assessment teams, the possibility of incorporating individual values and biases, and most importantly the limited timeframe for analysis of site conditions.

Past monitoring projects that used only water quality standards and quantitative methods have been unsuccessful primarily due to unrealistic performance measures. A large portion of current water quality standards fail to realise the temporal and spatial variability in water quality that occurs in a watershed (Ice, 2002). Assessments often impose unrealistic standards, that waterbodies may or may not experience in natural conditions.

Comparison analysis between different watersheds, or different periods of monitoring, is one of the most efficient methods to determine whether forestry BMPs are effective in protecting water quality. However, a problem associated with this technique is the question of how much of a change must be observed before a BMP is classified as ineffective, and whether or not the change can be entirely attributed to specific forestry activities.

The state of Oregon recently published a report entitled Sufficiency Analysis: A Statewide Evaluation of Forest Practices Act Effectiveness in Protecting Water Quality. The majority of parameters addressed in this report are interrelated, as are the forest practices that are being examined under the FPA. This led the Oregon Department of Forestry (ODF) to take a holistic approach and consider water quality conditions as a result of all the parameters interacting collectively (ODF, 2002). Figure. 3 illustrate the BMPs by category and their relationship to water quality criteria and standards.

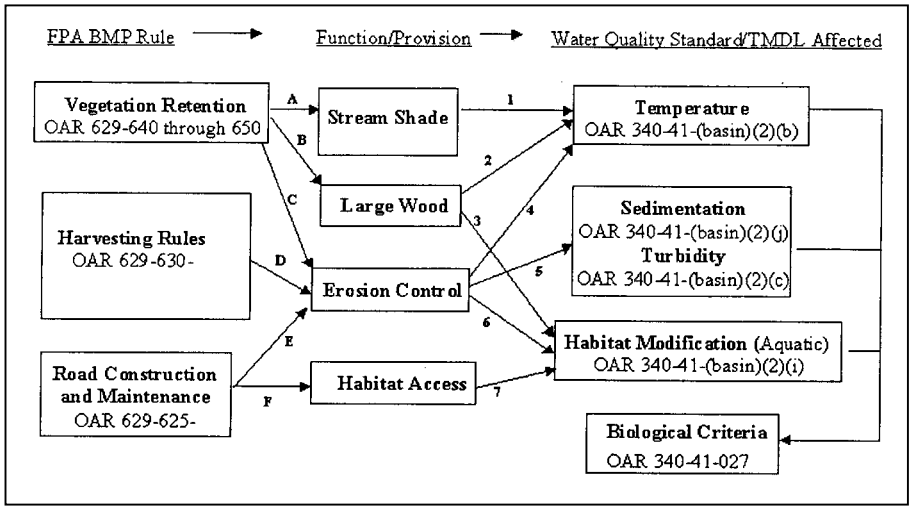


Figure 3. Water quality function pathways (ODF, 2002).

Temperature and turbidity are the only two variables that have specific quantitative numeric criteria under the Oregon FPA. The following table indicates the potential water-quality-protective functions related to the flow pathways indicated in the previous diagram.

Table 6. Potential water-quality-protective functions related to forest practices (ODF, 2002)

Flowchart Pathway	*Function/Provision Description for Specified Parameter*
	Water Temperature
A1	Retained trees and understory vegetation in riparian areas adjacent to streams provides shade to streams. Shade reduces heat loading from solar radiation at levels corresponding to the percent effective shade on the stream, and can alternate diurnal maximum and minimum stream temperatures.
B2	Large wood, placed or fallen into streams from retained riparian vegetation and positioned in the stream channel, may increase the complexity of in-channel habitat, creating pools and riffles. Deep-water areas of cooler temperatures, or cold-water refugia, can also result from large wood in streams.
C4	Vegetation retention on banks can decrease channel bank erosion and prevent channel widening. Narrow channels receive less solar radiation and stream heating relative to wider channels.
D4, E4	Road construction and maintenance practices that minimise sediment inputs to streams, such as location, drainage control, hard surfacing and choice of hauling time, may prevent channel widening and temperature increases as described in C4.
	Sedimentation and Turbidity
C5	Vegetation retention on banks can decrease channel bank erosion, decreasing sediment inputs.
D5,E5	Road construction and maintenance practices that minimise sediment inputs to streams, such as location, drainage control, hard surfacing, and choice of hauling time, reduce undesirable levels of sediment and turbidity.
	Habitat Modification
B3	Tree retention in riparian areas may provide future recruitment of large wood to streams. Historically, large wood in channels recruited from fallen trees has been a valuable component of aquatic habitat. Managed placement of large wood can be an effective means to accelerate inputs.
C6, D6	Large wood, placed or fallen into or near streams from retained riparian vegetation may serve to trap sediments in place, influencing habitat quality.
E6	The movement of large wood and sediment downstream is an important function that provides for, and maintains, fish habitat. Stream crossings that are designed to accommodate this function can have a positive influence on habitat quality.
F7	Culverts that block fish passage reduce the amount of fish habitat available.
	Biological Criteria
Interrelated	Forest practices that influence water quality with respect to temperature, sedimentation, turbidity, and habitat modification may also affect biotic populations with respect to the biological criteria standard.

The intent of the ODF turbidity standard is to limit soil and debris entering aquatic systems. BMPs are determined to be ineffective if there is a ten percent cumulative

increase in natural stream turbidity, as measured relative to a control point immediately upstream of the turbidity causing activity (Oregon State Archives, 2003). Data collection is required at a frequent basis (e.g. daily) to establish a relationship between land use and water quality change.

Oregon's water standards for temperature includes qualitative description and numerical standards. The numerical standards are measured as a seven-day moving average of the daily maximum temperature. The standard states that no measurable surface water increase (increase > 0.25°F) from anthropogenic activities is allowed when surface water temperatures exceed:

- 64°F (17.8°C) in basins for which salmonid rearing is a beneficial use;
- 55°F (12.8°C) during times and in waters that support salmon spawning, egg incubation and fry emergence from the egg and from the gravel;
- 50°F (10°C) in waters that support Oregon Bull Trout;
- 68°F (20°C) in the Columbia River (mouth to river mile 309);
- 68°F (20°C) in the Willamette River (mouth to river mile 50)" (Oregon State Archives, 2003),

except when the air temperature during the warmest seven-day period of the year exceeds the 90^{th} percentile of the 7-day average daily maximum air temperature calculated in a yearly series over the historic record.

BMPs are also considered ineffective when 25 percent of grab sample data exceeds the appropriate criterion based on multiple year monitoring programs that collect representative samples.

Below the effectiveness criteria used to evaluate the effectiveness of BMPs is summarised for the projects examined in this report.

Table 7. Criteria for determining effectiveness of BMPs.

PROJECT TITLE	EFFECTIVENESS CRITERIA
Effectiveness of Silvicultural Streamside Management Zones in the Sand-Clay Hills of Mississippi.	-No statistical differences between pre-treatment and post-treatment conditions.
California Hillslope Monitoring Program: Monitoring Results from 1996 through 1998.	-Qualitative site surveys.
Effectiveness of Riparian Management Areas and Hardwood Conversions In Maintaining Stream Temperature.	-7 day moving average maximum temperature. -Stream temperature change through harvest area does not exceed 3°F.
Harvest Effects on Riparian Function and Structure Under Current Oregon Forest Practice Rules.	-No statistical differences between pre-treatment and post-treatment conditions.
Evaluating the Effectiveness of Maryland's Best Management Practices for Forest Harvest Operations.	-No statistical differences between pre-treatment and post-treatment conditions.
Evaluating Management Practices for Reducing Sediment Production from Forest Roads.	-No statistical differences between pre-treatment and post-treatment conditions.
Using Stream Bioassessment to Monitor Best Management Practice Effectiveness.	-Stream condition index, 27 and above excellent, 21-26 good, and below 21 ranked as poor. -No statistical differences between pre-treatment and post-treatment conditions.

The Effects of Roading, Harvesting and Forest Regeneration on Streamwater Turbidity Levels in a Moist Eucalypt Forest.	-No statistical differences between pre-treatment and post-treatment conditions.
Effectiveness of Washington's Forest Practice Riparian Management Zone Regulations for Protection of Stream Temperature	-Class AA streams, incremental temperature increases caused by forestry may not exceed 2.8°C when stream temperature is < 16°C. -When natural conditions > 16°C stream temperature increases limited to 0.3°C.
South Dakota Silviculture Best Management Practices Audit: Project Final Report.	-Qualitative site survey criteria.
Alaska Sediment BMPs Evaluation	-Turbidity levels may not exceed 5 NTU above natural conditions when turbidity is 50 NTU or less. -Turbidity may not increase more than 10 % when natural conditions are greater than 50 NTU. -Maximum increase of 25 NTU.
Effectiveness of Vegetation in Erosion Control from Forest Road Sideslopes	-No statistical differences between treatment areas.
Effects of Logging on Macroinvertebrates in Streams With and Without Buffer Strips	-No statistical differences between pre-treatment and post-treatment conditions.
Results of Voluntary Forest Management Practice Guidelines to Protect Water Quality in the South-eastern US: An Example from South Carolina.	-No statistical differences between pre-treatment and post-treatment conditions. -Sediment yields not lowered below 150kg/ha the first year of treatment.
Effects of Best Management Practices on forest Streamwater Quality In Eastern Kentucky	-No statistical differences between treatment areas.
Hydrologic Impacts of logging an Appalachian Watershed Using West Virginia's Best Management Practices	-No statistical differences between pre-treatment and post-treatment conditions. –Temperature remains below 24°C.

7.0 DATA ANALYSIS

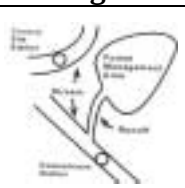
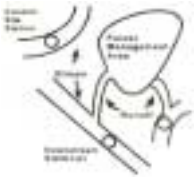
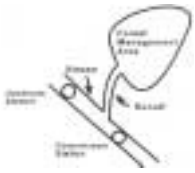
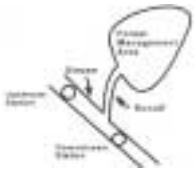
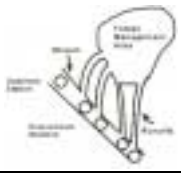
All monitoring programs culminate in the data analysis phase. During this phase, all possible data analysis techniques for answering management questions identified in the planning phase are reviewed and an appropriate data analysis methodology is selected. Before a final methodology is selected, an in-depth understanding of the data limitations is needed. Any conclusions or inferences resulting from the selected data analysis technique must be accompanied by an associated degree of confidence. Important considerations in assessing the degree of confidence are (1) the representativeness of the data variability in the hydrologic regime and (2) the sufficiency of the data to answer management questions to the desired degree of confidence (USEPA, 1997).

The use of inferential techniques, rather than qualitative methods, to evaluate BMP effectiveness lends greater credibility to any statement of effectiveness and allows the monitoring results to be used with greater confidence. Most statistical tests used to evaluate BMPs are hypothesis tests surrounding a single population (one-sample test) or tests comparing two populations (two-sample tests). Common data analysis approaches include parametric single/two sample tests, non-parametric single/two sample tests, and paired sample analysis. An additional method of analysis involving numerous data sources is the weight-of-evidence approach. This method considers multiple sources of data as well as varying types of data sources. The weight of evidence approach method

provides more information than using an individual criterion because there is a decrease in the probability of missing an effect or declaring an effect when in fact there is none. The downside of this approach is the increased costs of conducting multiple studies.

When examining specific BMPs that have the potential to influence stream water quality over a short period of time (e.g. culvert installation), there are a number of statistical methods that are available to analyse turbidity and suspended sediment response to short-term forestry activity. Table 8 describes five of these statistical methods.

Table 8. Statistical methods to observe short-term forestry impacts (WALP, 1997).

Test	Stations	Distribution	Non-Detects	Diagram
Mann-Whitney	2 independent stations, a control and downstream impacted site	Data-sets normally distributed	Moderate # permitted	
Kruskal-Wallis	Many independent stations, a control and potential downstream impact site	Data-sets need not be normally distributed	Moderate # permitted	
Sign	2 independent stations, a control and downstream impacted site	Data-sets need not be normally distributed or symmetrical	Few permitted	
Wilcoxson Signed Rank	2 independent stations, a control and downstream impacted site	Data-sets need not be normally distributed	None permitted	
Friedman	Many dependent stations, an upstream control and many downstream potentially impacted site	Data-sets need not be normally distributed or symmetrical	Moderate #	

The minimum recommended sample schedules for each of these statistical tests is to sample concurrently every hour for 24 hours or every day for 30 days. This is the minimum timeframe needed to capture significant statistical results from short-term forestry activities. Increased sample time-frames are recommended to capture any delayed water quality impacts.

8.0 EFFECTIVENESS OF PRACTICES EVALUATED

In most circumstances, BMPs were found to be effective in protecting water quality. Overall findings, from large scale BMP studies and individual research projects, indicate that properly implemented BMPs protect water quality, and that in the absence of BMPs water quality impacts are much more likely.

Large-scale audits show that when BMPs met or exceeded requirements, water quality was protected in 99 percent of situations. Even with minor departures from requirements, water quality was adequately protected almost 60 percent of the time. However, major departures from BMPs substantially increased long-term impacts to water resources (USEPA, 2002).

Review of the literature pertaining to forestry BMPs indicates a need for monitoring in several BMP areas, such as assessing the long-term cumulative impacts of forestry BMPs. There is also a need to increase the amount of existing statistically significant, qualitative data about specific water quality impacts (e.g. suspended sediment, temperature, nitrates, turbidity, etc.). Currently, specific BMP research needs are being identified and addressed in the scientific community. Current and future research on BMPs will lead to a greater understanding of forestry impacts on water quality, and the role BMPs can play in mitigating these possible impacts.

Below Table 9 briefly summarises the effectiveness of the BMPs evaluated in this paper. Overall, 87.5 percent of the BMPs were considered effective in protecting water quality. Two reports found BMPs only partially effective due to specific site conditions, such as stream size and certain road construction techniques.

Table 9. Effectiveness of BMPs evaluated in reviewed reports.

BMPs EVALUATED	# OF REPORTS	BMP EFFECTIVENESS
SMZs/RMAs/buffer strips	6	5 effective 1 partially effective
Comprehensive* BMP study	8	7 effective 1 partially effective
Forest Roads	2	2 effective

* Comprehensive BMP projects evaluated the cumulative impacts of all BMPs together, rather than trying to isolate and evaluate each BMP separately. Appendix A provides more information on the BMPs examined in each project.

9.0 CONCLUSION

A number of methodologies have been used to monitor BMP effectiveness in protecting water quality. Monitoring strategies will vary depending on the BMPs of interest, the budget of the project, the local environmental conditions, and the personnel available. There are however, some common aspects of importance, including a nested or paired watershed design, duration and frequency of monitoring (e.g. daily minimum) location of

monitoring stations, appropriate indicators, effectiveness criteria, and statistical analysis techniques.

There is not one single design strategy that can be used in all circumstances. Each effectiveness evaluation project must be developed based on its objectives, specific environment and the variables it is attempting to monitor. Broad-scale BMP monitoring is most useful from a policy perspective. Intensive, site-specific monitoring projects are needed to fine-tune BMPs, and detect stream quality impacts not readily perceived by less intensive assessments. These intensive, focused BMP monitoring projects and information are an essential basis of support for the more wide-ranging, less intensive BMP effectiveness evaluation programs.

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APPENDIX A

A1. Effectiveness of Silvicultural Streamside Management Zones In The Sand-Clay Hills of Mississippi

Practices Evaluated

This study evaluated the effectiveness of streamside management zones (SMZ's) in maintaining aquatic habitat and aquatic communities in low-order perennial streams of the Upper Coastal Plain of Mississippi. The effects of three SMZ treatments were evaluated: (1) unharvested reference, (2) maintenance of a SMZ adjacent to commercial clearcutting, and (3) commercial clearcutting with no SMZ.

Effectiveness Criteria

Effectiveness criteria considered for this project included the preservation of aquatic habitats, macroinvertebrate composition and diversity, and fish composition and diversity. No threshold was set for effectiveness levels, rather comparison of pre and post harvesting levels was used to determine the effectiveness of SMZ's. If a statistical difference was found between pre and post conditions, SMZ treatments would be considered ineffective.

Site Selection Criteria

Site selection criteria included low-order streams, ≥ 200 m in length within loblolly pine plantations scheduled for harvest. Nine first- and second-order streams within the Sand-Clay subsection were found that met these criteria. Three streams were randomly selected as reference sites, while the remaining six were located in planned harvest locations. Three stands had no SMZs and were logged to the stream bank with no regard for the stream or riparian habitat. The remaining three streams had a SMZ designed by the forester in charge of logging activity. Streamside management zones, ranging from 30 to 100 m in width, on each side of the stream, were set according to the contour of the land and vegetation present. Harvest treatments on these watersheds began in late February 2000 and were completed by the end of April 2000.

Variables Measured

Stream reaches were sampled for biotic parameters prior to harvesting and again following harvesting. Upstream and downstream sampling locations that corresponded to harvest boundaries were used. Parameters were measured within a 60 m sampling reach at the upstream and downstream location in each stream. In the upper 30 m section fish sampling was carrying out, and in the lower 30 m reach macroinvertebrate samples were collected. Streams were sampled monthly, for four months prior to harvesting, and again in the corresponding months of the following year. Electrical conductivity, DO, pH,

stream temperature and turbidity (LaMott turbidity meter) were measured for each upstream and downstream location at the same time as biotic sampling.

In addition, habitat parameters were measured at monthly intervals at three equally spaced transects within each 60 m upstream and downstream reach. Habitat parameters measured included: substrate classification, based on a modified Wentworth scale (Baine, 1985), bank height, bank width, percentage of canopy cover, percentage of vegetation cover on banks, bank erosion, bank vegetative stability, and streamside cover. Measurements were made from both sides of the stream and averaged across streambanks to create a scaling system that quantified stream habitat characteristics (modified from Plafkin et al, 1989).

Samples for macroinvertebrates were collected quantitatively at each transect, using a Wildco Surber stream bottom sampler (12-B90 Surber Std Nitex). Fish diversity and relative abundance were determined by shocking each location for approximately 12-15 minutes. Fish were counted, identified and then returned to the stream. Catch per unit effort was calculated at each sampling location by dividing the number of fish caught by the amount of shocking time. Species richness and diversity were also calculated for each sampling location using the Shannon-Weiner diversity Index (Shannon and Weaver 1949, Ludwig and Renolds 1988).

Data Analysis

Two statistical approaches were used to determine the effectiveness of SMZ's. The first compared mean values among treatments at downstream locations, while the second compared mean changes between upstream and downstream locations. Numbers were pooled within treatments and averaged across the duration of pre-treatment or post-treatment sampling periods. Analysis of variance (ANOVA) was then used to test the null hypotheses that there were no differences in (a) physicochemical properties, (b) habitat metrics, or (c) biotic metrics among treatments at a α=0.10 significance level. Changes between upstream and downstream reaches were also tested at a α=0.10 significance level.

Results

SMZ treatment effects on water quality, stream habitat, macroinvertebrates, and fish were difficult to detect statistically in this study. No detectable differences were found for pH, DO, electrical conductivity, turbidity, air temperature, or water temperature during pre-treatment or post treatment periods, or for changes between upstream and downstream sampling sites. However, a pattern did exist that suggested SMZ treatments were effective. There was no single statistical difference between logged sites with SMZs and reference streams for measured parameters after treatment, and no numerical trends that would suggest SMZ streams were different from reference streams. In contrast, non-SMZ streams did indicate patterns of slight statistical differences from reference streams.

Recommendations

Identifying index taxa of macroinveretabrates or fish is very difficult to achieve in highly variable low-order streams. This level of variability presents challenges to the development of accurate monitoring protocols for assessing the effectiveness of SMZ's.

Scholenholtz, S.H., E.D Dibble, and G.D Carroll. 2002. Effectiveness of Silvicultural Streamside Management Zones in the Sand-Clay Hills of Mississippi: Aquatic Habitat. Forest and Wildlife Research Center. Mississippi State University.

A2. California Hillslope Monitoring Program: Monitoring Results from 1996 through 1998

Practices Examined

This monitoring report was created by the California Board of Forestry to determine the effectiveness of California's Forest Rules in protecting water quality. Evaluation of individual Timber Harvest Plans (THPs) was carried out from 1996 to 1998, which focused on areas where past studies had indicated the greatest risk to water quality. These include roads, skid trails, landings, watercourse crossings, and watercourse and lake protection zones (WLPZs). Comprehensive forms were developed for each of these categories to record implementation and effectiveness information.

Effectiveness Criteria

Determining the effectiveness of California's Forest Rules is based on qualitative results. Site surveys identify Forest Practice Rule failures, causes of these failures, and whether the Forest Practice Rules were implemented correctly.

Site selection Criteria

Selecting THPs for this program was initiated in 1996 with a stratified random sampling design that resulting in 25 selected THPs. Based on erodibility ratings developed for a study completed by California Division of Mines and Geology (CDMG) (McKittrick, 1994), approximately 50% of the THPs were located in areas of high overall erosion hazard, 35% were included in the moderate category, and 15% were included in the low erosion hazard class. The second phase of the hillslope monitoring program included 50 THPs randomly selected from a state-wide pool no longer stratified on the CDMG erodible categories. THPs were included in the random selection for 1996 through 1998 if they (1) had been filed and completed under the Forest Practice Rules; (2) had been through at least one but not more that four winters since logging ceased; (3) primarily involved wildlands; (4) had significant components of either ground based logging and/or cable yarding systems; (5) had at least 500 continuous feet of a class 1 or 2 stream; (6) were at least 5 acres in size; and (7) were not previously sampled.

Within each THP, five sample areas were examined twice for each evaluation. These sample areas are landings, roads, logging operations (skid trails), WLPZs, and watercourse crossings. THP maps are subdivided into specific sample areas by marking approximate 500-foot segments on all roads. Each segment is assigned a number, and a random number table or generator is used to select site locations. A coin is flipped to determine the direction of travel on a road until the desired object is hit (landing, watercourse crossing, etc.). Additional rules are in place to deal with any irregularity and to ensure a random sampling design.

Variables Measured

The California Hillslope Monitoring program is entirely a qualitative method. At each selected THP location, specific BMPs were evaluated visually to determine whether implementation was carried out correctly and whether that specific BMP was effective in protecting water quality. Effectiveness rating tables were developed for all BMP categories (e.g. landings, stream crossings, SMZ)

Data Analysis

The first step in the fieldwork is the completion of Site Information sheets (Hillslope monitoring program, 1999). This is followed by an effectiveness evaluation of pertinent features that present erosion or water-quality problems, and that allow calculations of the relative proportion of problem to non-problem areas. Problem sites, such as cut bank failures, excessive gradients, and no WLPZ zone were recorded along with a rule implementation evaluation. Any rills, gullies, or mass failures along a transect were inspected and followed to determine whether sediment from these sources reached a WLPZ or stream channel. After the field review has been completed, an evaluation of all the rules was carried out based upon the overall frequency of problem sites and rule violations along the transect as a whole.

Results

The findings of this report indicate that the California Forest Rules generally provided adequate water quality protection when properly implemented. The following are the preliminary conclusions based on the site data and evaluations collected for criteria relating to water quality:

- Erosion problem points were almost always associated with improperly implemented Forest Practice Rules.
- Roads and associated crossings were found to have the greatest potential for delivery of sediment to watercourses. Implementation of Forest Practice Rules that specify drainage structure design, construction, and maintenance need improvement.
- Mass failures related to current timber operations are most closely associated with roads and produce the highest sediment delivery to watercourses when compared to other erosional processes.

- Numerous problems were found at watercourse crossings.
- WLPZs were found to meet Forest Practice Rules, resulting in very few erosion features recorded in these areas.
- Landings did not have substantial numbers of erosion events, and erosion events generally did not reach watercourses.
- Skid trails have a much smaller impact on water quality than roads.
- Based on the results on this study, recent timber operations could not be linked to instream channel conditions,.

Recommendations

The Hillslope monitoring program can be improved in many ways. The evaluation of non-standard practices will require considerably more work to identify whether these practices provide the same level of protection as the standard rules. In addition, quality assurance control work needs to be completed to test the accuracy and repeatability of the data reported.

Monitoring Study Group of the California State Board of Forestry and Fire Protection. 1999. Hillslope Monitoring Program: Monitoring Results from 1996 Through 1998. Interim Report to the California State board of Forestry and fire Protection.

A3. Effectiveness of Riparian Management Areas and Hardwood Conversions In Maintaining Stream Temperature in Oregon

Practices Examined

The purpose of this study was to determine the effectiveness of Riparian Management Areas (RMAs) and hardwood conversion (HWC) in maintaining stream temperature and water quality. Under the Oregon Forest Practices Rules, RMAs are unmanaged forest buffers that are established on streams that run through or adjacent to harvest areas. The width of RMAs varied depending on the width of the stream and the type of beneficial use (fish, domestic or none). HWC are managed riparian buffer areas that are capable of supporting coniferous tree communities, but are currently dominated by hardwood overstories. The goal of this rule is to restore riparian areas to their historical condition.

Effectiveness Criteria

- The 7-day moving average maximum does not exceed 64°F.
- Stream temperature increase through the harvest unit does not exceed 3°F. (Department of Environmental Quality, 1995).

Site Selection Criteria

The Oregon Forest Practice Rules use georegions to describe areas of similar combinations of climate, geomorphology and potential natural vegetation. The Forest Practices Monitoring Program stratifies sample sites on this georegion basis. For this particular study, only two georegions are represented (Coast Range and Interior).

Stream temperature was monitored on five RMAs and eight HWCs all located in harvested areas and all fish bearing streams. The requirements for site selection were: intact riparian condition 1000 feet upstream and 1000 feet downstream of the harvest unit, and harvesting conducted under the 1994 stream rules. All areas were harvested prior to monitoring periods so no pre-treatment data exists.

Variables Measured

Monitoring was carried out from July through September 1995. A stream temperature monitoring protocol (Runyon and Andrus, 1994) was used to select the streams and individual monitoring locations. Stream temperature was monitored at the upper and lower boundary of the harvested area, and 500 or 1000 feet downstream of the harvested unit. Temperature data was collected every 48 minutes using HOBO-temp monitoring thermistors. The period of monitoring varied slightly between streams but generally ran from July through September 1995. Physical and vegetative data was also collected within each harvest area by a total of 33 stations located above, within, and below harvested units. Physical and vegetative data included stream flow, aspect, elevation, gradient, thalweg depth, wetted and bankfull width, substrate, distance from divide, width of buffers, harvest unit length, and cover.

Data Analysis

Recorded stream temperature was used from the upstream boundary location, the downstream boundary location, and the station located 1000 feet downstream of the harvest unit. The 7-day moving mean of daily maximum, minimum and average stream temperature and diurnal fluctuation were used to analyse effectiveness of RMAs and HWCs in maintaining stream temperature. Various statistical methods were used to investigate relationships between environmental parameters, stream temperature and the effectiveness of RMAs and HWCs. Statistical methods included (1) Correlation analysis, (2) Repeated Measures ANOVA, and (3) Distribution Tests (SAS/STAT, 1998).

(1) Correlation analysis
This method was used to test the relationship between environmental parameters (i.e., gradient, buffer width) and stream temperature. All the stations were pooled and 7-day maximum, minimum and average values were correlated against the corresponding average environmental parameters. The same correlation analysis was also conducted for each of the three stations. The level of significance for Pearson correlation coefficients (r) was set at a p-value less than or equal to 0.001, 0.01 and 0.05.

(2) Repeated measures ANOVA:
A repeated ANOVA test was used rather than a straight ANOVA test to compensate for spatially dependent data. Utilising this statistical method also accounted for natural increases in stream temperatures that occur downstream. Residuals were calculated using the empirical model of stream temperature at station 1 versus distance at station 1. The residual at any station was the difference between the predicted stream temperature (station 1 model) and the actual stream temperature at that station. To test the effect of RMAs and HWCs on stream temperature, the 7-day maximum, minimum and diurnal fluctuation was again used. A statistically significant increase in temperature between station 1 and 2 would indicate a harvest effect. A decrease between station 2 and 3 would indicate downstream cooling, while a difference between stations 1 and 3 would indicate either a reach level increase or decrease in the 7-day max, min, average and diurnal fluctuations.

(3) Distribution Tests:
A Chi-squared test was applied to the frequency distributions of stream temperature data to test for harvest effects on the frequency of stream temperature above 64°F and 55°F. This analysis assesses a 21-day period to determine the effectiveness of rules in maintaining stream temperature at or below the DEQ standard (DEQ, 1995).

Results

This study suggests that RMAs and HWCs do not always protect stream water quality. This is reflected in the varying results and that only three of the eleven streams never exceeded the DEQ water quality standard. There was also an indication that as buffer width decreased the 7-day maximum and average stream temperature increased.

Vegetation manipulation in the harvest units resulted in varying buffer widths and canopy cover. Correlations between vegetation cover and stream temperature were not always present; however, special HWC practices designed to reduce solar exposure by leaving more trees on the south side of streams, may have been more effective at maintaining natural stream temperature.

Recommendations

Given the limitations of this study, more background information is needed on the natural variability of stream temperature before RMA and HWC effectiveness can be accurately understood. In future studies, pre-harvest data will be vital to addressing these types of questions.

Dent, L.F, and J. Walsh. 1997. Effectiveness of Riparian Management Areas and Hardwood Conversions in Maintaining Stream Temperature. Oregon Department of Forestry, Forest Practices Technical Report Number 3.

A5. Harvest Effects on Riparian Function and Structure Under Current Oregon Forest Practice Rules

Practices Examined

The purpose of this study was to determine if the Oregon forest practice riparian rules protect natural riparian conditions and whether these rules are effective at maintaining a structure that will promote desired future conditions for large wood recruitment (LWR), shade, and conifer regeneration. Incorporated in the riparian management rules are a number of practices that can be selected to achieve riparian protection. These include no-cut buffer, standard target basal area, active management, small type N streams, alternative prescription, and site specific planning.

Effectiveness Criteria

Testing the effectiveness of riparian functions in protecting water quality is problematic due to the fact that numerical standards (either regulatory or scientific) have not been established. This report uses before and after harvest comparisons and evaluates effectiveness by the degree to which potential large wood recruitment and shade are retained. The estimates of conifer basal area for unmanaged mature riparian forests are evaluated by comparing to a "standard target" derived from mature riparian forests (Lorensen et al, 1994).

Site Selection Criteria

This study was conducted on sites located throughout the state of Oregon. Landowners and forest practice foresters volunteered the locations for this study. The only constraint was that the sites had to be adjacent to fish-bearing streams.

Data was collected on the 40 resultant test sites before harvesting and then again one year after harvesting. For the results of this study, 25 of the 40 locations were revisited. There were 11 riparian management areas (RMAs) managed with target prescription, four managed with a riparian conifer restoration prescription, four with a no-cut RMA, six that were unknown, and 15 that were not harvested prior to the second survey.

Variables Measured

Riparian sample plots were 500 ft long by 100 ft wide, running parallel to the stream. These plots were located at a random distance from the bottom of the harvest unit on the left riverbank. The plot borders and subsections were established using a hip chain, and flagging was used on 25-ft intervals to define the sampling and cruising areas.

The riparian stand was separated into two zones. The first section was located within 20 feet of the stream channel. Trees in this region were measured for diameter at breast (dbh), distance from the stream, degree of lean to the stream, percent slope, and species. In addition, tree height and age were measured for one tree of each species in each

diameter class (10", 11-15", 16-20", and 21"). The second region between 20 feet and 100 feet was measured using an individual tree sampling (ITS) method. Twenty percent of the stand was measured regardless of species. The same tree parameters measured in the 20-ft zone were also calculated.

Shade and cover were measured along five evenly distributed transects (one every 100 feet) starting at one end of the plot. Cover was measured with a convex densiometer at all five transects at middle channel and on both banks. Shade was measured with a Solar Pathfinder at the upstream, downstream, and middle transects. In addition, stream gradient, stream orientation, dominant substrate, wetted channel width, and bankfull width were measured at each of the five transects.

Regeneration sampling was carried out on those areas that had been replanted before the post harvest survey. Seedlings were counted and identified by species in 20-ft randomly spaced plots. At each site, sampling was conducted on a total of 30 plots on three transects running parallel to the stream, at a distance of 25, 50, and 80 feet.

Data Analysis

Diameter distributions in RMAs were evaluated to determine if conifer trees were being disproportionately harvested, and whether diameter distributions were maintained. The average diameters were compared before harvesting and after harvesting using a two-sample t-test.

Additional parameter such as shade and cover were pooled into pre harvested and posts harvested groups and analysed using a two-sample t-test to determine if statistical changes occurred due to harvesting practices.

Results

Reduction in potential large wood recruitment was minimal on large streams, but statistically significant on small streams. The purpose of the riparian conifer restoration (RCR) rule is to provide a long-term source of large wood, even though there may be short term impacts on stream temperature. Additional studies are needed to examine the benefits of such a practice to overall riparian management.

The current rules are effective at protecting cover on large streams. Although the actual cover levels are relatively high, shade retention results are mixed for medium and small streams. The most consistent reduction in cover was observed on small streams and RCR sites.

In general, the rules are effective at maintaining structure that is thought to protect large wood recruitment and shade. Standard target underestimation of average basal areas for mature riparian forests likely led to reductions in large wood recruitment and cover on small streams and riparian areas managed with a RCR prescription. Moderate reductions were also observed on medium sized streams.

Recommendations

The Board of Forestry should re-evaluate and strengthen their understanding of the following prescriptions:

- Standard targets for basal areas.
- Vegetation retention rules to increase the maintenance and promotion of shade and potential LWR on small and medium streams.
- Advantages and disadvantages of the RCR prescription.

The Board of Forestry should also evaluate on a larger scale the trends in both conifer and hardwood regeneration with riparian areas. The goal should be to determine if the results of this study are reliable and if there are management strategies that will continue to improve regeneration with 100 feet of the stream.

Dent, L. 2001. Harvest Effects on Riparian Function and Structure Under Current Oregon Forest Practice Rules. Oregon Department of Forestry. Technical report #12.

A4. Evaluating the Effectiveness of Maryland's Best Management Practices for Forest Harvest Operations

Practices Examined

The overall objective of this project was to implement a range of BMPs on a small watershed to evaluate their effectiveness in protecting water quality. These BMPs pertained to truck haul roads, skid trails, landings, streamside forest buffers, wetlands, and stream crossings. Specific practices included, but were not limited to, temporary bridges, stabilisation by seeding, streamside forest buffer widths, wet area crossings, and road and trail drainages. Additional objectives of this study included:

(1) Calculate baseline suspended sediment concentrations/loads and baseline biotic conditions for both treatment and control watersheds.
(2) Install a BMP system on harvest sites with the treatment watershed.
(3) Calculate suspended sediment concentrations and loads resulting from harvest operations.
(4) Evaluate the efficiency of individual BMPs via on-site inspections during and/or immediately following storm events.

Effectiveness Criteria

To determine the effectiveness of Maryland's BMPs, three hypotheses were tested on the paired watersheds that were monitored from August 1995 to July 1999:

(1) There are no significant differences in stream suspended sediment concentration loads before and after harvesting with BMPs.

(2) There are no significant differences in the average daily temperature or daily minimum/maximum temperatures of the stream before and after harvesting with BMPs.
(3) There are no significant differences in the benthic macroinvertebrate populations of the stream before and after harvesting with BMPs.

Site Selection Criteria

Two small watersheds located in the Piedmont physiographic province were selected for this paired watershed sample design. The control watershed is 280 acres with elevations ranging from 520-1120 ft. Bear Branch is a second order stream located within this watershed that has not been disturbed by harvest activity for 75 years. The treatment watershed is 330 acres, with elevations ranging from 480-1282 ft. Furnace Branch is a second order stream that was evaluated in this study. The watersheds are similar in cover type, soils, and previous land use history.

Variables Measured

The paired watershed design required two watersheds (control and treatment) and two periods of study (calibration and treatment) (USEPA, 1993). At the end of the calibration period, the data was used to establish a relationship between the treatment and control watershed through regression analysis. At the end of the treatment period, a similar equation was developed, and the regression lines compared and tested for differences in overall significance, slope and intercept.

Automated monitoring stations were installed at the lower reaches of both watersheds. Stage was measured continuously at 15-minute intervals using ISCO 4230 Bubbler Flowmeters. Stage/discharge relationships were developed using a Swoffer current velocity meter to measure discharge at a variety of stages. Stage discharge curves were then created – one to predict discharges at lower stages and one to predict discharge at the higher stages. Flowmeters were downloaded monthly and data was edited and stored in QuattroPro data sets.

Biweekly grab samples were collected manually at the monitoring stations to establish baseflow water quality conditions. Storm events were collected by the ISCO 6700 portable samplers that were programmed to be stage activated. Based on the detection of a stream level rise of .05′, samples were automatically collected at half-hour intervals for the duration of the storm hydrograph. Total suspended solids (TSS) were measured for each water quality sample.

Annual and monthly load estimates were calculated for each station using Beale's Ration Estimator. The estimate is derived by multiplying the mean measured load by the ratio of the average flow for the year, divided by the average flow on days when concentrations were measured (Dolan et al, 1981).

A total of five Ryan Tempmentor sensors were used to measure temperature within these watersheds. Three were placed in the treatment watershed, at top and bottom reaches and at a proposed future harvest site. Two were located in the control watershed, one at the upper reach and one at the lower reach. Temperature was measured at twenty-minute intervals throughout the growing season.

Benthic macroinvertebrates were sampled quantitatively with Surber samplers during the spring and fall in each watershed. All samples were identified to the genus level and additional metrics (taxa richness, EPT taxa richness, percent of sample as EPT, EPT/Chironomidae ratio, percent dominant taxa, and total rapid bioassessment percentage) were calculated. Habitat assessments were also carried out using seven metrics that rated primary instream habitat, secondary bank and riparian zone habitat, and tertiary watershed characteristics (Plafkin et al, 1989).

Data Analysis

Data compilation and analysis between watersheds was carried out using the SAS statistical package. Daily averages for the treatment and control watershed were calculated for flow, TSS concentrations, and temperature. The calibration and treatment regression models were then used to analyse whether the BMPs were effective in protecting water quality. Monthly habitat measurements, taxa richness and biotic indices were also compared between watersheds.

Results

The BMPs implemented in this study are effective in preventing significant impacts on water quality, biology, and habitat. There was no significant difference between TSS, stream habitat, benthic macroinvertebrate populations, or stream temperature. Most BMPs performed as intended and none allowed observable sediment input into waterways.

Recommendations

No recommendations.

Forest Service and Chesapeake and Coastal watershed Services. 2000. Evaluating the Effectiveness of Maryland's Best Management Practices for Forest Harvest Operations. Maryland Department of Natural Resources. FWHS-FS-00-01/

A6. Evaluating Management Practices for Reducing Sediment Production from Forest Roads

Practices Examined

This study evaluates the effectiveness of seven different road management practices in reducing the sediment delivered by roads to watercourses. One practice used was a continuous berm along the roadside, while the other six practices used different combinations of aspect, gravel and vegetative strips. To date, the general consensus on road BMP's is that low slope along the road length and soil types with less silt and clay sized particles will result in lower sediment potential (Forestry BMP Manual, 1989). The overall purpose of this study was to: (1) determine the contribution of sediment from forest roads to adjacent surface waters; (2) determine surface runoff volumes from forest roads to adjacent surface waters; and (3) evaluate the effect of different management practices utilising gravelled surfaces, vegetative strips and roadside berms on sediment reduction in the coastal plains of North Carolina.

Effectiveness Criteria

Determining the effectiveness of different management practices for reducing sediment production from roads was based on comparison analysis. All road management practice data was converted to trend graphs for analysis.

Site Selection Criteria

This study was located on a five-mile stretch of Kendrick's Creek based in a watershed of 8100 hectares. The study area is located entirely on a Belhaven series soil that gives the area fairly uniform subsoils from which road materials are originated. All road system test sites were constructed by dredging soils from immediately alongside the road right of way, and placing it on the road surface to dry. Once dried it was formed into a road prism, which was used to analyse the surface runoff and sediment quantity contributed by the road surface.

All plots were located within a single half-mile stretch of road. The pre-existing gravel road sections were grouped in one area and the other treatments were grouped in two sets were no pre-existing gravel was present. Each plot was divided in half by a six inch road crown, one half collected surface runoff at the road edge and the other half collected surface runoff from the sideslope below the berm break. The roadside berm collected water from the road surface and transported it to the berm breaks for collection and sampling. The continuous berm plots used a ten-foot gutter to collect runoff from a predetermined side-slope area.

Variables Measured

For each non-continuous plot, two samples were taken during every rainfall event. One was taken from the road surface flow and the other from the road surface flow channelled

through a cut in the berm. For each continuous plot one sample per rainfall event was taken from the side-slope area located behind the berm. Continuous flow proportional samples were also taken during each rainfall event. Due to the low volumes and irregularity of runoff, a custom sampler was developed. This collected runoff into the sampler intake, where volume and flow proportions were metered at constant percentages. A lower sample bottle collected sediment sizes greater than 0.5 mm which in combination with the upper measurements created a 100% event sample.

Total rainfall events were collected at several sites, while rainfall intensity was recorded at only one site using a tipping bucket type rain gauge.

Traffic information was gathered at both entrances to the sites using traffic counters. All plots received similar traffic totals during each sampling period.

Data Analysis

Road surface samples were collected and analysed using the full particle size analysis method (Gee and Bauder, 1986) to determine the sand, silt, and clay composition of the road surface.

Rainfall amount and intensity for each rainfall event were combined into a kinetic energy term using the equation developed by Park et. al. (1983). Trend graphs of the total sediment transported from the road surface and side slopes per kilometre of road were used to analyse the effectiveness of different management practices for road constructions.

Results

The implementation and maintenance of a continuous berm was the best BMP for reducing road surface generation of sediment. No sediment was allowed to move off the road surface resulting in a 100% infiltration rate. If a continuous berm cannot be implemented or maintained, gravel is the next best option to prevent rainfall induced particle detachment. This study concluded that a newly applied gravel layer over a geotextile liner could reduce forest road related sediment by 67% and surface runoff by 39%. The installation of a grass strip on the drive surface along the road edge can also reduce sediment delivery by 56% and surface runoff by 40%.

Recommendations

The need for a comprehensive study of the effects BMP's have on forest road sediment production was realised during this study. This led to a current study that is underway to evaluate the cumulative effects of forest road BMP's on sediment production at a watershed scale.

Appelboom, T.W., G.M. Chescheir., R.W. Skaggs, and G.L Hesterberg. 1998. Presented at the 1998 ASAR Annual International Meeting. No. 987025.

A7. Using Stream Bioassessment to Monitor Best Management Practice Effectiveness in Florida

Practices Examined

An effectiveness study was conducted to evaluate Florida's BMPs for protecting aquatic ecosystems during intensive forestry operations. A complete list of Florida's BMPs can be viewed at http://www.fl-dof.com/Conservation/hydrology/page_37.html. During the silviculture treatments, all applicable BMPs were adhered to, with a specific focus on special management zones (SMZ) or buffers. According to the BMP manual (Division of Forestry, 1993), roads, clearcut harvesting, primary skid trails, and mechanical site preparation are prohibited within the primary SMZ. Timber harvesting is also limited to 50% with no harvesting on immediate stream banks. The width of SMZs was based on special designation and stream width, ranging from 10.6 to 60.9 meters.

Effectiveness Criteria

A bioassessment methodology known as the Stream Condition Index (SCI) (Barbour et al., 1996), was used to characterise water along the test sites. The SCI is a composite macroinvertebrate metric for use in flowing streams. Sampling consists of 20 sweeps of the most productive habitats found in a 100-meter stretch of stream using a dip net. SCI values of 27 or above were ranked as excellent, those between 21 and 26 were ranked as good, and those below 21 were ranked as poor. Based on the SCI, an unimpaired stream in the ecoregion represented would have a taxa richness value of 27 or higher.

Overall effectiveness of the BMPs would also be testing by examining the pre and post harvest data. No biological change, water chemistry change, or habitat index change would indicate that BMPs are effective in protecting overall water quality.

Habitat assessment values compiled for each location prior to and post harvesting were ranked from poor to optimal by comparing field observations to ecoregion reference stream conditions.

Site Selection Criteria

Four study sites were selected in four ecological sub-regions of Florida. Factors influencing the classification of these regions include climate, physiography, water, soils, air, hydrology, and potential natural communities. Detailed descriptions of Florida's ecological regions can be found at http://www.fs.fed.us/land/pubs/ecoregions/toc.html.

Selected sites were located adjacent to a perennial stream and selected to represent some of the state's higher slope and soil erodibility conditions. All four sites were slash pine plantations less than 35 years old, and all contained active road networks.

Variables Measured

Monitoring for both bioassessments and water quality parameters was carried out for pre-harvesting data in February 1996, and post harvest conditions in February 1997. Bioassessments were done in three 100-m segments for each monitoring location. The SCI scores were based on benthic macroinvertebrate sampling which generated a composite score for the following biological metrics: taxa richness, EPT index, % filter feeders, number of chironomidae taxa, % dominance, and % diptera. The actual sampling for benthic macroinvertebrates utilised a 20 dip-net sweep method developed specifically for the SCI (Barbour et al., 1996).

One segment of the reference and test sites for each stream was measured for standard water chemistry using a grab sampling method. Water chemistry parameters included: dissolved oxygen, pH, conductivity, temperature, total suspended solids, turbidity, colour, nutrients and coliform bacteria.

A habitat assessment was carried out on each reference and test site. The habitat assessment was based on visual observations and measurements of the following physical stream attributes: substrate type and availability, water velocity, artificial channelization, habitat smothering, stream bank stability, riparian buffer width, and riparian buffer quality.

The time between final site preparation treatments and post-treatment sampling varied among sites from 2 to 5 months.

Data Analysis

Water chemistry and aquatic habitat assessment data was compared and evaluated before and after treatments. This study focused on aquatic organisms as the principal measure of water quality and hence BMP effectiveness. For this reason, a statistical analysis was performed on the benthic macroinvertebrate data. A paired t-test was used to compare differences between pre and post-treatment SCI values. This analysis was also used to test for differences in mean SCI values between the reference and test sections within sites. This compensated for any natural variability that may be attributed to a treatment affect.

Results

Water chemistry results showed no differences between pre-treatment and post-treatment water quality at any of the study sites. Any small differences were considered part of the natural variability of stream conditions.

Average habitat assessment values within the reference and test segments of each stream were within the optimal range (≥112) both before and after silviculture treatments. Water velocity and riparian zone width reported notable changes in post-treatment data;

however, this was considered minor, temporal variability and was not attributed to the harvesting treatments.

Variation between SCI values calculated for each reference and test section were relatively low. Mean SCI values for pre-treatment and post-treatment samples at site 1 were in the excellent range, although post-treatment values decreased slightly. In general, SCI data showed no treatment effect on the test section of the stream at all four-study sites.

Recommendations

Because the bioassessments were conducted less than a year after treatment, there was still some question about BMP effectiveness over longer periods of time. Additionally, the timing, intensity and duration of rainfall events did not encompass the full spectrum of possible storm conditions and seasonal variations. For these reasons, this study has been extended to include additional bioassessments at two and three-year intervals beyond harvesting.

Vowell, Jeffery L. 2001. Using stream bioassessment to monitor best management practice effectiveness. Forest Ecology and Management. 143: 237–244.

A8. The Effects of Roading, Harvesting and Forest Regeneration on Streamwater Turbidity Levels in a Moist Eucalypt Forest in Australia

Practices Examined

This fifteen-year study examines the effects of roading, harvesting, and forest regeneration (with BMPs) on streamwater turbidity levels in a moist eucalypt forest in eastern New South Wales. The principle BMPs evaluated in this study pertain to harvesting activities, including undisturbed 20-m buffers on each site of streams, the barring of snig tracks (skid trails) on completion of harvesting, slope limits to harvesting (30°) and snig construction (25°), and the revegetation of road cut-slopes.

Effectiveness Criteria

Turbidity data, both from continuous sampling and grab sampling, are the basis for evaluating the effectiveness of the BMPs in this study. Numerous statistical approaches were used to analyse mean turbidity levels between treatment sites and treatment periods. Conclusions about BMPs effectiveness are based on a comparison analysis of mean turbidity levels for pre- and post-treatment periods and between catchments of different treatment methods.

Site Selection Criteria

The research area consists of eight small, relatively steep and previously unharvested eucalypt catchment areas. Road access was constructed in four catchments and six catchments were harvested using varying methods. In summary, the treatments consisted of (1) unharvested control; (2) harvesting without a regeneration burn; (3) harvesting with a regeneration burn; and (4) eucalypt plantation establishment (700 trees/ha) after tractor clearing, windrowing and burning. Each treatment location was split to include one catchment permanently roaded and its duplicate unroaded. A control watershed was also present with no road networks or harvesting activity.

Variables Measured

A V-notch weir, stilling well, stream height recorder and pluviograph were installed in the lower most region of each catchment. Gamet automatic water samplers collected samples over storm events and were paired with additional weekly grab sampling data. Seven pre-treatment and eight post-treatment grab samples were collected in total. Grab samples were always collected coincidentally on the same day in all eight steams, generally within a 3-h period and on the same limb of the hydrograph. All samples were analysed for turbidity using a HACH Model 2100AN Turbidity meter.

Data Analysis

A comparison of the streamflow data was made by selecting a subset of post-treatment storms during which a treated and a control catchment were sampled in an equivalent manner. Since turbidity values are not normally distributed, a log transformation was used in the statistical analysis of the hydrological data (Helsel and Hirsch, 1992). The mean turbidity values for these matched storms were then compared using an analysis of variance suited to unequal sample sizes.

A further analysis of post-treatment data obtained from the matched storms was carried out by calculating a mean discharge-weighted turbidity value for all catchments. These means were obtained by summing the product of turbidity multiplied by corresponding discharge for all matched storm samples, and dividing by the sum of these discharges.

A subset of the grab sample data was analysed in which treated catchment turbidity values were paired with values from samples collected on the same day in a control catchment. These paired turbidity values were then summed cumulatively from the start of the record to prepare a set of paired cumulative turbidity values for treated and control catchments. Cumulative totals for treated catchments were plotted against coincident cumulative totals for the appropriate control catchments and non-treated catchments to analyse slope (turbidity) variance.

Paired data obtained in the pre-treatment period were also used to construct regression relationships between individual turbidity values for future treatment catchments and corresponding values in control catchments. This regression was improved by including

stream discharge as a covariant in order to compute predicted values of turbidity. The means of the pre-treatment residuals were statistically compared with post-treatment residual means using a T-test.

Grab sample data from each catchment were split into ten strata based on discharge at the time of sampling. Samples were further stratified into pre-treatment or post-treatment periods, and turbidity values log-transformed. An analysis of variance was carried out on these transformed values to allow a statistical comparison of flowgroup turbidity means before and after treatment. The means were then back transformed to determine the differences between post-treatment and pre-treatment turbidity means.

Results

Increases in streamwater turbidity were observed in roaded and harvested catchment areas. Road generated sediment appeared to reach stream watercourses at stream crossings where specific measures to prevent or reduce sediment supply to streams (BMPs) were not in place. The effect of road construction on turbidity levels was immediate, and far greater than those effects caused by harvesting activities. However, these increases were small and mean differences between roaded catchments and controls were less then 20 NTU's.

In general, harvesting BMPs employed in these catchment areas appeared effective in preventing additional sediment delivery to streams. Road construction and maintenance were identified as the primary cause of increased turbidity levels, due to lack of BMP implementation.

Recommendations

During the course of this study road construction BMPs and road crossing BMPs should have been incorporated to evaluate their effectiveness and aid in the effectiveness evaluation of harvesting BMPs.

Cornish PM (2001) The effects of roading, harvesting and forest regeneration on streamwater turbidity levels in a moist eucalypt forest. Forest Ecology and Management 152:293-312.

A9. Effectiveness of Washington's Forest Practice Riparian Management Zone Regulations for Protection of Stream Temperature

Practices Examined

This study examined thirteen watersheds in various ecoregions of Washington State. During the summer of 1990, monitoring began with a goal of identifying stream temperature response to timber harvesting. The purpose of this study was to test the

effectiveness of Riparian Management Zones (RMZ) at achieving water quality standards for temperature.

Effectiveness Criteria

For Class AA streams, the maximum allowable temperature is 16.3°C, except when exceedence is due to natural conditions. Any incremental temperature increases caused by forest harvesting may not exceed 2.8°C. When natural conditions exceed 16°C incremental increases are limited to 0.3°C.

Class A streams have a maximum allowable temperature of 18.3°C and an incremental increase limit of 2.8°C. When natural conditions exceed 18°C increases caused by human activity may not exceed 0.3°C.

In order for SMZs to be considered effective, both the criteria for maximum temperature and incremental increase in temperature had to be met.

Site Selection Criteria

Study sites were selected using a Department of Wildlife database on RMZ characteristics (Carlson, 1991). Criteria for selection included: representative examples of both east side and west side RMZ prescriptions, examples of both 1 and 2 sided RMZs, units harvested in accordance with RMZ rules, road access within a reasonable distance of monitoring sites, and RMZ lengths greater than 600 meters. RMZs representing a wide range of elevation and canopy cover, located on type 2 and 3 streams, were also given priority.

Areas with relatively mature riparian canopy cover upstream of the study sites were also given preference, since these sites are most representative of the natural conditions. Stream reaches without tributaries were chosen because it was desirable to have minimal change in flow within each area. The final characteristic considered for site approval was the compliance and implementation of RMZ rules. Sites that did not appear to be in compliance with RMZ rules were excluded from monitoring.

Variables Measured

Temperature data was collected using Unidata loggers and temperature probes during the summer of 1990. Individual data loggers and two-thermistor probe sets were paired throughout each study area. Thermographs were placed upstream of the RMZ boundary to monitor background conditions, and in the downstream portion of the RMZ to record temperature response in the study reach. The optimal timeframe to conduct temperature monitoring was during the mid-July to mid-August periods when the highest air temperatures generally occur.

Discharge data was measured at both upstream and downstream thermograph sites at the time of thermograph deployment or retrieval. In some cases, discharge data was taken at

both times. The velocity measures were obtained using a Marsh-McBirney flow meter at multiple points in each cross-section.

Riparian shade levels were measured using a spherical densiometer at the upstream and downstream sites. Densiometer values were taken in four directions (downstream, upstream, left-bank, right-bank) and averaged.

Numerous physical parameters were also measured that contributed to the effectiveness evaluation of the SMZs. These included: RMZ length, stream gradient, distance from divide, elevation, stream depth, bankfull stream width, stream azimuth, RMZ width and tree count information.

Data Analysis

Site characteristics were evaluated by grouping the sites into categories of effectiveness and comparing site attributes with and between the categories. A principle components analysis was then used to further explore the relationships between site characteristics, temperature parameters, and BMP effectiveness. Simple linear regression was also used to examine correlation between temperature parameters and site characteristics.

Results

The RMZ prescriptions were effective at meeting water quality standards in five of the thirteen watersheds. Six watershed RMZs were ineffective at protecting water quality and two were considered inconclusive due to monitoring difficulties.

The primary site factors associated with effective RMZs included: moderately high elevations (> 600m), high average levels of riparian shading, relatively wide RMZs, dense woody vegetation, groundwater inflow, stream morphology associated with relatively high gradients, and partial cut harvesting.

The primary factors associated with ineffective RMZs included: low to moderate elevation (< 500m), low to moderate levels of riparian shade, loss of streamflow within the reach, stream morphology associated with low gradients, clearcut harvesting, and beaver activity.

Recommendations

In certain cases when streams are highly temperature sensitive, the only way to ensure BMP effectiveness is to design the RMZ so there is no reduction in stream shade levels. A proposed new TFW method for identifying temperature sensitive streams and designing RMZs takes many important site-specific factors into account to achieve this goal. Incorporating the new proposed TFW temperature method (TRWTEMP model) into the Forest Practices rules would yield a number of benefits to RMZ effectiveness.

Additional recommendations for promoting RMZ effectiveness include:

- Develop procedures for identifying and addressing site specific anomalies in the stream temperature method for designing RMZs.
- Add provisions in the RMZ rules for retention of 100% of stream shading for the most sensitive stream reaches.
- Consideration to revising minimum RMZ widths for low elevation, west side type 3 streams.
- Revise the water quality standards classification system for the purpose of temperature criteria in forest streams in order to be more representative of naturally occurring temperature regimes.
- BMP effectiveness monitoring of stream temperature should be carried out exclusively during the July 15 to August 15 period to ensure results are representative of critical stream temperatures.

Rashin, Ed and Craig G. 1992. Effectiveness of Washington's Forest Practice Riparian Management Zone Regulations for Protection of Stream Temperature. Prepared for Timber/Fish/Wildlife Cooperatives Monitoring, Evaluation, and Research Committee. Water Quality Steering Committee. TFW-WQ6-92-001, Ecology Publication #92-64. 59pp.

A10. South Dakota Silviculture Best Management Practices Audit: Project Final Report

Practices Examined

The 2001 South Dakota BMP audit had many objectives. These included: (1) evaluate the effectiveness of South Dakota silviculture BMPs in protecting soil and water resources; (2) Assess future education needed to improve BMP training; and (3) Evaluate how SMZs should be sited and designed with regard to wet/dry springs in the Black Hills arid ecology and identify a simplified system of identification and designation.

Effectiveness Criteria

The following criteria were selected for rating BMP effectiveness, which are outlined in a flow chart in the BMP Audit Process Guidebook.

Rating	Criteria
1	Major and prolonged impacts on soil and water resources.
2	Major and temporary, or minor and prolonged, impact on soil and water resources.
3	Minor and temporary impacts on soil and water resources.
4	Adequate protection of soil and water resources.
5	Improves protection of soil and water resources over pre-project condition.

Site Selection Criteria

Audit sites were selected from maps of timber sales and other information contributed by the U.S Forest Service. Site selection was predisposed to bias since certain criteria were imposed in the selection process. These criteria were:

- Harvest was completed within the last two years.
- A minimum of 2000 bd. ft. per acre was cut at the site.
- Harvest site has landings, temporary roads, and skid trails within drainage.
- Harvest site must contain a stream or have significant water concerns.

Six sites were chosen, three on private land, two on Forest Service lands, and one area from the state lands. The audits were a spot check of silvicultural activities considered to have characteristics that might generate non-point pollution.

Variables Measured

The BMP categories evaluated in this audit include road design, surface drainage, construction, maintenance, timber harvesting, SMZ, slash treatment/site preparations, and streamside management practices.

Audit teams had a one-time look or spot check for assessment and documentation of BMP effectiveness. All observations of any impact to the soil or water were done by visual appraisal. BMPs relating to effects on water quality over very long periods of time could not be properly evaluated in this study.

Data Analysis

No specific statistical analysis was carried out. Effectiveness ratings were simply compared to ineffectiveness ratings.

Results

BMP effectiveness was found to have met or exceeded the standard on 317, or 84 percent of the 374 rating points. No gross neglect in effectiveness was found. Minor departures were identified at 47 points (13 percent) and major departures at ten points (three percent). Major departures included the failure to designate a SMZ, not dewatering when installing a culvert, improper culvert sizing, failure to remove a temporary plastic culvert pipe from a wetland, and not using siltation traps. All of these activities led to erosion problems. Minor departures came from the lack of maintenance on erosion control features, such as rolling dips and water bars.

Recommendations

- Continue interdisciplinary BMP audits on a two-year cycle.
- Improve site selection through centralised data collection.
- Revise the rating guide to fewer, but more pertinent questions.

- Involve the non-industry forest landowners in the Forestry BMP program.
- A BMP team should include a soil scientist, hydrologist, forester, engineer, a fish or wildlife biologist, the landowner or representative, the logging contractor/road builder, and an administrating forester where applicable.
- Develop guidelines on "how to" install proper covert sizes and placement, rolling dips, cross drains, waterbars, and seed mixtures.
- Develop and incorporate an easily understood stream classification system.

Lee, K.W., and A. Everett. 2001. South Dakota silviculture Best Management Practices Audit Project final Report. Black Hills Forest Resource Association. OCLC#48673370

A11. Alaska Sediment BMPs Evaluation

Practices Examined

The objective of this study was to determine if BMPs are effective in meeting state water quality criteria and in maintaining physical habitat conditions. Recent water quality monitoring in the Tongass region has focused on the effectiveness of the road BMPs because of the potentially significant effect on stream beneficial uses, especially the growth of aquatic organisms.

The road condition survey that was carried out can be used to perform effectiveness monitoring for the following BMPs:

- Access and travel management.
- Road maintenance.
- Measures to minimize mass failures.
- Measures to minimize surface erosion.
- Revegetation of disturbed areas.
- Control of excavation and sidecast material.
- Drainage control to minimize erosion and sedimentation.
- Control on in-channel operations.
- Bridge and culvert design and installation.
- Development and rehabilitation of gravel sources and quarries.

Effectiveness Criteria

The basis of the turbidity sampling procedure was to determine if BMPs are effective in preventing water quality degradation, using turbidity as the sole parameter of water quality. According to the Alaska Forest Resources & Practices Regulations, the degradation of water quality means a decrease in water quality such that affected waters are unable to fully maintain existing or designated uses. Degradation of water quality does not include temporary, localized, and reparable conditions. Temporary is defined as

48 hours or less and reparable is defined as an effect that is reversible by natural processes.

The most stringent criteria in the Alaska Water Quality Standards are those surrounding "water supply, drinking, culinary, and food processing". This rule states that turbidity levels may not exceed 5 NTU above natural conditions when the turbidity is 50 NTU or less. In addition, turbidity may not increase more than 10 percent when the natural turbidity level is more than 50 NTU, and may not exceed a maximum increase of 25 NTU.

Site Selection

Over the past two years approximately 2,000 miles of road have been surveyed in the Tongass National Forest. These road condition surveys have focused on forest system road segments. The program goal is to complete surveys on all road systems and temporary roads within five years. This goal led to surveys that were not based on a specific survey design but rather on availability of resources and time.

Monitoring locations for turbidity measures was based on new large stream crossing locations. During the period of 1999, turbidity was measured on three stream crossings installed on Nemo Loop Road. Only two other major stream culverts (48 inches or larger) had been installed in the study area at this time. Therefore, the study sites represented a 60 percent sample of all new stream-crossings installed.

Variables Measured

Two types of road-related water quality monitoring were conducted throughout 1999: (1) direct measurements of stream turbidity and (2) indirect measurements of road erosion sources through road condition surveys.

The key indices of BMP effectiveness that were recorded in the road condition survey's include: length of ditch erosion; frequency of functional cross drains per mile; number of diverted stream channels; number of cut and fill slope mass failures per mile; number of damaged road drainage structures; and area of un-vegetated road cut slopes. This data was summarised and reported by road segment (mileposts), watershed (6^{th} level) and ranger district.

Precipitation data were collected at a site approximately eleven miles north of the project area. Turbidity samples were measured 20 feet downstream of the culvert outlet by a Hach 2100P portable turbidity meter. The turbidity samples were collected approximately 3 hours, 42 hours and 49 hours after completing structure installation.

Data Analysis

Turbidity results were compared with thresholds set in the Alaskan Water Quality Standards. No specific statistical methods were carried out to aid in the analysis of this data.

Results

The State water quality standard for "water supply" was achieved within approximately 48 hours at two of three sites monitored. Given the site conditions and results from the other areas, it is likely that this third site returned to within 5 NTU of upstream conditions by the following day. It was therefore concluded that the BMPs employed at these sites are effective in preventing water quality degradation of the turbidity parameter.

Recommendations

The Guidebook of Water Quality Standards needs to be improved to define when "water supply" standards are to be used and when "aquatic life" standards are to be used. From this study it was recommended that the "water supply' standard of 5 NTU be used to reflect the desired stream quality conditions.

The road conditions survey had not been competed at the time of this report. However, once the road conditions survey is completed it will provide a wealth of information to be used in analysing the overall effectiveness of BMPs.

Tongass Monitoring & Evaluation Report. 1999. Alaska Sediment Best Management Practices Evaluations. USDA Forest Services. R10 – MB – 414.

A12. Effectiveness of Vegetation in Erosion Control From Forest Road Sideslopes in Alabama

Practices Examined

This four-year study evaluates the effect of erosion control treatments (specifically native species vegetation) on forest road sideslope erosion from 1995-1999. The effectiveness of a wood excelsior erosion mat, and exotic species vegetation treatments were also evaluated in the Talladega National Forest of Alabama.

Effectiveness Criteria

The effectiveness of each erosion control method will be determined by comparison analysis with each other prescription and treatment area. The hypothesis of this study is that there are no differences in the sediment yield from two commonly applied erosion control treatments, such as native species vegetation and a bare soil control.

Site Selection Criteria

The road selected as the study site for this project was constructed in 1995. The road is a mid-slope half-bench crowned road with inside ditching that traverses a west-facing slope. Road construction featured 2.2:1 cutslopes and 1:1 fillslopes. The soils in this area are of the Tatum series; a fine loamy mixed thermic typic hapudult.

During the fall of 1995, 12 small plots each 1.5 X 3.1 m, were established on both a cutslope and a fillslope with homogenous slope, soils, and slope length. Plots were installed so that treatment areas were isolated from the surrounding slope. On three sides of each plot, 20-cm high borders were driven 5cm into the soil surface to exclude runoff from the surrounding areas. A collection gutter at the bottom of each plot routed runoff to a 130-L sediment tank.

Variables Measured

An on-site rain gauge recorded precipitation amounts and intensity during this four-year study period. The frequency of the data collection events varied from one to twelve weeks depending on the time required to fill the sediment tanks. Data collection began with recording runoff volume after measuring its depth in the pre-calibrated sediment tank. Suspended sediment was measured by collecting 500-mL grab samples of the stored runoff and processing them for gravimetric analysis. Total sediment yield from each plot was the combination of suspended and deposited sediment fractions collected.

Eighteen inspections of ground cover consisted of classifying 100 random points within each plot as either covered or bare. The sum of vegetation and mulch cover was taken as the percent ground cover for each plot.

Data Analysis

Sediment and runoff yield responses were tested by SAS GLM repeated measures procedures as functions of the treatment effects, with time as the repeated measure. The variables that were considered to influence the responses were precipitation amount and intensity, treatment method, and cover condition. Individual treatment mean values were tested for significance (α=0.05) where repeated measures ANOVA indicated significant differences.

To correct any influence of precipitation differences on sediment and runoff yields, analysis of sediment and runoff concentrated on yield per unit depth of precipitation, instead of overall yield.

Results

Sediment yields were significantly reduced by all treatments used in this investigation. Over the 4-year study period, the erosion mat, exotic species, and native species

treatments were not statistically different in sediment yield, although differences were detected in runoff yield. Reductions greater than 70% of total soil losses from treatments were observed during the first six months of the study period.

The results of this investigation indicate that native species vegetation offer similar erosion control benefits to that of exotic species vegetation and the wood excelsior erosion mat. Therefore, the findings indicate that the selection of exotic species over native species is not justified.

Recommendations

The BMPs pertaining to revegetation should be revised to incorporate native plant species rather than exotic species vegetation.

Grace, J.M. 2002. Effectiveness of Vegetation in Erosion Control From Forest Road Sideslopes. Transactions of the ASAE. Vol. 45(3): 681-685 2002 American Society of Agricultural Engineers ISSN 0001–2351.

A13. Effects of Logging on Macroinvertebrates in Streams With and Without Buffer Strips

Practices Examined

This study evaluates the impacts of logging, with and without buffer strip protection, on stream macroinvertebrates. Comparison of macroinvertebrate community structure in commercially logged and control watersheds were examined throughout northern California.

Effectiveness Criteria

For the purpose of effectiveness analysis, the buffered streams were placed into two categories based on the average width of the buffer strip: narrow buffers (<30m) and wide buffer (≥ 30m). Each stream was then matched in blocks with pairs of control stations, to determine effectiveness by dissimilarity analysis.

Site Selection Criteria

Sampling at 57 stations in 50 northern California streams ran from May 3 to September 13, 1975. These streams ranged geographically from coastal to mid-elevation Sierra Nevada mountains. Most of these streams were located in National Forest Service lands and selected by US forest Service personnel. Sampling stations fell into three categories: (1) control, lying in reaches with negligible upstream disturbance to the watershed; (2) logged, in areas without buffers; and (3) buffered in logged reaches with a 3 to 60-m zone of unharvested or slightly harvested timber adjacent to the stream channel.

Variables Measured

Individual sampling stations were located in the upper, lower and mid portions of each study stream reach. Eight benthic invertebrate samples were taken at each station using a modified Surber sampler. Successive pairs of samples were combined so that four (double) samples were obtained from each station. In the laboratory, organisms were separated from debris by floatation in MgSO solution, and removed by hand under magnification. Most invertebrates were identified to the genus or species level while certain Coleoptera could only be identified to the family level.

Riffle complexes were also measured at sample locations determined by sight, in an attempt to minimise variation in current, gradient, depth and substrate size.

Data Analysis

The comparison of logged sites with unlogged sites was done by means of indices of dissimilarity. Because dissimilarity indices themselves reflect different aspects of variation in community structure, three indices were chosen which span a range of properties and have some precedent in the ecological literature. These include Euclidean distance, Chord distance, and Mutual distance (Orloci, 1975).

Euclidean distance reflected logging effects more consistently than the other techniques used, apparently due to the high densities associated with logging. The sensitivity of Euclidean distance to logging effects is a major reason why it was selected for the majority of statistical analyses.

The initial assessment of logging effects was based on dissimilarity analysis of six logged sites that were matched in blocks with control pairs. Two tests, Euclidean distance and Shannon diversity, gave the clearest indication of logging effects. The null hypothesis, stating no logging effects, was rejected at $P=0.0003$.

For the purpose of analysis, buffered streams were placed into two categories based on average approximate buffer width (<30 m and ≥ 30 m). The buffered streams were then matched into blocks with pairs of control stations to allow for dissimilarity analysis. Euclidean distance was the primary method of comparison and Shannon distances secondary.

All stations were also compared simultaneously in a non-parametric, one-way ANOVA test, using diversity as the dependent variable.

Results

Streams with narrow buffer strips (<30 m) showed significant effects by the Euclidean distance test, while diversity varied widely and was not significantly different from that in either unprotected or control streams. Macroinvertebrate communities in streams with

wide buffers (≥30 m) could not be distinguished from those of controls by either Euclidean distance or diversity. The diversity level in wide-buffered streams was significantly greater than in streams without buffer strips, indicating effective protection from logging effects.

Recommendations

The statistical analysis carried out in this study was based on the assumption of random assignment of stations to treatment or to control sites. Actual selection of sites was made after logging had occurred and was based on the availability of reasonably matched logged and unlogged sites. Future studies should be based, to the fullest extent, on random sampling designs to select stream study sites and locations of monitoring.

Newbold, J.D., D.C. Erman and K.B. Roby. 1980. Effects of logging on macroinvertebrates in streams with and without buffer strips. Can. J. Fish. Aquat. Sci. 37: 1076-1085.

A14. Results of Voluntary Forest Management Practice Guidelines To Protect Water Quality In The South-eastern US: An Example from South Carolina

Practices Examined

This study examined the effectiveness of the South Carolina Forestry Commission BMPs for protecting water quality. The major BMPs investigated in this study included a fixed-width primary streamside management zone (12.2m) and a secondary zone based on slope (0-36.6m) on each side of a perennial stream. Additional BMPs included haul roads generally following ridgelines, broad based dips and water bars on permanent roads; and landings carefully located to minimise skidding across streams. The study of these BMPs was carried out on four experimental watersheds in the Clemson Experimental Forest, in the Piedmont of South Carolina.

Effectiveness Criteria

For comparison of natural and altered watersheds, the study by Hewlett (1979) was used to determine the natural loss rate of sediment for watersheds in the Piedmont of South Carolina. Based on this study it was concluded that successful BMPs would not be expected to lower sediment yields below 150kg/ha the first year after treatment.

Site Selection Criteria

Forestry BMPs were evaluated in a catchment study located in the Carolina Piedmont. This location was chosen since it contained steep slopes, erodible soils, and a history of

severe erosion. The Piedmont was considered the most critical physiographic province within the state and would therefore provide a threshold to BMP effectiveness. The selection of the four watersheds in the Seneca River watershed on the Clemson Experimental Forest were based on physiographic variables and the availability of pre and post-harvesting conditions.

Variables Monitored

Logging treatments were applied to three watersheds to test three common types of site preparation practiced. All areas and site preparation plans were based on silvicultural prescriptions and resulted in portions of each watershed treated as either logged, herbicide and burn, control, and clearcut.

Each watershed was measured at the lower-most reach for continuous flow, using a 61 cm H Flume equipped with an ISCO model 4230-flow recorder. Flow rates were averaged hourly and data transferred to Hewlett Packard model 540 palmtop computers and later to Excel spreadsheets.

Water quality parameters were determined on one stormflow sample and two baseflow samples each month. Water quality parameters included: dissolved oxygen, pH, conductivity, temperature, total suspended solids, turbidity, colour, nutrients, and coliform bacteria. Stormflow samples were taken by the ISCO automated samplers, which were triggered when the flow recorders detected a stage rise greater than a predetermined amount. Once the sampler was triggered, one-litre samples were collected each hour for the first 12 hours, then a 250ml sample was collected each hour with four samples aggregated into a single bottle. Each sample set was collected for the duration of 60 hours. Also two, 1-L samples were taken during baseflow by manual triggering of the automated samplers.

Data Analysis

Sediment and elemental loss were estimated using flow records and a flow volume to nutrient concentration relation determined from the storm flow sampling of each particular month. The flow rates and elemental concentrations were used to determine 60 hourly estimates of elemental loss. Regression was then calculated between the flow rates and elemental loss. Separate regression equations were used for each element and month on each watershed.

Statistical analysis was conducted as paired watersheds with each of the three treated watersheds compared to the control in separate analyses. For sediment and each water quality element, a monthly export amount and flow-weighted mean concentration were calculated. A paired T-test was used to compare differences between each watershed value and control during the pre-treatment period to those obtained during the post-treatment period. Post treatment values in each watershed were also compared to pre-treatment values with a simple two tailed T-test.

Results

This study placed the most severe treatments on the steepest watersheds. Post treatment also coincided with a very heavy rain season (> 250 mm per month) associated with the El Nino event of 1997-1998. The result of the most severe tests indicated sediment concentrations that averaged below 100 mg/L for all treated watersheds. Therefore, the South Carolina Forestry BMPs, which are used in over 90% of logging operations, protected water quality in all of the case studies in this project.

Recommendations

No recommendations made.

Richardson, J., Blorheden, r., Hakkila, P., Lowe, A.T. and Smith, C.T. (Comp.) 2001: "Bioenergy from Sustainable Forestry: Principles and Practices". Proceedings of IEA Bioenergy Task 18 Workshop, 16-20 October 2000, Coffs Harbour, New South Wales, Australia. New Zealand Forest Research Institute, Forest Research Bulletin No. 223.

A15. Effects of Best Management Practices on Forest Streamwater Quality in Eastern Kentucky

Practices Examined

The primary objective of this study was to examine the long-term impacts of forest harvesting on stream water quality in Eastern Kentucky, and the effectiveness of current BMPs in protecting aquatic systems. The specific BMPs incorporated into this study include streamside buffer strips, minimization of road building impacts, use of water control structures on all roads, and retirement of roads and skid trails after logging.

Effectiveness Criteria

A paired and multiple watershed approach was used to evaluate the effectiveness of BMPs. Streamflow data were analysed as the difference between actual and predicted monthly values. Differences in suspended sediment between the three watersheds were analysed using paired daily flux data. Differences in suspended sediment and nutrients were determined significant at $p \leq 0.05$.

Site Selection Criteria

A multiple watershed approach was used to determine the effectiveness of BMPs in protecting water quality. Three watersheds were used in total, selected primarily on the availability of pre-harvesting data. Watershed A was the uncut reference watershed.

Harvesting of watershed B (BMPs applied) incorporated past BMP guidelines, and was harvested between early September and late October 1983. Watershed C was harvested during November 1983, and was used to represent conditions when BMPs are not applied. This watershed was logged without attention to water quality impacts. There were no buffer strips present, trees were fallen into and across streams, and no retirement practices were enforced on roads and skid trails.

Variables Monitored

Streamwater flow data were monitored at the lowermost reach in the three watersheds, for 18 months prior to harvesting. This established baseline surface water flow data using the multiple watershed approach. Linear regression was then used to develop predictive relationships between the reference watershed and the two treated watersheds. Precipitation volume was also recorded during this time at the confluence of the three watersheds using a tipping bucket recording gauge.

Water flow data were recorded on the three watersheds using H-flumes equipped with water stage recorders to monitor continuous rates and quantity of streamflow. Sampling of suspended sediment began in February 1983, resulting in six months of pre-harvest data. Suspended sediment samples were collected every six hours using automatic water samplers (ISCO Model 1680) installed near the H-flumes.

Weekly water quality grab samples were collected immediately above each flume. Water quality analysis included specific conductivity, total alkalinity, pH, and numerous chemical properties. Stream and ambient air temperature were also recorded near the flumes with thermistors sensors equipped with twin-probe data loggers.

With the exception of suspended sediment, all sampling began in February 1982 and ran to 1993, when leaks in the H-flumes caused the termination of the project.

Data Analysis

All data analysis was conducted on weekly or monthly flows calculated as the sum of the daily flows and reported as centimetres of water yield. Paired comparisons of data sets were made using the Wilcoxon signed rank test for abnormally distributed data (Scedecor and Cochran, 1980). Within treatment periods, and water year, streamflow data were analysed as the difference between actual and predicted monthly values for watersheds B and C. Significant differences in suspended sediment loads and nutrients were determined using paired daily flux data. Significance was evaluated at $p \leq 0.05$. All statistical analysis was carried out on JMP statistical software (SAS Institute, 1995).

Results

This study observed dramatic differences between the two treated watersheds (A and B) in nutrient and sediment export. There was some indication that streamside buffer strips did function as a biological filter, in extremely steep terrain, limiting the transport of

nitrogen from watershed B. In general, the BMPs applied to watershed B resulted in less sediment loss and a slight significant difference in nutrient exporting.

Recommendations

Future research is needed to reveal the biological function of forest streamside buffer strips in controlling solute transport under varying topographic conditions. Because this study used BMP guidelines current 14 years ago, the results of this report provide conservative measures of the effectiveness of current BMP guidelines, which have evolved to include more stringent guidelines for road construction.

Arthur, M. A., G. B. Coltharp and D. L. Brown. 1998. Effects of Best Management Practices on Forest Streamwater Quality in Eastern Kentucky. Journal of the American Water Resources Association. 34(3): 481-495.

A16. Hydrologic Impacts of Logging an Appalachian Watershed Using West Virginia's Best Management Practices

Practices Examined

The objective of this study was to evaluate hydrologic impacts associated with the use of BMP guidelines adopted by West Virginia from 1979 to 1989 in an attempt to minimise harvesting related nonpoint-source pollution and subsequent impacts.

Effectiveness Criteria

Determination of the effectiveness of BMPs was based primarily on comparison analysis between the harvested watershed and reference watershed. Temperature was also required to remain below 24°C for BMPs to be considered effective in protecting water quality.

Site Selection Criteria

A paired watershed approach was used to analyse the effectiveness of West Virginia's BMPs. A 39 ha watershed (Haddix) was used as the harvest watershed, and a second watershed (Fernow) was used as the control watershed. The selection of these watersheds was based on harvest plans scheduled for Haddix watershed and the large amount of existing data (1930 to present) from the Fernow reference watershed.

Variables Monitored

Measurements of streamflow and water quality for the Haddix watershed began on May 1, 1983. All hydrologic data was measured in the lowest reach of the watersheds and presented using a May 1 to April 30 water year. Stream water was sampled weekly, and

more frequently during high flows. Sediment samples were also measured during large storms by grab samples and automatic pumping samplers.

A maximum/minimum thermometer was placed above the gauging station in each watershed to read weekly temperatures. At this same location, water grab sampling occurred for water quality characteristics. Parameters included pH, major ion concentrations, calcium, magnesium, potassium, nitrate, and sulphate.

Data Analysis

Comparison analysis using regression was the primary method to determining whether a statistical difference existed between harvested areas with BMPs and reference conditions. Wilcoxon statistical tests were also carried out at α=0.05 to determine statistical difference of non-uniform data sets.

Results

The BMPs used in this study were effective in minimising impacts to soil and water resources. The BMPs included the use of such devices as broad-based dips, culverts, waterbars, seeding roads and landing to control erosion, and traffic regulation during wet weather.

Neither annual peak flows or total annual stormflow volumes were changed by harvesting and related activities. The relatively small increases in growing-season storm flows reported here are attributed to: (1) a road system that was well laid out and the use of water control structures, (2) keeping roads landings, and machinery at least 30 m from streams except at crossing sites, and (3) minimal soil disturbance and compaction on logged area.

Recommendations

No recommendations.

Kochenderfer, J.N., Edwards, P.J, and F. Wood. 1997. Hydrologic Impacts of Logging an Appalachian Watershed Using West Virginia's Best Management Practices. USDA Forest Service, NJAF 14(4).