THE ROLE AND DESIGN OF WATER QUALITY MONITORING ON FORESTED WATERSHEDS

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INTRODUCTION

While many point sources of pollution have been ameliorated over the last twenty years, nonpoint sources (NPSs) of pollution remain a serious threat to the nation's water quality (Reilly, 1991). On a national scale, silviculture is one of the leading causes of NPS pollution, and has been identified as a localized problem in the Southeast (Myers, et al., 1985). Because forested watersheds often possess the nation's best quality waters, NPS control programs for protecting these waters must be undertaken.

In this paper, a conceptual framework is established that shows the complex interrelationships between management mechanisms, investigation methods, and criteria and assessment methodologies for silvicultural NPS pollution control. The role and definition of water quality monitoring for the operation of this management framework is discussed, and the fundamental components related to the design of water quality monitoring programs are discussed. The monitoring programs include monitoring objectives, sampling stations and frequency, and environmental parameters.

It should be emphasized that there does not currently exist a technical guide for forest water quality monitoring in the Southeast. It is the intent of this paper, therefore, to draw upon monitoring guidelines developed for other regions, and to clarify the role of water quality monitoring and to propose general design guidelines for implementing forest water quality monitoring programs in the Southeast.

ROLE OF WATER QUALITY MONITORING

Important differences between point and nonpoint sources of pollution include: (1) an increased emphasis on institutional and technical management for controlling NPSs over uniform technological treatments that are more important for point sources; and (2) a recognition that NPSs generate many non-chemical stresses (e.g., habitat alteration, hydromodification) while point sources normally involve conventional or toxic chemicals (e.g., BOD, heavy metals). With these differences in mind, it is now possible to evaluate the role of water quality monitoring with respect to the management framework for controlling silvicultural NPS pollution, and then to present a broadened definition of water quality monitoring on forested watersheds.

Management Framework

EPA recognizes and advocates the use of Best Management Practices (BMPs) as a means for NPS pollution control. EPA has provided guidance for establishing control strategies that include: (1) selection and design of BMPs; (2) monitoring to assure that practices are correctly designed, applied, and effective; and (3) adjustment of BMPs and/or water quality standards when it is found that the beneficial use of water is not protected (US EPA, 1987).

It has been proposed that the EPA strategy include simulation modeling as an element in the determination of environmental impacts associated with forest activities. It has also been suggested that water quality standards be extended from physico-chemical criteria (US EPA, 1986) to include biological and ecological criteria (US EPA, 1990; US EPA, 1992) to supplement conventional monitoring techniques. The improved management framework uses an iterative process for controlling NPS pollution (Fig. 1). Although the detailed characteristics of each component and the overall functions of the framework is beyond the scope of this paper, the role of water quality monitoring for silvicultural NPS control is clearly reflected in this management framework.

Because BMPs do not assure the attainment of water quality goals (e.g., see Maxted, 1989; Solomon, 1989), investigations must be conducted to determine the environmental impacts of proposed forest BMPs. Operationally, this task can be accomplished using either direct methods (i.e., monitoring) or indirect methods (i.e., simulation modeling). It is important to note that monitoring not only provides Measured Environmental Values (MEVs) for conducting environmental, biological, and ecological assessments based on various criteria, but also provides information for simulation models that in turn provide Estimated Environmental Values (EEVs) for assessment purposes.

There are at least three reasons that monitoring is necessary for water quality management framework: (1) NPS models normally require calibration and evaluation using observed data; (2) NPS models may not be sufficiently accurate to provide estimates with sufficient temporal and spatial resolution, because of the limitations of the model capabilities and the inadequacies of resources for modeling exercises; and (3) NPS models are currently limited to estimating alterations in stream flow quantity and the physical/chemical quality of water columns, and do not provide estimates of many NPS stresses such as habitat degradation and channel modification which are also critical to the aquatic ecological integrity, particularly on forested watersheds because land use activities can more directly affect the low-order stream ecosystems.

Broadened Definition

Early water pollution control efforts were primarily directed toward point source discharges, characterized by physical and chemical parameters. However, water pollution problems, especially for NPSs, can only be successfully controlled from a broader and integrative ecological perspective, because the environmental impacts on aquatic ecosystems include not only the physical properties and chemical constituents of water columns, but also many other factors such as flow regime, habitat structure, food (energy) sources for aquatic organisms, and biotic interactions (Karr et al., 1986; Karr, 1991). Although standards now exist for 98 parameters (US EPA, 1986), only a few of these parameters (e.g., dissolved oxygen, temperature, turbidity, and perhaps nitrogen, phosphorus, and pesticides) are likely to be important in describing the impacts of silvicultural activities. Many additional environmental factors may indicate important adverse effects on stream ecosystems in forested watersheds, for example, degradation of invertebrate and juvenile fish habitats due to cobble embededness, and composition change of macroinvertebrate community due to the reduction of allochthonous organic matter inputs after riparian vegetation harvest. Monitoring for these impacts may include physical and chemical constituents, flow, sediment, channel, and riparian characteristics, and aquatic organisms (MacDonald et al., 1991).

WATER QUALITY MONITORING DESIGN

Careful design of a monitoring project is the key to the successful detection and evaluation of physical, chemical, and biological impairments of forest stream ecosystems. It is proposed that water quality monitoring plans should include the specification of monitoring objectives, the sampling location and frequency, and the selection of water quality parameters to be monitored. These are addressed in greater detail below.

Monitoring Objectives

Technical guidelines suggest that an important initial step in the formulation of a water quality monitoring project is to define the existing problem and monitoring objectives (MacDonald et al., 1991; Ponce, 1980; Potyondy, 1980). A clear and direct problem definition usually includes: (1) the land use management activity of interest; (2) the affected water resource; and (3) the type of water resource impairments (Ponce, 1980). The monitoring objectives should specify the measurable results to be obtained within a stated time period. The objectives affect the type, intensity, and spatial and temporal scales of measurements, as well as the strategies for realizing the desired goals.

Unfortunately, different federal and state agencies use different classification system for describing monitoring types. Table 1 lists monitoring types for four classification systems. The inconsistent definitions and overlapping classification systems may result in semantic confusion (MacDonald et al., 1991). A clear and specific definition of water quality problem and monitoring objectives is the key for designing and implementing a successful monitoring project.

Sampling Stations and Frequency

There are many factors to consider in selecting the sampling stations and frequency, among which the following three factors are normally most important.

Monitoring objectives are usually not beyond four categories, each of which has a specific purpose in monitoring design: (1) determination of baseline water quality for detecting possible water quality criteria violations, or for establishing a data base for planning or future comparisons (MacDonald et al., 1991); (2) temporal comparison of water quality for determining the long-term trend of particular water quality parameters, for determining whether BMPs are properly implemented, and for assessing the effectiveness of BMPs; (3) spatial comparison of water quality for detecting the environmental impacts of a specific forestry activity; and (4) monitoring for NPS water quality model calibration or evaluation.

Type of waterbody and seasonal hydrologic changes must be considered in selecting sampling stations and determining sampling time schedules, respectively. Upstream-downstream and paired watershed methods can be used in forest stream monitoring programs, and the near-field and far-field method is often appropriate for lakes and reservoirs. Usually the longitudinal gradient is important for stream systems, especially for small headwater low-order forest streams, while water quality and organism distributions over the vertical axis is more important in lakes, and both longitudinal and vertical gradients need to be considered in reservoirs. In addition, silvicultural activities may create groundwater pollution problems, such as applications of chemicals (herbicides,

Table 1 Classification of forest water quality monitoring types

Agency/Region	Types of Monitoring	Reference
EPA Region X	Trend, Baseline, Implementation, Compliance, Effectiveness, Project, Validation	MacDonald et al. (1991)
USDA-FS	Cause-and-effect, Compliance, Baseline, Inventory	Ponce (1980)
USDA-FS Inter-mountain Region	Baseline, Project	Potyondy (1980)
USDA-FS	Implementation, Effectiveness, Validation	Solomon (1987)

pesticides, fertilizers) and landfills for solid waste disposal on forested lands, that require monitoring.

Statistical considerations for water quality monitoring design require examination to reduce the uncertainties associated with management decisions. Due to the existence of spatial and temporal variations in hydrologic and water quality parameters, the variances of the parameters must be considered when selecting sampling stations and frequency. Usually there are three schemes for sampling design: random sampling, stratified random sampling, and systematic sampling, each of which is used to determine the required sample size and frequency (Gilbert, 1987; Ponce, 1980).

In addition, many other factors such as cost constraints, types of constituents measured, access to monitoring sites, and the availability of existing data should be considered in the design of monitoring programs.

Monitoring Parameters

The only comprehensive technical guidance for water quality monitoring on forested watersheds is offered by MacDonald et al. (1991), which augments monitoring parameters to include many other environmental factors influencing the structure and function of stream ecosystems. They recommend that a total of 30 parameters or groups of parameters be used to determine silvicultural impacts. The parameters can be grouped into six categories: physical and chemical constituents, flow characteristics, sediment characteristics, channel characteristics, riparian characteristics, and aquatic organisms.

The selection and use of monitoring parameters depends upon a wide range of factors that include monitoring objectives, designated uses of water, forestry activities of concern, cost, environmental setting, etc. (MacDonald et al., 1991). The analysis should be performed through cooperative multidisciplinary effort including hydrologists, silviculturists, and stream ecologists. An interactive expert system called PASSSFA (PArameter Selection System for Streams in Forested Areas) has been developed by MacDonald et al. (1991) to assist forest managers in selecting the monitoring parameters for asuite of conditions.

SUMMARY

Nonpoint source pollution issues remain an issue of significant interest, especially in relation to silvicultural activities in the Southeast. The role of water quality monitoring is important for resolving issues related to the selection of Best Management Practices for silvicultural NPS pollution control. Water quality monitoring provides direct information related to the suitability of various management options, as well as for use in simulation of water quality processes. It is recommended that monitoring should not just focus on the traditional physical and chemical parameters, which are often useful for point source pollution abatement, but should also focus on other environmental and biological indicators of ecosystem structure and function.

A framework for designing water quality monitoring systems is presented that emphasizes the need to specify the objectives of the program, along with the need to determine the location and frequency of sampling. The identification of the parameters is also an important component in which we should consider the special conditions on forested watersheds.

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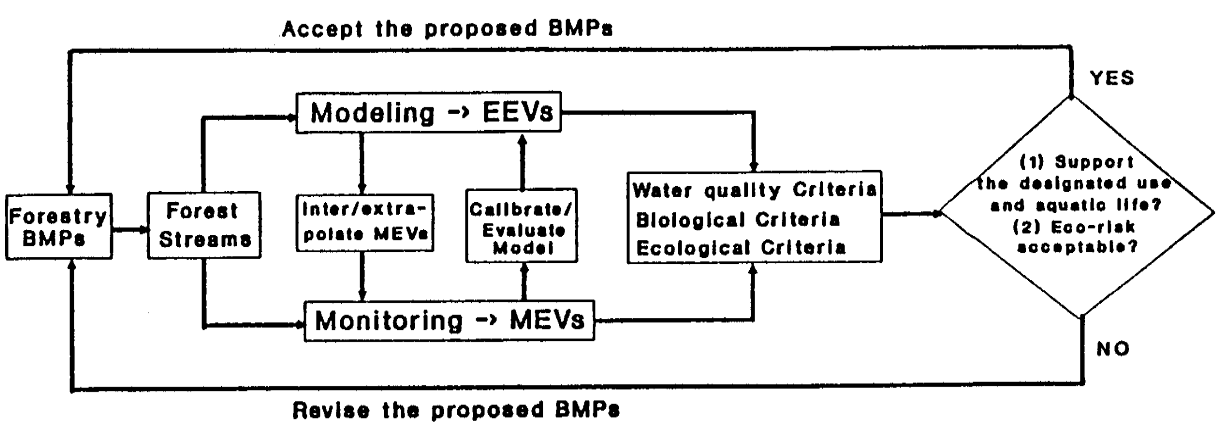

Figure 1 Management framework for nonpoint source control