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GUIDELINES FOR ASSESSING THE BENEFITS OF BEST MANAGEMENT PRACTICES TO STREAM ECOSYSTEMS

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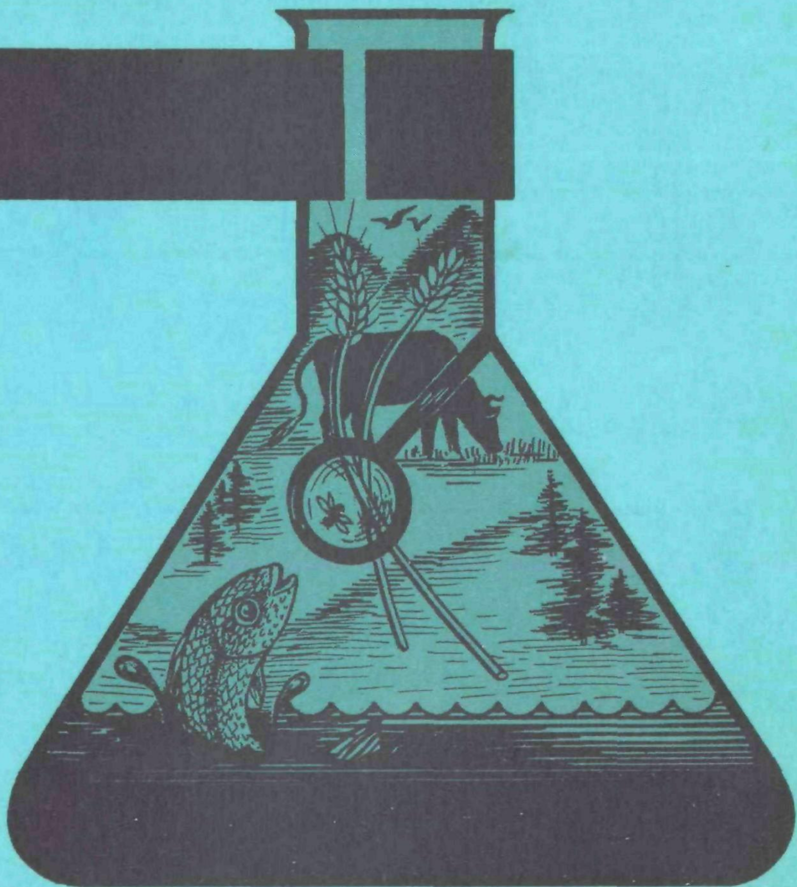

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Introduction

The Environmental Protection Agency recognizes the biological responses of water bodies to best management practices (BMP) as an important measure of their effectiveness and enhancement of stream or lake health and utility. This is especially true where BMP's focus on control of pollutants from nonpoint sources (NPS).

Testing, evaluation, and development of ecological assessment methods for linking pollution controls with benefits to man's use of water is one of the four objectives of the nonpoint source ecological effects research program begun in FY 77 at the Corvallis Environmental Research Laboratory (CERL). The impetus for release of this document at this time is the initiation of the interagency Model Implementation Program (MIP) and the many requests from the Section 208 sector. The guidelines presented here should be considered state-of-the-art. As research outputs develop, these guidelines will be updated and improved.

Recently an interagency agreement was established between the U.S. Environmental Protection Agency and the U.S. Department of Agriculture for the common interest of developing Model Implementation Programs (MIP) for water quality management. This effort will involve selecting 3-5 geographic areas in the United States, implementing best management practices (BMP) in those areas, and evaluating their effectiveness. The evaluations will include measuring decreases in nonpoint source (NPS) pollutants delivered in runoff to surface waters and subsequent changes in surface water quality. CERL's involvement will carry the evaluation one step further and examine the response of the biological stream community to reduced levels of NPS pollutants. The biological evaluations will be limited to one or two MIP areas.

Objectives

The purpose of the approach outlined herein is to evaluate the effect of BMP's by examining biological changes in stream systems and relating these changes to the observed reduction of NPS pollutants.

The objective of establishing guidelines at this time serves several purposes. First these guidelines fix the level of effort that must be dedicated to a project if realistic and usable data are to be obtained. Second, they serve as partial criteria in selecting or determining the adequacy of the sites and third, they identify the approach that must be followed in attempting to interpret the effects of nonsteady state, nonpoint source inputs on stream communities.

These guidelines will also serve as the basis for evaluating extramural research proposals which may be solicited at some future time to support the MIP Program.

Approach

It is assumed that the major pollutants to be controlled via BMP's are sediment, phosphorus, nitrogen and/or degradable organics. Pesticides, herbicides, and trace metals may also be of interest depending upon the nature of the study area(s). If the latter pollutants are of specific concern, the scope of the basic biological studies would not change, but the study plan would be modified to include measures of bioaccumulation which are relevant to human health and the well-being of the aquatic ecosystem.

There are at least three approaches or experimental designs which could be used to evaluate the impact of BMP's on stream ecosystems. The design of choice for a given MIP area will depend on a number of factors including:

(1) size of the MIP area and the number of watersheds amenable to study therein,

(2) availability of a non-contributing* watershed(s) within or near the MIP area to serve as a control,

(3) spatial orientation of the non-contributing watershed to the contributing watershed, if both are located in the same drainage basin,

(4) availability of adequate physical, chemical and biological baseline data,

(5) time available to gather baseline data if they do not exist.

The first approach or design involves a minimum of three study areas, but preferably four or five, within a MIP area and is called the "gradient" approach. The term gradient is used because BMP's will be implemented on varying percentages of the total area of each contributing watershed. An example of this design, using five watershed/stream (W/S) systems, is illustrated in Table 1. Each of the five watersheds (and associated stream reaches) must be geomorphologically similar and the land uses in the four contributing watersheds must be the same.

* a non-contributing watershed is covered by a land use which generated minimal quantities of NPS constituents; e.g., forest or ungrazed grassland. A contributing watershed generates relatively high levels of NPS constituents; e.g., row crop agriculture or construction activities.

TABLE 1. Gradient Analysis Design

Watershed/stream identification	% of watershed area covered by a contributing land use	% of contributing land use area treated by BMP's
A	100	0
B	100	33
C	100	66
D	100	100
E	0 (non-contributing)	0

The sample design, illustrated in Table 1, can be modified as necessary to fit a specific area; i.e., the percent of the contributing land use area treated by BMP's does not have to be exactly as shown. The simplest but least desirable form of this design includes only three W/S systems: W/S systems A and D, as shown in Table 1, plus a third W/S system in which 50% of the contributing land use is treated by BMP's.

The inclusion of W/S E (a non-contributing watershed) is desirable as an indication of the best stream quality achievable through BMP implementation in a specific geomorphologic setting. In reality, it may be impossible to find a suitable non-contributing watershed in an area of intensive land use. If W/S E is not included in the study, the relative stream quality improvements attributable to BMP implementation can still be determined.

A modified gradient approach can be used to rank the effectiveness of different BMP's as well as the effect of different intensities of a given BMP.

The advantages of the design outlined above are that, (1) a minimal amount of pre-BMP data are required, (2) W/S A (100% covered by a contributing land use; no BMP's) serves as a control for the between year variation which will occur in stream discharges, pollutant loads, concentrations and biological responses resulting from climate differences, and (3) the gradient approach will demonstrate the relationship between the intensity of BMP implementation in the watersheds and the impact on the stream ecosystem as illustrated in Figure 1.

The "biological index," represented by the ordinate in Figure 1, may reflect aquatic species diversity, biomass, hatchability and survival of fish eggs or a combination of factors indicative of the biological "health" of a stream system. Curves A, B, and C in Figure 1 are hypothetical examples of the biological response to different intensities of BMP implementation. A response corresponding to curve B indicates improvement in biological quality proportional to the percent of total watershed influenced by BMP's. Curve A indicates substantial biological improvement with BMP implementation over the initial 50% of a watershed's area with a diminished rate of improvement thereafter. Curve C indicates that significant biological improvement only occurs when runoff from most of a watershed is controlled by BMP's. Although Figure 1 is a hypothetical example, data of this type obtained from a MIP's project would provide extremely useful guidance in the future application of BMP's.

The disadvantages of the gradient approach are that (1) it may be difficult to find a set of geomorphologically similar systems which fit the design, and (2) an extensive sampling and data analysis program will be required.

The second design involves paired watershed/stream systems both similar in geomorphologic and land use characteristics. Best management practices would be implemented in one of the watersheds but not the other. Both watersheds should be heavily impacted (i.e. nearly 100% coverage) by the selected

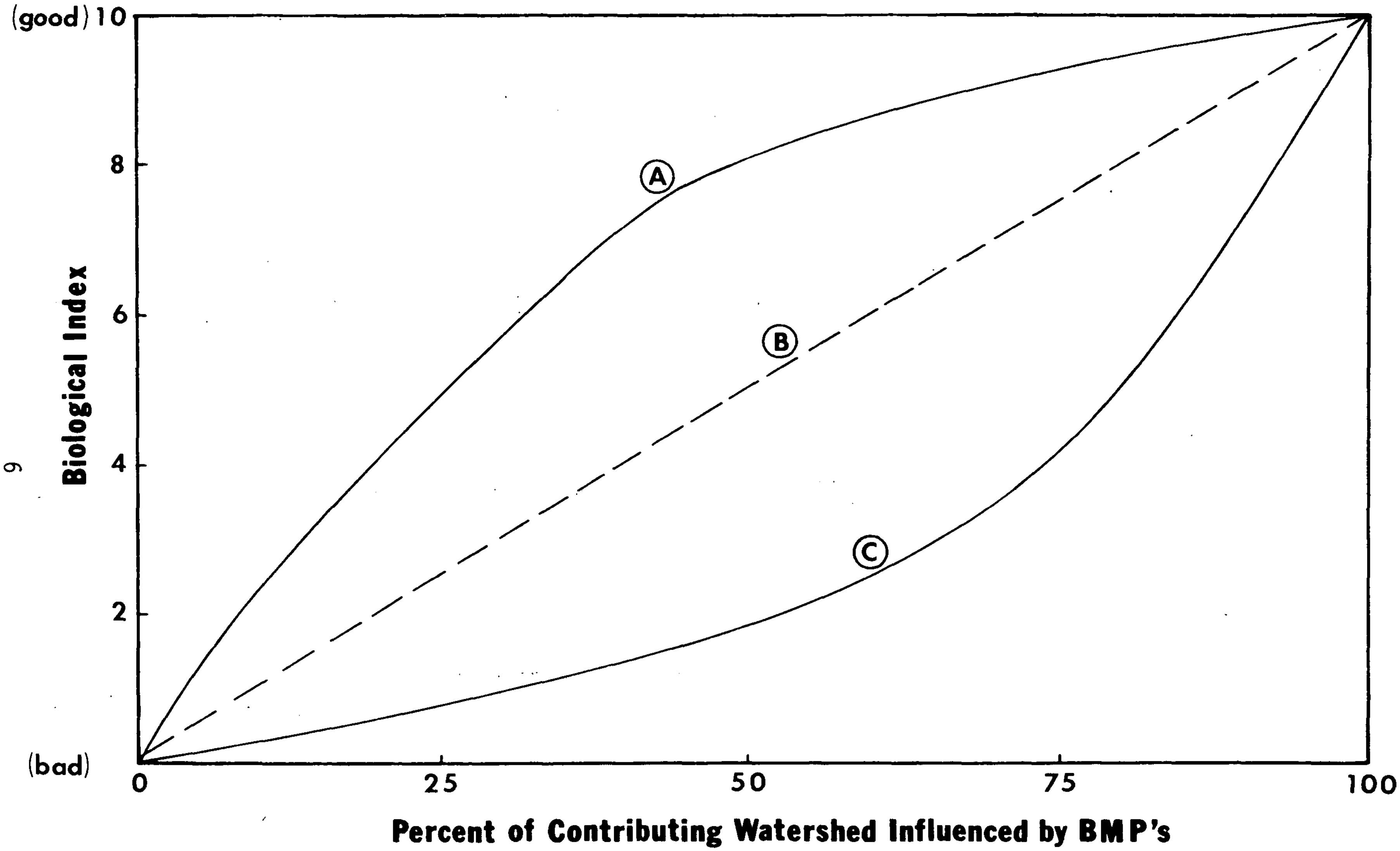

FIGURE 1. An example of possible relationships between the biological quality of streams and the percent of watershed area influenced by BMP's.

land use. A desired variation to this design would include a third watershed/stream system geomorphologicaly similar to the first two but unimpacted by cultural activities, (i.e. forested or ungrazed grass land). Advantages to this design are, (1) that the relative effects of BMP implementation could be measured without lengthy baseline studies, and (2) the sampling program would be smaller than that required for the gradient approach. The major disadvantage is that the approach is "all or nothing" and no information will be obtained about the effects of BMP implementation over part of a watershed.

The third approach involves an intensive study of one stream draining a watershed heavily impacted by NPS activities. The nature of the biological community and associated water quality would have to be established in its "stressed" condition prior to the implementation of BMP's. After BMP implementation, the same studies would be conducted at the same sites to determine the extent of water quality improvement and the associated changes in the biological community. Advantages of this approach are that, (1) a watershed of this kind would be relatively easy to locate, and (2) the sampling program would not be as large as that required for the gradient approach. The greatest disadvantage is that the natural year to year variations caused by climatic differences may mask any benefits achieved by BMP implementation unless the magnitude of the variation is well defined by collecting (or having in hand) several years of baseline data.

Study Duration

If the gradient analysis design is used, a minimum of one year of baseline data will be required to demonstrate that the biological communities in the stream draining each of the "contributing" watersheds are, in fact, the same. Following the baseline study period and BMP implementation, at least three years of study will be needed to demonstrate the impact of BMP's on stream biota.

The second (paired watershed/stream systems) approach should also include one year of baseline data to demonstrate that the physical, chemical and biological features of the two stream systems are similar. Following BMP implementation in one of the watersheds, a three year study period would be required.

The third approach, using a single watershed, requires the longest baseline study of the three options. Three to five years of baseline data would have to be collected to establish the variability of the physical, chemical and biological characteristics of the stream system before BMP implementation followed by three years of post-BMP study to demonstrate the change.

Measurements

To evaluate the impact of BMP's a number of in-stream physical, chemical and biological measurements will be necessary. It is assumed that the majority of the physical and chemical measurements will be required as part of the MIP whether or not the biological studies are included. These physical-chemical measurements will be needed to evaluate the water quality change related to BMP implementation. However, they also will be useful in explaining observed changes in the biological community.

The following measurements will be needed in addition to the biological data, but should be provided as part of the routine MIP evaluation.

1. Stream discharge rate:

A continuous record of the stream discharge rates is required at the downsteam end of each study reach.*

* Depending upon the length of the study reach, additional sites for measuring stream discharges as well as other physical and chemical parameters may be desired.

Rationale: discharge will be needed to estimate the total quantity of various constituents of interest to quantify the physical-chemical effects of BMP's. The pattern of runoff events, particularly the first "flush" after an extended dry period, will be of interest regarding its impact on stream water quality and the biological community. The frequency, duration, and intensity of runoff events will be documented by the continuous discharge record.

2. Total sediment load/suspended sediments:

Measurement of the total sediment delivered via the stream from each study reach is required as a quantitative measure of the effectiveness of the BMP's. From a biological standpoint, concentration, duration, frequency, and composition (organic versus inert inorganic) of suspended solids are significant as well as that portion of the total sediment that is deposited on the stream bed following a runoff event and which constitutes a net increase in stream bed sediment. Measurements should therefore include suspended solids, differentiated into fixed and volatile fractions, during a range of flow conditions including intensive measurement during storm events following extended dry periods.

Rationale: suspended solids delivered to streams in surface runoff, particularly after extended dry periods, may contain substantial amounts of biodegradable organic material which exerts a significant dissolved oxygen demand. The reduced dissolved oxygen concentrations, in combination with additional stresses of high suspended solid concentrations and increased stream velocities, may have an adverse biological effect. Inert suspended matter <3 mm in diameter, delivered via surface runoff and deposited on the stream bed, produces a homogeneous substrate which eliminates the niches occupied by many important stream organisms. Substrates with a range of grain sizes (including fine particles) are most desirable for a healthy stream community.

3. Particle size distribution and composition of bed materials:

Particle size distribution and composition of stream bed materials should be determined at approximately the same times and locations as for benthic invertebrate sampling and salmonid egg survival tests if used.

Rationale: see item 2.

4. Turbidity:

Turbidity measurements should be made daily at the downstream end of each study reach with provisions for continuous or short interval measurements during and immediately following runoff events.

Rationale: turbidity limits light penetration through water. Light, in combination with other factors such as nutrient availability, determines the quality and quantity of primary production; e.g., periphyton growth may be the most important part of the base of the food web, hence, productivity of all trophic levels is affected. High turbidities for extended periods also give a competitive edge to nonselectively feeding fish, which are frequently undesirable species such as carp, and discriminate against most of the game fish which are sight feeding predators.

5. Nutrients:

Total phosphorus, dissolved orthophosphorus, total organic nitrogen, ammonia-nitrogen and nitrate-nitrogen should be measured at the lower end of each study reach with sufficient frequency to quantify the impact of the BMP's. The median and range of concentrations of these nutrients during the growing season are, from a biological standpoint, most meaningful. It is recommended that samples for nutrient analysis be collected at least every two weeks during stable flow conditions and that sampling times be varied sufficiently to include a range of flow conditions. Short interval sampling (hourly or even more frequently in some cases) should be conducted during heavy runoff, particularly after extended dry periods, to characterize the extremes resulting from NPS inputs.

Rationale: nutrient levels (especially phosphorus) are important factors in controlling the amount of primary production which occurs in streams and lakes. While a limited amount of primary production is desirable, higher concentrations of nutrients may cause excessive and undesirable quantities of both microscopic and macroscopic plant growth. A criterion of 100 μg/l of total phosphorus has been recommended (U.S. E.P.A., 1976) for flowing streams although there is little scientific basis for this level. Other recommended total phosphorus criteria include 50 μg/l where streams enter lakes or reserviors and 25 μg/l within lakes or reserviors.

The nitrogen constituents in water are important for three reasons: (1) inorganic nitrogen serves as a plant nutrient and in some situations be the limiting factor for plant growth, (2) ammonia (free, un-ionized) is toxic to fish and may be present in significant amounts during heavy runoff events and (3) nitrite-nitrates are significant if the stream is used as a water supply in that concentrations above 10 mg/l (as NO_3-N) may cause methemoglobinemia in infants.

6. Temperature and dissolved oxygen:

These parameters should be continuously monitored at the downstream end of each study reach.

Rationale: water temperature determines the metabolic rate of a stream community and, to a significant degree, determines which species of aquatic life are present in a stream. Water temperatures could be influenced by certain kinds of BMP's such as establishment of greenbelts. Dissolved oxygen (DO) concentrations are critically important to most stream biota. Most water quality standards specify that at least 5 mg/l be maintained in trout streams and 4 mg/l in streams supporting warm-water fisheries. Dissolved oxygen concentration in a stream at any time reflects the balance between photosynthesis, respiration and the physical reaeration which is occurring. Dissolved oxygen concentrations during heavy runoff periods will be particularly indicative of the quantity of decomposable organic matter entering a stream from nonpoint sources.

7. Total organic carbon, BOD, COD:

A measure of the degradable organics delivered to a stream, particularly during runoff events, is desired. Although the BOD test is the only direct measure of the decomposable fraction of the total organics, the idiosyncrasies of the test are many. For that reason, the measure of total organic carbon or chemical oxygen demand may be desired as a substitute for the BOD test with the results used in conjunction with dissolved oxygen data to assess changes in the levels of degradable organic material delivered to the streams.

Rationale: see item 6 rationale.

8. Other Water Quality Parameters:

Other water quality data such as pH, alkalinity, hardness, conductivity, trace metals and mineral constituents should be determined periodically (monthly to quarterly) to characterize the general water quality of the stream. It may be desirable to sample at frequent intervals, at least during one heavy runoff event, to document parameter changes during a period of rapidly changing stream flows.

Rationale: the general water quality of any stream in which biological life is studied should be documented because, to a degree, water chemistry influences the kinds of organisms which are present.

9. Climatological data:

A weather station should be located centrally in each drainage area to record precipitation intensity and amount, air temperature and light intensity.

Rationale: climatic factors are the driving force behind NPS pollution and the functioning of stream ecosystems.

The following factors should be included where biological evaluations of stream systems are made.

1. Stream Morphometry and Habitat Survey:

The study reach of each stream should be mapped to scale showing such features as width, depth, composition of bottom substrate (sand, silt, cobbles, bedrock, etc), riffle and pool areas, sinuosity, stream bed gradient, nature and stability of the stream bank, and riparian vegetation. The suitability of a stream reach as a habitat to support an adequate fish population should also be assessed. The habitat assessment should be made prior to the selection of a stream as a biological evaluation site. If suitable habitat for fish and other aquatic organisms is not available; e.g., if the stream has been straightened, channelized, and riparian vegetation removed, there will be little value in making a biological evaluation unless the BMP's include restoration of the stream habitat.

Rationale: the scale maps, indicating pertinent physical features, will be necessary for making estimates of the standing crop of benthic organisms and fish. The maps will also be of value in comparing the similarities and dissimilarities between study areas.

The habitat survey will demonstrate whether a stream has potential to be biologically productive. Unless suitable habitat is present, biological productivity will be minimal regardless of water quality.

2. Fish:

Fish populations of each study reach should be sampled in a quantitative manner at least annually and should include data on kinds, numbers, lengths and weights, and total biomass of fish present. The sampling procedure should be nondestructive, i.e. the collected fish should be kept in live boxes after capture and returned to the stream in good condition after the appropriate data have been recorded. The recommended sampling method is electrofishing in stream sections blocked at each end by nets. Season of the year to sample should be determined by the life history of the species inhabiting the stream, although, in general, it probably should be done during late summer. It is important that sampling be conducted at approximately the same time each year so that the between year data are comparable.

If the stream of interest supports an anadromous salmonid fishery, additional studies should be conducted on the hatching success of "eyed eggs" (Everest, 1975). "Eyed" salmonid eggs can be placed in small wire baskets and buried in spawning gravels at depths simulating natural spawning conditions. Egg development and hatchability is subsequently monitored. A less quantitative, but still informative procedure, would be the use of a nylon fry trap described by Phillips and Koski (1969). This trap consists of a nylon cap placed over a natural redd in a stream. Emergence of the fry is then monitored during the incubation and hatching period. While the number of eggs which had been deposited within each redd are not known, average numbers of fry emerging from a number of redds could be compared from year to year and between control and NPS impacted stream reaches.

Rationale: the fish population of a stream, including the species present and their abundance, is perhaps the primary concern of the general public interested in using that stream for recreational purposes. Density and composition of the fish population is also the best measure of the health of a stream community, since fish represent the top of the aquatic food web and therefore reflect the well-being of the components at lower trophic levels.

3. Benthic invertebrates:

Using Surber samplers, Ponar dredges, or comparable devices which sample a fixed area of the stream bed, benthic organisms should be sampled at least seasonally in each study reach although more frequent sampling, particularly when macroinvertebrate biomass "peaks" in the early spring, would be desirable. Invertebrate drift, using submerged nets with openings of known size, should also be measured at night at the same approximate locations as the bottom sampling stations. Sampling and analysis should be of sufficient intensity and sensitivity to estimate standing crop, species diversity and similar measures of the health of the benthic community before and after the implementation of BMP's in the drainage area affecting the selected stream reaches. Sampling should be conducted at approximately the same time each year so that between year comparisons can be made.

Rationale: benthic invertebrates, particularly the insects, are a major food source for fish in stream ecosystems. Total numbers, number of taxa, and biomass of benthic invertebrates reflect water quality as well as the physical characteristics of a stream. A diverse and abundant population of benthic invertebrates implies a suitable habitat and water quality for a healthy fish population.

4. Primary productivity:

   a. Periphyton - using submerged glass slides or a comparable technique the rate of production and estimates of total biomass of attached algae should be determined throughout the study reach during the growing season. The glass slide technique may be supplemented by scraping and analyzing the periphyton from natural substrates in the stream.

   b. Phytoplankton - the algal assay bottle test should be used to evaluate, (1) the potential productivity of the stream water, (2) the growth limiting nutrient, and (3) the presence of any growth inhibiting substances that may occur in the stream as the result of NPS runoff. Since these characteristics will probably vary with stream flow, it is recommended that assays be performed on samples collected over a range of stream flows including heavy runoff events.

Rationale: in intermediate size streams and unshaded smaller streams, periphyton productivity represents a large portion of the food web base and is influenced by the availability of nutrients and light (turbidity) both of which are NPS related. One would expect to be able to relate periphyton productivity not only to changes in nutrient and turbidity levels, as they might be changed by BMP's, but also the standing crops of macroinvertebrates and fish.

Phytoplankton, per se, are not particularly important in smaller stream systems. The purpose of the algal assay bottle test is primarily as a tool to determine the limiting nutrient, to indicate potential productivity levels should the water reach a lake or impoundment, and to determine if toxicants are present.

5. Bacteriology:

Bacteriological indicators of fecal contamination are more closely related to impacts on man rather than on stream ecosystems; nevertheless, relatively little additional effort would be required to gather data on the impact of BMP's on a fecal coliform levels in streams. Collection of fecal coliform data is therefore recommended if livestock pasturing is a predominant land use in the watersheds of interest. Samples for fecal coliform samples should be collected over a range of flow conditions and at frequent intervals during significant runoff events.

General Methodology

When applicable, standard methods of sample collection and analysis should be used. Such methods are described in detail in Standard Methods for the Examination of Water and Wastewater (APHA, 1975), National Handbook of Recommended Methods for Water Data Aquisition (USGS, 1977) and Biological Field and Laboratory Methods for Measuring the Quality of Surface Water and Effluents (USEPA, 1973).

References

American Public Health Association. 1975. Standard Methods for the Examination of Water and Wastewater. 14th Edition. Washington, D.C.

Everest, Fred H. 1975. Biological Non-Point Pollution Monitoring Guidelines U.S. Forest Service. Corvallis, Oregon.

Phillips, R.W. and K.V. Koski. 1969. A Fry Trap Method for Estimating Salmonid Survival from Egg Deposition to Fry Emergence. J. Fish. Res. Bd. Canada, 26:133-141.

U.S. Environmental Protection Agency. 1973. Biological Field and Laboratory Methods for Measuring the Quality of Surface Waters and Effluents. EPA-670/4-73-001. Cincinnati, Ohio.

U.S. Environmental Protection Agency. 1976. Quality Criteria for Water. EPA-440/9-76-023. Washington, D.C.

U.S. Geological Survey. 1977. National Handbook of Recommended Methods for Water Data Acquisition. Washington, D.C.