In-Stream Monitoring Handbook

A Guide For Project Development, Implementation, and Assessment

California Department of Fish and Game
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ACKNOWLEDGMENTS

A basic handbook like this does not intend to present much in the way of original information regarding techniques or protocols for in-stream monitoring. Creating this handbook required the utilization of technical information and ideas that are currently available in existing published literature. The handbook does include information, however, that was originally developed for the Pilot Monitoring Program (PMP) by the California Department of Fish and Game for the Monitoring Study Group (MSG) that was established by the State Board of Forestry in 1993.

A significant portion of the information in this handbook was drawn from existing publications that were developed in the states of Oregon, Colorado, Montana, Idaho, Washington, Alaska, New York, Iowa, Maryland, and Michigan, as well as publications by the Environmental Protection Agency, and the U.S. Forest Service. These publications are listed in the reference section of this handbook. The monitoring procedures and graphics were borrowed from these reference publications to complete this handbook and special appreciation is extended for the permission to utilize this information, without which this handbook would not be possible.

Several review and editing cycles were incorporated into the production of this report. Early recommendations on project design and assessment technique coverage (and subsequent technical reviews) were received from Frank Reichmuth and Bob Klamt of the North Coast Regional Water Quality Control Board, Gaylon Lee of the State Water Board, and staff of the California Department of Fish and Game (Tim Curtis, James Harrington, David Richter, Bill Snider, Gary Stacey, James Steele, Rob Titus, and Kris Vyverberg), Chris Knopf of the US Forest Service Lake Tahoe Basin Management Unit (originally on contract to the North Coast Regional Water Quality Control Board). Detailed technical and editorial comments were provided by Ken Roby (US Forest Service, Plumas National Forest), watershed specialists George Ice and Walt Magahan (both with the National Council for the Paper Industry for Air and Stream Improvement), and John Munn (California Department of Forestry and Fire Protection). Tom Lisle (US Forest Service Redwood Sciences Laboratory) and Robert Kasun (US Forest Service Idaho Panhandle National Forests) commented specifically on sediment analysis.

During the conduct of field operations, cooperating landowners commented on assessment procedures and their application to private land management planning. Their representatives were Larry Costick, Ron Monk, Pete Pebar, and John Ambrose (Georgia-Pacific Corporation), John Williams (Gualala Redwoods Company), and Charlie Brown and Doug Miglaw (Fruitgrowers Supply Company). Concurrently, the many Department of Fish and Game temporary field personnel assigned to the project, personnel loaned from North Coast Regional Water Quality Control Board, volunteers from Pacific Northwest Biological Resources Consultants and the public sector all helped to conduct the project and comment on their efforts.

From the initial stages of project pre-planning through the successive progress reports and final presentations, technical and editorial comments were generously offered by representatives of the Monitoring Study Group and the Ecosystem Management Committee of the California Board of Forestry. And, continued support and direction has been provided by Department of Forestry and Fire Protection contract administrator Pete Cafferata and Department of Fish and Game contract administrator Stephen Rae.

The following publications were major sources of information that were utilized in this handbook:

Dissmeyer, G.E., USFS. 1994. Evaluating the Effectiveness of Forestry Best Management Practices in Meeting Water Quality Goals or Standards.

EPA, 1993. Region 10 In-stream Biological Monitoring Handbook For Wadable Streams in the Pacific Northwest. Seattle, WA. EPA Rep 910/9-92-013.

MacDonald, L.H.; Alan W. Smart, and Robert C. Wissmar. 1991. Monitoring Guidelines to Evaluate Effects of Forestry Activities on Streams in the Pacific Northwest and Alaska. EPA REP. 910/9-91-001. Seattle WA. EPA. 166p.

Rae, S. P. 1995. Board of Forestry Pilot Monitoring Program In-Stream Report. Vol I Calif Dept. Fish and game. Environmental Services Division, Sacramento, CA.

Rae, S. P.; A. Tuttle, T.E. Spittler. 1995. Pilot Monitoring Program Reports, In-Stream Component, Hillslope Component, and Geologic Impact for the Hillslope Component. State Board of Forestry Monitoring Study Group, draft.

USDA Forest Service, 1996. Pacific Southwest Region Stream Condition Inventory. Version 3.

EXECUTIVE SUMMARY

This handbook was prepared to assist landowners and State agencies in designing water quality monitoring projects. The focus has been on forest management and streams throughout the North Coast of California. The handbook is intended to supplement the monitoring objectives and knowledge gained in the Pilot Monitoring Program, further explain some of the procedures and results, and improve upon the established methods and protocols for monitoring in-stream water resources.

The in-stream monitoring handbook also draws upon the existing monitoring protocols developed by the Environmental Protection Agency (EPA) and the U.S. Forest Service and recognizes the effectiveness and uncertainties within the design of the protocols discussed. The protocols provide a group of procedures and techniques that attempt to facilitate the implementation of consistent measurements.

The handbook is presented as a set of guidelines to assist those in the development and implementation of instream monitoring programs and conducting biological assessment of in-stream habitat. Changes to the contents are anticipated and will be welcomed that improve the purpose of the guidelines and contribute to the final development of the handbook as the official field reference for Northern California.

Chapter I describes the objectives of the handbook and reveals the background accomplished by the Pilot Monitoring Program under the direction of the Monitoring Study Group that was authorized by the State Board of Forestry.

Chapter II discusses the purpose of developing a monitoring plan and the objectives that should be considered. Further discussion is included regarding costs, identifying the watershed, selecting the reach, and habitat assessment.

Chapter III provides ideas on a step-by-step basis for implementing a monitoring program including the necessary equipment, selecting the parameters, developing a computer supported data management system, and training recommendations.

Chapter IV reviews the monitoring parameters that should be considered and the procedures for conducting the actual field assessments.

Chapter V is a technical review of statistical methods of analysis, the principles of sampling, the frequency of monitoring, and the importance of maintaining and effective quality control and quality assurance element throughout the monitoring project.

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Chapter I: INTRODUCTION [1]

A. OVERVIEW

The Clean Water Act directs the U.S. Environmental Protection Agency (EPA) to develop programs that evaluate, restore and maintain the chemical, physical and biological integrity of the Nation's waters.

The States and EPA have implemented water management programs primarily using chemical and physical indicators, and more recently toxicological indicators to protect water quality. These programs have resulted in significant water quality improvements in the past 20 years.

Water programs based on chemical and physical variables alone are not sufficient to identify or address all surface water problems. Ambient biological assessments are important because they directly measure the condition of the resource at risk, detect problems that other methods may miss or underestimate, and provide a systematic process for measuring progress resulting from the implementation of water quality programs (EPA 1990a). Ambient biological assessments do not replace chemical, physical or toxicological methods, but are intended as a supplement to more holistically assess water resource quality.

This handbook is provided as a reference for those interested in developing instream monitoring programs and conducting biological assessments of wadable streams in northern California.

In 1987, EPA initiated a major study of the Agency's surface water monitoring activities. The report emphasized the restructuring of existing monitoring programs to better address the Agency's priorities, including nonpoint source impacts and documentation of 'environmental results' (EPA 1987).

In 1989 EPA published the Rapid Bioassessment Protocols (RBPS) as a rapid method to obtain and interpret aquatic life data (Plafkin et al. 1989).The RBPs are a valuable tool for: developing aquatic biological criteria; evaluating the effectiveness of nonpoint source control projects; site ranking for planning and management purposes; and trend monitoring. The RBPs were written at a national level with the acknowledgment that different regions of the country would need to modify the protocols. This handbook is intended to be used as a supplement to the RBPs so that they better address northern California.

Professional foresters and other resource professionals are interested in conducting instream monitoring in northern California.The protocols established in this handbook are an attempt to provide a consistent minimal set of methods to facilitate information exchange and interpretation.

[1] Taken directly from EPA (1994).

The protocols use fundamentally accepted assessment techniques to generate basic information on physical, chemical, and biological conditions. The protocols have major components which are discussed in the Background section of Chapter I.

1. Purpose of the handbook [1]

1. Educate resource professionals on how to develop an in-stream monitoring program;

2. Encourage consistency of sampling methods throughout the streams in northern California and to facilitate sharing of data;

3. Define the minimum components necessary to conduct a bioassessment and provide additional levels of resolution;

4. List the biological assessment activities, including objectives and methods; and

5. Increase the amount and consistency of bioassessment activities by providing a regional method.

This handbook is designed to help forest landowners and managers of water-quality monitoring plans to evaluate the effectiveness of management practices in meeting water-quality goals or standards. (The term water quality refers to the chemical, physical, biological, and habitat condition of streams.)

The handbook is a reference, not a state or regional protocol. It deals with the design of monitoring projects and the selection of variables and methods for monitoring them given (1) the designated beneficial use, (2) the type and intensity of management, (3) the stream/ecosystem setting, and (4) monitoring objectives or questions related to nonpoint-source (NPS) pollution. The methods apply only to streams of the 4th order and smaller that can be waded during low-flow periods.

2. Objectives

1. To conduct a complete biological assessment of a stream it is recommended that macro-invertebrate, fish, water column and habitat information be collected. In the subsequent sections, we will identify what is the minimum level of data needed, as well as methods for collecting additional assessment data for each category.

[1] Taken directly from MacDonald et al. (1991).

2. This handbook is limited to monitoring nonpoint source pollution in forested areas, which means that the management activities of primary concern are forest harvest, road construction, and maintenance. Other aspects of forest management, such as site preparation and intermediate stand treatments, are not explicitly considered, as their impact on water quality is conceptually similar to the impact of forest harvest and road building.

3. The handbook is designed to be applicable to perennial streams and small rivers. In larger river systems water quality usually is controlled by agricultural, industrial, and municipal wastes, and it becomes very difficult to distinguish the impact of forest management activities.

4. The design of water quality monitoring projects for lakes is not included in this handbook as lakes are distinct in terms of their physical and biological characteristics. Most lake monitoring projects rely on the collection and analysis of water samples, while a much broader range of monitoring parameters can be used in streams and rivers.

5. Finally, the handbook considers only those measurements which can be made either in or immediately adjacent to the stream channel. Observations on upslope areas often are essential to understanding the cause of changes observed in the stream channel, and they also may exhibit a higher sensitivity to management actions than in channel measurements (Tuttle 1995). Nevertheless, hillslope monitoring represents a completely different set of monitoring techniques that are not addressed in this handbook (MacDonald et al. 1991).

B. ORGANIZATION AND USE OF THE HANDBOOK

The handbook is divided into five sections:

Chapter I introduces the handbook with a background discussion of the purpose, the objectives, and above all, its limitations.

Chapter II presents the principles of developing a water quality monitoring plan for nonpoint source pollution in forested areas. It includes a discussion of the factors that should be considered in developing a monitoring program and the usefulness of the various monitoring parameters. Of most importance are the discussions regarding the purpose of monitoring, and the selection of the watershed.

Chapter III reviews the steps for structuring a monitoring program, and identifies the management activity to be monitored, objectives, inventory principles, data management systems, training, and the tools and supplies needed.

Chapter IV presents individual technical reviews of the monitoring parameters that have been or might be used to monitor water quality in forested areas.

Chapter V provides a review of the significance of statistics in the design of a monitoring program to ensure that replication can be accomplished. The principles of sampling are examined to determine the frequency, amount of data to be collected, and most importantly, the quality assurance and quality controls needed to develop an effective monitoring program.

Appendix: Within the appendix are copies of various forms recommended to record habitat assessment data, figures illustrating assessment techniques, a list of equipment and supplies, database structure, definitions, a glossary, illustrations, and references of reports and studies relevant to in-stream monitoring.

C. BACKGROUND [1]

The Board of Forestry (BOF) established the Monitoring Study Group (MSG) to develop and facilitate implementation of a long-term program for monitoring the effects of timber operations as conducted pursuant to the BOF's Forest Practice Rules on the quality and beneficial uses of waters.

MSG determined that a two-year Pilot Monitoring Program (PMP) should be conducted prior to final design of the long-term program. The scope and objectives of the Pilot Monitoring Program are identified in a report entitled, Pilot Monitoring Program Summary and Recommendations for the Long Term Monitoring Program (Lee 1997). MSG determined that coldwater fisheries and domestic water supplies are the beneficial uses of water most sensitive to changes in-stream conditions due to timber operations. The PMP included two parts: hillslope monitoring and in-stream monitoring. The goal of the PMP was to test and develop methods that can be used in a long-term monitoring program.

MSG also decided that the monitoring sites should be located within or adjacent to approved timber operations to facilitate legal access. The selected sites should also be clustered within selected watersheds to facilitate physical access and minimize travel time. Finally, the sites should be located within different parts of the State (western Sierra Nevada, Klamath Mountains, and north Coast Ranges) to provide opportunities to see differences in the various timber producing areas with their different environmental characteristics.

After considering a wide variety of monitoring parameters and techniques, MSG approved testing of several in-stream and near stream parameters and techniques for evaluating current stream

[1] Taken directly from Rae (1995).

condition and long-term trends (residual pool volume, V^{STAR}, site specific parameters , temperature, pebble count, rifle armor stability index-RASI, embeddedness, turbidity/suspended sediments, temperature, canopy, gradient, stream bank stability, and macro-invertebrates). These parameters and techniques were selected because they appeared to be:

1. sensitive to effects of timber operations on the condition of domestic water supplies and coldwater fisheries,

2. feasible for State agency personnel, professional foresters, and members of the public to utilize without excessive training and equipment,

3. capable of providing reliable and reproducible data for land managers and agency decision makers, and

4. representative of the condition of coldwater fisheries and domestic water supplies.

The California Department of Forestry and Fire Protection contracted with the Department of Fish and Game (Department) to conduct the in-stream component of the PMP. During the project, the Department tested and refined the above parameters and techniques (Rae 1995).

Monitoring parameters (habitat types, sediment, and temperature) were selected by the MSG. The assessment techniques were selected based upon recommendations by a technical advisory team composed of Department technical specialists (James Harrington, Stephen Rae, Bill Snider, and Kris Vyverberg). Initial recommendations received a limited peer review that resulted in the deletion of one assessment technique (use of in-stream sediment capture boxes) and the addition of four techniques (macro-invertebrates, V^{STAR}, RASI, and D_{50}). Frank Reichmuth, Chris Knopp (now with the U S Forest Service, Lake Tahoe Basin Management Unit), and Elmer Dudik of the North Coast Regional Water Quality Control Board in Santa Rosa helped to refine the sediment sampling techniques. During the 1993 season, riparian zone measurement techniques were added. A preliminary assessment of site descriptions following the 1993 season suggested that canopy measurements would be helpful in describing site conditions. Stand and canopy assessment techniques (spherical densiometer, sighting tube, and Cruz-All) were added during the 1994 season. During implementation, suggestions generated periodically by field crew members, landowners, and observers were incorporated.

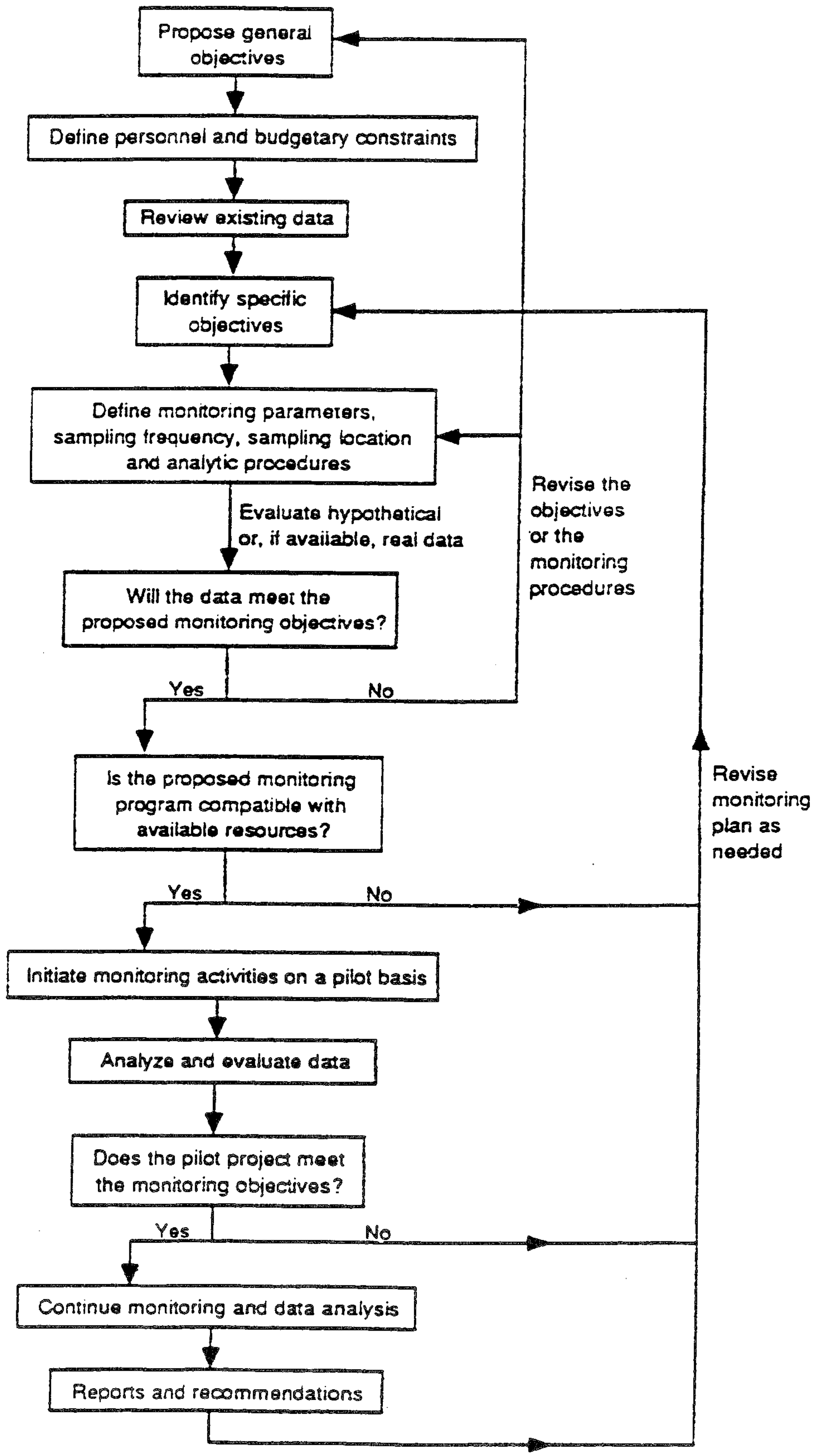
1. Goals and Objectives of the Pilot Monitoring Program

The purpose of the Pilot Monitoring Program was to provide a substantive basis and analytical decision making process for implementing a monitoring effort. The objectives of the study were to:

1) Develop procedures for selecting sample sites
2) Test procedures approved by MSG
3) Develop field sampling protocols
4) Develop training materials

Thus, the project extended earlier efforts of the Board of Forestry to assess the effects of timber harvest activities on private lands (California State Water Resources Board, 1987). The concept of "Resource-at-Risk" (California Department of Fish and Game, 1994) was applied to focus on important parameters in a watershed and apply the best monitoring techniques to measure changes in those parameters. The In-Stream component of the PMP illustrates how the generalized decision making process as diagramed in (Figure A) can be utilized.

Figure A: Development of a Monitoring Project
(MacDonald et al. 1991)



The program paralleled efforts to produce 'how-to publications' recently initiated by other agencies (Washington Department of Wildlife, 1990; Flosi and Reynolds 1991, 1994; MacDonald et al. 1991; Washington State Forest Practice Board 1992; Hayslip 1993; (USDA 1994). The current emphasis on issuing a comprehensive field assessment guide or handbook was judged to be necessary, since there is currently no comprehensive document available for private landowners illustrating how to develop a complete in-stream monitoring program for California.

The focus of the PMP project was to assess the utility, applicability, and feasibility of implementing the selected assessment techniques. Each assessment technique was applied in all the stream reaches. Among those site selection and information management criteria evaluated were:

1. Methods for relocating study reaches on return visits

2. Minimum qualifications for reach components to be recognized as sample units

3. Sequence of parameters to sampled

4. Format and relationship of field data forms

5. Physical maintenance and analysis of information

Maintenance of information within a database management system was evaluated; consistency of observations within study reaches and among sampling sites was examined; and the effectiveness of field team training and the utility of a field training manual were assessed.

2. Monitoring Parameters and Protocols Utilized During The Pilot Monitoring Program

The parameters selected for monitoring were reported by several authors as appropriate in defining high quality in-stream habitat (Flosi and Reynolds 1991, 1994; Knopp 1993; USDA 1994; Washington State Forest Practice Board 1992). These authors conducted field studies that demonstrated the capability of different techniques to discriminate between the background variation of the parameter in the watershed and the change of the parameter due to land management activities. An observed variation in a parameter may result from cumulative watershed effects, rather than be linked to the application of individual land management practices at specific locations within the watershed (California State Water Resources Board 1987; MacDonald at al. 1991; Dissmeyer 1994; California Department of Fish and Game 1994).

a. Marking the Study Reach. Based on direction from MSG, each study reach was usually fixed first on the basis of proximity to timber harvest activities, suitability, and physical access. A permanent reach marker was placed in a secure spot not subject to removal by seasonal flows or land management activities. The distance and bearing to the start of the study reach was recorded. Photographs were taken of the permanent reach marker and its relationship to the upper and lower end of the study reach.

b. Channel Typing and Habitat Inventory. In-stream channel typing and a habitat inventory were conducted within the study reach as described in Flosi and Reynolds (1991, 1994) to quickly characterize the biological condition of streams (Barbour and Karr 1993; Boechler and McAllister 1992; Dissmeyer 1994; Hayslip 1993; MacDonald et al. 1991; Montgomery and Buffington 1993; Raid 1994; EPA 1990; Washington State Forest Practice Board 1992, 1994). Channel type units were consistent with the classification developed by Rosgen (1994) and implemented in a manner similar to the process outlined for coho salmon habitat assessment (California Department of Fish and Game 1994). MSG decided that habitat type units defined as Level II in Rosgen (1992) and clarified for California by Flosi and Reynolds (1991, 1994) were appropriate to the study; higher levels would have provided information more detailed than required in the study. The application of subjective quality classes to describe channel types and habitat units followed techniques refined during the '208' study (California State Water Resources Board 1987).

Preliminary habitat typing was conducted from the upstream end of the study reach down the stream until a sufficient number of habitat types were enumerated or 1000 m was traversed. For the study, the number of habitat types to sample was set at six pools, three riffles, and three runs in each stream reach. Habitat types were numbered consecutively from the bottom of the reach according to their category: P for pool, V for Run, R for Riffle. The lowest pool was Pl, while the third riffle was R3. Once preliminary habitat typing was completed, sampling began at the bottom of the reach and proceeded upstream to reduce the possibility of sampling activities affecting subsequent sampling sites (Harrington 1993a).

c. Site Descriptions. Site descriptions were developed for the in-stream channel, the near-stream corridor (Erman et al. 1997), and contiguous up-slope areas that could directly affect the study reach. Aerial photographs were consulted in planning site assessments and in developing descriptions. Conspicuous features (such as erodible bedrock, woody debris recruitment, and canopy) that may introduce sediments into the channel were noted (Boechier and McAllister 1992; Flosi and Reynolds 1991,1994; O'Connor and Harr 1994; Rashin et al. 1993). Before sampling was initiated, a channel reconnaissance was conducted upstream from the upstream permanent reach marker for an arbitrary distance of 1000 m. If a channel branched with significant flow into more than one channel, the reconnaissance was conducted along all branches to an aggregate of 1000 m. Channel characteristics, current land practices, and evidence of historical land uses that could affect in-stream conditions were recorded. If problems were encountered during the initial site reconnaissance and assessment, the study reach was discarded and a new site selected which did not include similar problems. Problems encountered during sampling resulted in sampling being stopped at that point. During early field assessment, observations were recorded within the study reach. The reconnaissance ended at any point where channel alterations (e.g., water diversion), channel events (e.g., crossing failure), or up slope features (e.g., landing failure) were present and may have introduced materials that would have overwhelmed the sampling techniques.

Habitat unit descriptions and the placement of transects, sampling sites, and channel features were recorded for pools and riffles (Flosi and Reynolds 1991, 1994; Knopp 1993, 1994; Harrelson et al. 1994). Also identified was the source and amount of shade, dominant vegetation, bottom substrate, bank morphology and composition, obvious sediment sources, local disturbances, side stream influences (including drainages or rivulets), or any other feature which may be of importance (Plafkin et al. 1989; Washington Department of Wildlife 1990). Included within the site description of each sampled pool was a cross-sectional diagram (oriented as viewed from the bottom of the pool looking upstream), showing the bank slopes, riparian vegetation (overstory, midstory, and emergent, wetted edge of the pool, and any debris or rock formations present (Harrelson et al. 1994).

d. Sediment Movement. Sediment transport and the size of particles transported was reported as indicative of the quality of the stream by Kappesser (1992, 1993a, 1993b); Knopp (1993, 1994). One measure of stream sediment as an indicator of stream condition was considered to be the distribution of particle size classes represented in a riffle (Flosi and Reynolds 1991, 1994). The change in particle size distribution over time and through the reach catalogued the movement of sediment plugs or flushes through the system. The Riffle Armor Stability Index (RASI),(i.e., the largest particle transported during bank full stage), was determined by measuring particle sizes in those riffles sampled for macro-invertebrates (Kappesser 1992, 1993a, and 1993b). The particle size distribution of riffle materials were sampled according to the 'Wolman Pebble Count' method (Wolman 1954) and particle size class distribution (D_{50}) and RASI were calculated with custom application software created by Kappesser.

Sediment retention within a pool was measured according to the particular V^{STAR} technique developed by Lisle (1991), based on earlier work by Lisle and Hilton (1991, 1992). V^{STAR} (pronounced 'vee-star'), is the fraction of residual pool volume filled with fine sediment. The amount of annually mobile sediment retained within a pool is in a dynamic balance between upstream natural supply sources and the rapidity at which the sediments can move through the system (see the review by Flosi & Reynolds 1995; and others). The fraction of pool volume filled with fine sediment was reported to be directly related to sediment supply and channel mobility (Lisle and Hilton 1991, Knopp 1994). Lisle and Hilton (1992) reported that V^{STAR} correlated well with scoured pool volume in channels with abundant sediment. Thus, fine sediment deposition was determined to be 'volume-related.' Additionally, minor variations between pools may result in local differences in sediment transport and deposition. That is, the size of the low energy zone that fills with sediment was proportionately larger in large pools than in small pools. However, in channels with limited sediment, V^{STAR} correlated with local stream gradient. Fine sediment content was determined to be 'jet-limited.' When the scouring mechanism is strong, filling ceased at moderate flows. And, variations in scour strength caused large pool-to-pool V^{STAR} variations. The V^{STAR}

method was found to be practical in detecting and evaluating sediment inputs along stream channels. Again, according to Lisle and Hilton (1992) V^{STAR} measures the most active component of the sediment stored in a channel, quantifies a sediment-related effect on an important habitat component, and implements easily in small to moderate sized stream reaches. Fine pool sediments were distinguished from coarser substrates by being unarmored, distinctly finer than other bed materials, and easily penetrated by a metal rod.

Sediment deposits collected within study reach pools were measured by the V^{STAR} assessment technique developed by Lisle (Lisle and Eads 1991; Lisle and Hilton 1991; Hilton and Lisle 1993, Lisle 1993) and modified by others (e.g., Knopp 1993, 1994). Data analysis was performed using the custom application software developed by Knopp (1993, 1994), and revised by him several times during 1994 and 1995. Tom Lisle and Sue Hilton also provide custom software (Lotus™ templates) for calculating the V^{STAR} index.

e. Canopy. The effects of canopy coverage on stream temperature through shading and its contribution to stream nutrients through leaf-fall and generation of small and large woody debris has been reported (Plafkin et al. 1989; Flosi and Reynolds 1991, 1994; MacDonald et al. 1991; O'Connor and Harr 1994). Erman et al. (1977) measured canopy density and estimated temperature increases related to canopy openings following timber harvest activities. Shading decreases the penetration of sunlight to the stream surface within a forest stand. Therefore, stream temperature may be increased within stands due to increased insolation where canopy coverage has been removed. The canopy (both immediately above and adjacent to the stream) has been identified as the source of both nutrients and woody debris for the stream (Erman et al. 1977; Flosi and Reynolds 1991, 1994). Within the study reach, canopy coverage measurements were taken by use of the spherical densiometer (observation of shade intercepting subdivisions of reflected sky (Lemmon 1956, 1957)) and sighting tube (overhead canopy line-intercept observation). An indirect measure of canopy coverage over sampled pools and riffles included basal area measurement by the Cruz-All™ (Bell and Dilworth 1993). Portions of the sky blocked by the proximity and height of watercourse banks or ridgelines were also measured by observing adjacent hillside slopes with a clinometer.

The three canopy assessment techniques measured different physical parameters (line intercept-ocular tube; percent cover - spherical densiometer; and biomass - Cruz-All ™) . In addition, the measured feature of the canopy for each technique occurred in different parts of the in-stream and near-stream environment. The ocular tube was used to record canopy intercepts along a transect directly over the thalweg in pools and riffles. The area monitored by the ocular tube is a line (of infinite thinness). The spherical densiometer was used to record the number of quadrants in the overhead sky that are either obstructed or not obstructed by a canopy. The area monitored by the spherical densiometer is an area reflected in the curved mirror that can be seen from the point of observation. The width of the observed area depends on the slope of the land or height of the canopy at increasing distances from the observer. The spherical densiometer measures a large area in flat terrain, and a relatively smaller area in rugged terrain (a function of image reflection from the curved mirror). In any case, the area of measurement extends beyond the channel boundaries, and, sometimes includes vegetation outside of the near-stream or riparian corridor. The Cruz-All™ measures trees with diameters exceeding specified angles, when viewed from a point. A small tree close to the observation point may encompass the same angle of incidence as a large tree further away. In any case, the size of the tree and the its angle of incidence are the criteria for recording rather than the location of the tree within either the in-stream or near-stream environment.

f. Temperature. Flosi and Reynolds (1991, 1994) and Barbour et al. (1980), among others, have reported on the importance of temperature in defining the in-stream habitat. However, maximum and minimum temperature limitations are different for each organism in the stream at different times throughout the year (MacDonald et al. 1991). Temperature within the canopy over the stream and in the water was recorded in pools, and in riffles sampled for macroinvertebrates. Instantaneous measurements were obtained with hand held electronic sensors and mercury thermometers. Recording temperature sensors (Hobo™) were placed within pools in fall 1993 and removed in late spring 1994. Instantaneous temperature measurements were also taken in the pools at the time of Hobo™ installation.

g. Macroinvertebrates. The composition of a macroinvertebrate community has been reported as an indicator of the biological quality of in-stream habitat (Plafkin et al. 1989). The use of macroinvertebrate communities as a parameter validly assessing logging impacts has been established for some time, and has been demonstrated specifically for logging in California (Erman et al. 1977; Mahoney and Erman 1984, and others). Macroinvertebrate sampling was completed prior to the initiation of other in-stream sampling in order to gather the mobile creatures that would otherwise evade collection nets once water disturbance began (Harrington 1993a; Hayslip 1993). The California Stream Bioassessment Procedure (CSSP), developed by the Department closely followed the Rapid Bioassessment Protocol (RBP 111) for benthic macroinvertebrates as outlined by the Environmental Protection Agency (EPA 1989), was used to determine macroinvertebrate assemblages. This procedure has been used successfully by the Department to detect point source pollution (Harrington 1993b) and to establish evidence for Fish and Game Code 5650 water pollution cases (Harrington 1993c). Physical habitat assessments were performed at each riffle using the EPA Physical Habitat Assessment Protocol Level 1 (Hayslip 1993).

Macro-invertebrate samples were identified at the Department's Water Pollution Control Laboratory (WPCL) to the lowest taxonomic level. Macroinvertebrate sampling included the collection of replicate samples at each riffles on the stream reaches. Sub-samples of each sample were evaluated to determine a minimum sub-sample size that adequately represented the riffle. Specimens of each identified macroinvertebrate taxon was retained within the WPCL Sample Depository reference collection. Taxonomic lists, diversity index and bioassessment metrics (statistical indices) were generated for each of the samples. Each taxon was assigned to a functional feeding group consistent with Merritt and Cummins (1984) and additional unpublished information on regional aquatic macroinvertebrates. A diversity index value, as in Shannon and Weaver (1963), was calculated for each subsample (Rae 1995).

D. CONCLUSIONS OF THE PILOT MONITORING PROGRAM [1]

The in-stream monitoring component of the Board of Forestry (BOF) pilot monitoring program was a field test of some in-stream monitoring techniques. This pilot program tested the feasibility of in-stream monitoring in remote areas, including problems of crew training and consistency, the ability to collect usable data given the variability of the medium sampled, and the ability of the monitoring technique to detect a signal.

This project was limited to an evaluation of selected field assessment tools. It did not include a watershed analysis necessary to determine which monitoring techniques were the most appropriate or the level of effort needed to develop useful results for a real monitoring situation. The resources at risk or the root cause of the risk was not a subject for examination. For an example of a watershed analysis protocol which determines possible impacts to anadromous fisheries the reader is referred to the document titled "Coho Salmon Habitat Impacts: Qualitative Assessment Techniques for Registered Professional Foresters," which is available from the Department of Fish and Game, Environmental Services Division, Sacramento, California. In practical applications, a watershed analysis would be conducted to determine the techniques to be used and the location of the appropriate study reaches. The project designer or reviewer must decide whether or not a monitoring effort is necessary by: 1) identifying the problems within a watershed, 2) identifying relevant monitoring tools, and 3) determining the purpose and type of monitoring appropriate (e.g., trend, baseline, implementation, effectiveness, project, validation, or compliance) (MacDonald et al. 1991, and California Department of Fish and Game 1994).

The results of the Pilot Monitoring Program indicated that the following issues are important to remember and that limitations do exist:

1. A pre-project objective is necessary to focus efforts and interpret results.

2. Crews with limited natural resource background can be trained to deliver results, but some precautions must be taken.

3. Protocols have to be carefully chosen for the situation to be monitored.

4. Data acquisition costs are inversely proportional to the training and supervision of the study participants.

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[1] Taken directly from Rae (1995).

5. Training must prepare the survey crew for the range of conditions to be encountered.

6. Error and range checking procedures for data entry and information analysis must be clearly identified and pertinent to the data anticipated in the study

7. Macroinvertebrate sampling can be conducted quickly and consistently.

8. Information analysis should be conducted with well documented and easy to use application software packages.

9. Selected monitoring parameters and protocols should be implemented in additional study reaches to further determine their limitations, ranges of acceptable values, and needed refinements.

10. Additional monitoring procedures and protocols should be selected and field tested to determine their utility in assessing watershed conditions on private timberland.

11. Cooperative private-public field studies can be effectively conducted on private timberlands.

Chapter II: PRINCIPLES OF DEVELOPING A MONITORING PLAN [1]

A. TYPES OF MONITORING

The term "monitor" is defined as to watch or check. Although it is not an explicit part of the definition, the term monitoring suggests a series of observations over time. This repetition of measurements over time for the purpose of detecting change distinguishes monitoring from inventory and assessment. While both inventories and assessments can be based on a single measurement or observation, they also can incorporate a series of observations to obtain a better estimate of a particular parameter. For example, the number of species of fish in a particular reach might be counted as part of an inventory of fish species, and several counts might be made in order to obtain a more accurate estimate. Similarity, maximum daily water temperature might be measured several times over the course of a summer to assess whether summer temperatures might be an important limitation to the quality of fish habitat under the existing conditions. However, if water temperatures are measured over several years to determine the effect of upstream management activities or climatic variations, this is clearly monitoring. The overlap in the definitions of assessment, inventory, and monitoring means that in some cases the primary distinguishing feature of monitoring will be the intent to assess change rather than the number or type of measurements.

Often an assessment or inventory serves as the first step towards establishing a monitoring project. Knowledge of the spatial and temporal variability is essential to developing an efficient monitoring plan. To the extent that inventory and assessment techniques overlap with monitoring procedures, the guidelines in this handbook can help with the conceptual problems of deciding what, where, and how to inventory or assess water quality.

For the purposes of this handbook, the following types of monitoring are defined:

1. ***Trend Monitoring***. In view of the definition of monitoring, this term is redundant. Use of the adjective "trend" implies that measurements will be made at regular, well-spaced time intervals in order to determine the long-term trend in a particular parameter. Typically the observations are not taken specifically to evaluate management practices (as in type 4), management activities (as in type 5), water quality models (as in type 6), or water quality standards (as in type 7), although trend data may be utilized for one or all of these other purposes.

2. ***Baseline monitoring***. Baseline monitoring is used to characterize existing water quality conditions, and to establish a data base for planning or future comparisons. The intent of baseline monitoring is to capture much of the temporal variability of the constituent(s) of

[1] Taken directly from MacDonald et al.(1991).

interest, but there is no explicit end point at which continued baseline monitoring becomes trend monitoring. Those who prefer the terms "inventory monitoring" and "assessment monitoring" often define them such that they are essentially synonymous with baseline monitoring. Others use baseline monitoring to refer to long-term trend monitoring on major streams (Potyondy 1980).

3. ***Implementation Monitoring*** This type of monitoring assesses whether activities were carried out as planned. The most common use of implementation monitoring is to determine whether Best Management Practices (BMPs) were implemented as specified in an environmental assessment, environmental impact statement, other planning document, timber harvest plans, or contract. Typically this is carried out as an administrative review and does not involve any water quality measurements. Implementation monitoring is one of the few terms which has a relatively wide spread and consistent definition. Many believe that implementation monitoring is the most cost-effective means to reduce nonpoint source pollution because it provides immediate feedback to the managers on whether the BMP process is being carried out as intended. On its own, however, implementation monitoring cannot directly link management activities to water quality, as no water quality measurements are being made.

4. ***Effectiveness Monitoring***. While implementation monitoring is used to assess whether a particular activity was carried out as planned, effectiveness monitoring is used to evaluate whether the specified activities had the desired effect (Solomon 1989). Confusion arises over whether effectiveness monitoring should be limited to evaluating individual BMPs, or whether it also can be used to evaluate the total effect of an entire set of practices. The problem with this broader definition is that the distinction between effectiveness monitoring and other terms, such as project or compliance monitoring, becomes blurred. To minimize confusion within this handbook, effectiveness monitoring will be used in the narrow sense of evaluating individual management practices, particularly BMPs.

5. ***Project Monitoring***. This type of monitoring assesses the impact of a particular activity or project such as a timber sale on water quality. Often this assessment is done by comparing data taken upstream and downstream of the particular project, although in some cases, such as a fish habitat improvement project, the comparison may be on a before and after basis. Because such comparisons may, in part, indicate the overall effectiveness of the BMPs and other mitigation measures associated with the project, some programs consider project monitoring to be a subset of effectiveness monitoring. Again the problem is that water quality is a function of more than the effectiveness of the BMPs associated with the project.

6. ***Validation Monitoring***. Since the issue of validating water quality standards is beyond the scope of this handbook, validation monitoring in this handbook is discussed primarily with regard to the quantitative evaluation of a proposed water quality model to predict a particular water quality parameter. In keeping with the basic principles of modeling

(James and Burges 1982), the data set used for validation should be different from the data set used to construct and calibrate the model. This separation helps ensure that the validation data will provide an unbiased evaluation of the overall performance of the model. The intensity and type of sampling for validation monitoring should be consistent with the output of the model being validated.

7. ***Compliance Monitoring***. This is the type of monitoring used to determine whether specified water- quality criteria are being met. The criteria can be numerical or descriptive. Usually the regulations associated with individual criterion specify the location, frequency, and method of measurement.

These guidelines are not equally applicable to all seven monitoring types as defined above. Most of the parameters used for trend, baseline, and project monitoring are explicitly considered, and the general discussion on developing monitoring plan is directly relevant. On the other hand, implementation monitoring generally does not involve water quality measurements, and so the guidelines in the handbook are less applicable. Effectiveness monitoring of individual BMPs also may use different parameters than the ones discussed in this handbook.

Since validation monitoring is used to evaluate model accuracy, the parameters to be measured are defined by the model output. Usually these will correspond to some of the monitoring parameters reviewed in this handbook, but this may not necessarily be the case. Similarly, the parameters and procedures for compliance monitoring usually are specified by the regulating agency.

B. PURPOSE OF DEVELOPING A MONITORING PLAN [1]

1. Objectives of a Monitoring Plan

In this section the key factors are discussed that influence the development of a monitoring plan. The objectives and the selection of monitoring parameters are probably the most crucial of these factors in the formulation of specific monitoring objectives. The cost of monitoring is briefly discussed and is included with the frequency of measurements.

The importance of properly formulating the monitoring objectives can be illustrated by an example. A typical concern of forest managers, regulators, and fishery scientists is whether forest management activities are adversely affecting the fish in watershed X. This general question provides no indication as to whether the concern is directed towards trophy-sized trout

[1] Taken directly from MacDonald et al.(1991).

or the biological integrity of the fish populations. A more specific identification of the designated uses and perceived adverse effect(s) is needed to determine whether the monitoring should focus on the number of fish, species diversity, total biomass, productivity, or condition.

Under most circumstances a more precise set of objectives can be defined prior to initiating a monitoring project through discussions and qualitative investigations. If the general question is defined as the effects of forest harvest activities on the fish populations on watershed X, one might first identify the fish species present and the relative importance of the beneficial uses associated with those fish populations. Once the key species and beneficial uses have been identified, an experienced fish biologist should be able to qualitatively suggest what factor(s) might be limiting to the various species (e.g., spawning habitat, winter or summer rearing habitat, or food availability). This assessment then helps the manager to identify those monitoring parameters most closely correlated with the limiting factor(s) for the fish population(s) of concern. The objective of the monitoring program might then be refined to a more specific question such as: Do the forest management activities in watershed X adversely affect the over wintering habitat for coho salmon? This clarification of the monitoring objective immediately begins to suggest that certain habitat parameters, such as pool characteristics and large woody debris, might be more useful or easier to monitor than the actual population of over-wintering coho.

A further narrowing of the monitoring objectives can occur by identifying the specific management activities that could affect the designated uses of concern. In the above sample, the question is what activities might reduce the availability of over wintering habitat for coho salmon. If the road network in Watershed X is stable and well established, the monitoring might be directed towards evaluating the impact of forest harvest activities. In such cases information on the layout of the harvest units can be crucial to determining whether the impacts on riparian zones and stream channels will be direct or indirect. A harvest unit located well upslope, for example, would not be expected to directly affect the amount or recruitment of large woody debris, but it could contribute sediment, which might reduce pool volumes. Harvest units adjacent to the stream channel could more directly influence the amount of cover and structure for over-wintering coho. Such spatial information can be very helpful in identifying which parameters should be included in a particular monitoring program (e.g., large woody debris or pool characteristics), which stream reaches should be monitored, and what type of upslope information needs to be collected in order to make association between management activities and changes in water quality.

This process of specifying the objectives usually will require more time and effort than simply initiating measurements of a standard water quality parameter such as turbidity or suspended sediment. Nevertheless, the potential savings in monitoring effort and improvement in the project results usually makes this front-end investment extremely worthwhile.

2. Cost of Monitoring

Other key factors in assessing the cost of a monitoring project include the amount of staff time, funds, expertise and equipment needed to make and interpret an individual measurement. The monitoring parameters evaluated in this Handbook exhibit a wide variation in terms of their ease of measurement and in the equipment required. For many parameters a simultaneous discharge measurement is needed to properly interpret the data. Certain parameters also require more expertise to collect and analyze the field samples or data, as well as to interpret the results. Hence the value of a parameter for a particular monitoring project depends on the availability of staff time, expertise, equipment, and expendable funds for outside analyses.

The last three columns in Table 1 provide a qualitative ranking of the parameters with regard to the time needed to collect a sample, the equipment needed to collect a sample, and the costs of analyzing the sample or the raw data. For some parameters a range of techniques or measurements could be used, and the table is based on the techniques most commonly used for monitoring streams in forested areas. Associated costs, such as the need to house and maintain equipment, or improve access to the monitoring site, can be significant but are not included in Table 1 because these costs vary greatly.

The differences in sampling and analytic costs shown in Table 1 are important in determining the spatial and temporal intensity of sampling and in selecting the appropriate parameters for monitoring. This predisposes the monitoring program towards those parameters (e.g., channel characteristics) that can be measured annually and which do not incur high analytic costs.

Table 1 . Frequency and cost of data or sample collection by monitoring parameters. L = low, M = medium; H= high; V = variable; NA = not applicable. (from MacDonald et al. 1991).

Parameter	Typical Frequency	Flow conditions for sampling	Collection time	Equipment Costs	Analysis Costs
Water column					
Temerature					
pH	L-M	L	L	L	L
Conductivity	M	All	L	L	L
Dissolved oxygen	L-M	L	L	L	L
Intergravel DO	M	V	L	M-H	L
Nitrogen	L-H	V	L	L	M
Phosphorus	L-H	V	L	L	M
Herbicides and pesticides	L	L-M	L	L	H
Flow					
Peak flows	H	H	M-H	M-H	H
Low flows	M	L	M-H	M-H	L-H
Water yield	H	All	M-H	H	H
Sediment					
Suspended	H	H	L-M	L	M
Turbidity	H	H	L	M	L
Bedload	H	H	M	M	M
Channel characteristic					
Channel cross-section	L	L	M	M	M
Channel width/width depth ratio	L	L	M	L	L
Pool parameters	L	L	M	L-M	L-M
Thalweg profile	L	L	M	M	M
Habitat units	L	L	M	L	M
Bed material					
Size	L	L	M	L	M
Embeddedness	L	L	H	L	L
Surface vs. subsurface	L	L	H	M	M-H
Large woody debris	L	L	M	L	L
Bank stability	L	L	L-M	L	L
Riparian					
Riparian canopy opening	L	NA	L-M	L-M	L-M
Riparian vegetation	L	NA	L-M	L	L
Aquatic organisms					
Bacteria	M-H	All	L	L	M
Algae	L-M	L	M	L-M	H
Invertebrates	L-M	L-M	L-M	L-M	M-H
Fish	L-H	L	H	M-H	M

3. Access to Monitoring Sites

The ease of access to a monitoring site, particularly during storm events, can be a controlling factor in selecting the parameters to be monitored. As shown in the second column of Table 1, several parameters must be measured during high flow events. If access to the sampling site is not possible during high flow events, or there are no structures from which measurements can be made, this precludes the use of those parameters. Many of the other parameters are relatively independent of discharge and can be measured at the most convenient time, such as during summer low flows. To the extent that a monitoring program is based on this latter category of parameters, access is not as important a criterion.

4. Availability of Existing Data

Another important consideration in developing a water quality monitoring plan is the amount of data that currently exist. A major shortcoming of many monitoring projects is that they are initiated subsequent to management activities. This means the background or undisturbed value of a particular parameter must be extrapolated from a comparable, undisturbed site, which in many cases is difficult, and one can never completely resolve the question as to the comparability of the sites.

In cases when baseline or pre-disturbance data are inadequate, the third approach-collecting additional physical data to link management effects to changes in water quality-must be used. Often this will require measurements closer to the areas where the management activities are taking place (i.e., farther upstream or out of the stream channel). The intent is to directly observe the management induced changes in erosion, runoff, or other processes, and relate these to changes in one or more of the in-stream parameters. Of course data making this linkage are useful even when pre-disturbance or long-term data sets are available, but they are particularly necessary when no data exist prior to management As noted in the introduction, up slope measurements and hillslope monitoring techniques are not discussed in this handbook, even though some watershed information is essential to interpreting any instream water quality data. The best chance of linking hill slope measurements would occur when both in-stream and hillslope monitoring takes place at the same time in relatively small (2nd and 3rd)order watersheds.

As data accumulate there is an increasing capability to evaluate fluctuations and discern change. This can be a strong argument for continuing an existing monitoring project even though the project may not necessarily be optimal in terms of parameter selection or sampling location. Often the best means to alter an existing project is to begin monitoring the additional desired sites or parameters while continuing with the existing project. As data accumulate on the additional parameters or from additional sites, it may be possible to statistically relate these to the original sites or parameters. Some of the parameters or sampling locations in the original monitoring project then can be eliminated. Clearly any alteration of a monitoring project will carry some cost in terms of the statistical reliability of the results, and this must be weighed against the potential benefits (MacDonald et al. 1991).

C. IDENTIFYING THE WATERSHED [1]

To design a monitoring effort, you must first evaluate and characterize the present conditions of the biological resources and other beneficial uses of interest (including water quality) within the watershed that has been identified, locate hazards pertinent to those resources and uses, and estimate the level of risk from those hazards (California Department of Fish and Game 1994). Next, survey to locate continuing and proposed land management activities that will add to the existing hazards, degrade habitat, or slow the natural rate of habitat recovery from prior impacts. For each problem identified, describe the hazard and risk, determine specific mitigation to reduce those hazards, and enumerate a monitoring program to evaluate the effectiveness of protection and mitigation measures in reaching the goal of protecting and enhancing fish populations and other beneficial uses throughout the watershed.

1. Habitat Assessment

The effectiveness of habitat monitoring procedures should be tested within watersheds over extended periods. Such "demonstration watersheds" could anchor efforts to test new and revised assessment techniques, as well as provide opportunities to generate reference data sets. Long term monitoring in demonstration watersheds could also focus on possible linkages between management practices and resources, at risk, so long as issues associated with mixed ownerships and monitoring continuity are addressed.

2. Designating the Reach and Identification

The following description for designating reaches used in an instream monitoring program is based on work done in the Pilot Monitoring Program. It illustrates one possible approach to for a monitoring program relying heavily on channel characteristics.

The upstream limit of the study reach may be fixed first on the basis of proximity to timber harvest activities, reach integrity, channel characteristics, and physical access. A permanent reach marker is placed in a secure spot not subject to removal by seasonal flows or maintenance activities. The distance and bearing to the start of the study reach is recorded. Photographs are taken of the permanent reach marker and its relationship to the upper edge of the study reach.

The permanent marker can be a four or six foot steel reinforcing bar. The bar is driven into upper bank soil and/or wedged between larger rocks until immovable. Placement near an obvious landmark or readily visible location from the access road is preferred. A four inch square brass or aluminum tag is inscribed with reach identification information and attached to the reinforcing bar with heavy wire. Fluorescent paint is sprayed on the bar and the tag. Measurements are metric and recorded on standardized data sheets.

[1] Taken directly from Rae (1995).

Habitat Inventory.

Preliminary habitat typing generally begins by surveys conducted downstream of the upstream permanent reach marker. Walking downstream, but not in the channel, each successive habitat unit is preliminarily identified and delineated with flagging. Preliminary habitat typing continues until six pools (P), three runs (V), and three riffles (R) are encountered and their lengths measured, or until 1000 m of study reach have been traversed. Identified pools, riffles, and runs that don't meet the criteria for sampling or are within the reach but in excess of the numbers needed (6,3,3) are indicated as non-criteria (NC). Reach portions that cannot be classified as a pool, a run, or a riffle are indicated as non-sample (NS).

An in-stream, near-stream, and side channel reconnaissance is conducted upstream from the upstream marker for 1000 m. If the channel branches with significant flow in more than one channel, the reconnaissance is conducted along all branches to an aggregate of 1000 m. Using a hip-chain to determine distance from the permanent reach marker, the observer records channel characteristics, current land practices, and evidence of historical land uses that may affect in-stream conditions. Observations center on the in-stream channel, include the near-stream corridor, and extend up-slope to include features that may introduce sediments into the channel or otherwise affect parameters to be measured. The reconnaissance is ended if channel alterations (e.g., water diversion), channel events (e.g., crossing failure), or upslope events (e.g., landing failure) are present and may introduce materials or change parameter levels more than that expected from the associated land practices being monitored.

Channel Typing.

Once the preliminary habitat typing has been completed, sampling begins at the bottom of the reach and proceeds upstream. An upstream sampling direction reduces the possibility of sampling activities affecting subsequent sampling sites. Field crew members record the length and gradient of all the separate habitat units on the Habitat Inventory Form. The length is measured with a tape measure, and the gradient is measured with Abney level and stadia rod.

Length and gradient are recorded for each habitat unit in sequence from the downstream edge of the reach to the upstream edge of the reach. During gradient observation, any necessary adjustments are made to habitat type identification and unit upstream/downstream limit determination. Units designated as NC or NS are measured only for length and gradient. For all pools, riffles, and runs, the average width and depth are measured. Several widths and depths are observed with direct measurement by use of stadia rod or V^{STAR} penetration rod.

Upon sampling the last habitat unit or encountering the 1000 m distance, the upstream end of the study reach is determined. A permanent marker is set similar to the downstream permanent marker.

Site descriptions are recorded for pools and riffles to indicate the placement of transects, sampling sites, and channel features. Pool and riffle site descriptions include significant plant species in the overstory, midstory, understory, and groundcover, and the average height of each layer. Also identified is the source and amount of shade, dominant vegetation, bottom substrate, bank morphology and general area composition, obvious sediment sources, local disturbances, sidestream influences (including drainages or rivulets), wildlife, or any other feature which may be of importance. Included within the site description is a cross-sectional diagram drawn from the bottom of the pool looking upstream, showing the bank slopes, riparian vegetation (overstory, midstory, and emergent), wetted edge of the pool, and any debris or rock formations present.

An areal diagram of each pool and riffle is prepared that portrays the orientation of the habitat unit, major habitat features, location of significant vegetation, and sites of diagram cross-sections, transects, and sampling sites. Drawn to scale on a grid, the diagram correlates distance measurements and is documented with photographs. Pool features include: riffle crest, top of pool, wetted area of the pool, sediment/cobble bars, debris and rock formations in and out of the water, streambanks, nearby vegetation in the riparian corridor, emergent vegetation, and the area over the pool which is covered by tree canopy (labeled). One of the most important aspects of these drawings are the locations of the transects, as these as well as photographs may be used to explain questions arising in the V^{STAR} data forms. All transects should be drawn as accurately as possible at the correct distances in the pool and show important features such as rocks or logs. The diagram also should reflect overhang and undercut banks, submerged or emergent logs, and rocks which define the pool but whose contribution to pool volume is difficult to determine (Rae 1995).

Chapter III: IMPLEMENTING A MONITORING PROGRAM [1]

A. INTRODUCTION

This handbook is intended for professional foresters, forest industry personnel, State Water Quality Control Board personnel, consultants, and other organizations or individuals involved in evaluating the effectiveness of forest management practices in meeting water-quality goals or standards.

With a few exceptions, forest management affects naturally occurring water-quality variables rather than the introduction of unnatural pollutants. This handbook attempts to describe monitoring projects designed to isolate the effect of forest management from other nonpoint sources of pollution and determine whether management practices or management activities meet nonpoint-source goals or standards. Best management practices (BMPs) are practices designed to meet water quality goals or standards.

The specific objectives of a monitoring program are to: (1) assure that monitoring projects consider all factors influencing nonpoint-source pollution, (2) design monitoring systems that isolate the impacts of BMPs or management activities, (3) review variables to consider when monitoring BMP effectiveness, (4) summarize representative methods appropriate for monitoring nonpoint-source variables, and (5) provide some examples of BMP effectiveness monitoring and decisions.

B. STRUCTURING AN IN-STREAM MONITORING PROGRAM

Many of the key steps for defining and implementing a water quality monitoring program have been identified through the discussion in the previous sections. Although the definition of the specific steps in developing a monitoring project tends to vary according to the author of the guidelines and the particular monitoring situation, the key steps are as follows:

- propose, together with the forest land managers, the general objectives;
- define the approximate budget and personnel constraints;
- review existing data;
- determine monitoring parameters, sampling locations, sampling procedures, and analytic techniques;
- evaluate hypothetical or real data;

[1] Taken directly from MacDonald et al.(1991).

- reassess monitoring objectives and compatibility with existing resources;

- initiate monitoring activities on a pilot basis;

- analyze and evaluate data;

- reassess monitoring objectives and compatibility with existing resources;

- modify monitoring project as necessary;

- continue monitoring;

- prepare regular reports and recommendations.

Figure A , is a schematic representation of these key steps, and it also indicates some of the critical feedback loops in developing and implementing a water quality monitoring project. In most cases, however, the key steps are not nearly as distinct and sequential as indicated in Figure A. Decisions made at each step often have repercussions for the entire monitoring project, and sometimes this may force a reassessment of previous steps. For example, preliminary identification of the possible sampling locations may necessitate a review of the budget constraints or the monitoring objectives. Hence the feedback loops shown represent only the most critical pathways, and each step may not always be completed in the order indicated. What is essential is that each key step be explicitly addressed, and the sequence indicated in Figure A is one approach to optimize the process of developing a monitoring project.

As shown in Figure A, the results of the pilot project can lead either to a revision of the monitoring project or to continued monitoring. In most cases a pilot project if properly formulated, will result in some modifications in the monitoring procedures, but will not alter the basic structure or objectives of the overall monitoring project. Continued monitoring will then lead to the accumulation of data that must be checked, stored, and analyzed. A description of these steps is beyond the scope of this handbook, but data storage, retrieval and analysis is another key aspect of monitoring that is often neglected in the planning phase.

The final step as indicated in Figure A is the preparation of reports and recommendations. For a variety of reasons many monitoring projects do not follow through to this step, and in such cases the worth of conducting the project must be questioned. In general, the multiple demands on staff time mean that the monitoring data will be used only if they are summarized, analyzed, and interpreted. If the results are clearly presented, the information will be much more widely disseminated, and this will reflect favorably on those responsible for the monitoring project. More importantly, the data are more likely to be evaluated by the managers and used for the original purpose, namely the guidance of management decisions. Failure to follow through to this final step implies a basic failure in achieving the objectives of a monitoring project (McDonald et al.1991).

C. DESIGNATING THE WATERSHED AND REACH [1]

Based on the discussions presented above, and in response to the refinements implemented during the Pilot Monitoring Program study, implementation recommendations are offered in this chapter for short-term monitoring efforts. Additional specific procedures for long-term monitoring projects are identified under each heading. Generally, short-term monitoring recommendations deal with project or site specific issues, while recommendations for long-term monitoring focus on concept, procedure, data sets, and training.

The selection of monitoring parameters should be based on the watershed processes operating within the assessment areas, the significant biological issues in the watershed, and the beneficial uses at risk. Selected techniques should be easy to understand and implement, and for fish and wildlife issues, focus on changes in the habitat that affect the most critical aspect of the life history of the resource at risk. The monitoring program should be designed to be easily replicated on the same and similar sites. All parameters to be monitored should be linked to management issues.

Prior to initiating a monitoring effort, the project designer or reviewer should determine whether a short-term or long-term monitoring program is appropriate. The questions of appropriateness apply equally to both short-term and long-term monitoring.

1. Short-Term and Long-Term Monitoring

A. Identify the resources at risk within the watershed and whether the project occurs in an area which may affect those resources.

B. Identify whether monitoring tools exist to measure changes in the parameters affecting critical periods in the life history of targeted resources at risk, or established beneficial uses.

C. Determine monitoring objectives (i.e., what is the management information need?).

<u>Short-Term Monitoring</u>

A. Define the purpose of the study prior to selecting study reaches.

[1] Taken directly from Rae (1995).

B. Conduct a field examination of available sites prior to selecting assessment techniques.

C. Identify the resources at risk prior to selecting which physical parameters to monitor.

D. Determine whether the parameter that directly affects a critical component of the identified resource at risk can be monitored at the proposed study sites.

E. Rank potential monitoring sites according to resource at risk sensitivity and select the most sensitive sites for study.

F. Develop criteria for ranking the sensitivity of the resource at risk to habitat changes at different sites.

<u>Long-Term Monitoring</u>

A. Perform a watershed assessment to determine resources at risk and beneficial uses, parameters directly affecting critical components of life histories and water quality, and study sites that optimize monitoring.

B. Determine permanent study reaches and sample sites with both long-term access and site integrity.

C. Integrate the assessment of private and public lands in monitoring studies.

D. Develop criteria for ranking the sensitivity of the resource at risk or other beneficial use to physical changes at different sites.

D. REFERENCE SITE SELECTION [1]

Reference sites are selected to represent the biological potential based on the best attainable watershed condition, habitat structure, water quality, and biological parameters for a specific ecoregion. Then an impaired watershed, or one suspected of being impacted, is compared to this reference condition to see if it supports a biological community comparable to that of the reference condition.

Some of the advantages of using ecoregions to establish reference conditions are that results can be used to: compare regional land/water patterns, establish reasonable standards, predict effects of management practices/controls, locate monitoring and special study sites, and extrapolate site specific information.

Reference sites must be selected with care because the resultant database will be used as a benchmark against which test sites will be compared. The conditions at reference sites represent the best that is presently achievable for similar streams of a particular ecoregion. (Ecoregions are areas of relative homogeneity, or similar quality, defined by similarity of land form, soil, vegetation, hydrology, and general land use.) Two primary criteria guide the selection of reference sites (EPA 1992):

1. Minimal impact: Sites that are not disturbed by human activities are ideal as reference sites. However, human activity has altered much of the landscape, so truly undisturbed sites will usually be available as 1st and 2nd order streams at higher elevations than the drainages being monitored. Therefore a criterion of minimal impact is used to guide selection from a suite of candidate reference sites.

2. Representativeness: Reference sites must be representative of the water bodies under investigation,(i.e., those expected to be found in that region).

The overall goal in the characterization of the reference condition from carefully selected reference sites is to describe the biota that are optimal for the area of interest.Test sites can then be compared to the benchmark to determine whether an impact exists.The characteristics of appropriate reference sites will vary among ecoregions and for different stream and habitat types.

Below are some criteria for selection of reference sites on wadable streams. Additional criteria will depend upon your study objectives (Plafkin et al. 1989; Hughes et al. 1986; EPA 1992b).

<u>Some Criteria for Selecting Perennial, Wadable Stream Reference Sites</u>

Perennial flow

Wadable streams

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[1] Taken directly from EPA (1994).

Relatively unimpacted (minimal human disturbance to the watershed and stream system)
Relatively high heterogeneity of substrate materials (mines, gravel cobbles, boulders)
Natural channel morphology (variety in channel width and depth; presences of pools riffles, backwaters, glides as are typical of the region)
Natural hydrograph: flow patterns typical of the region
Stable banks: includes banks generally covered with riparian vegetation with little evidence of bank erosion; undercut banks stabilized by root wads provide stable cover for aquatic biota
Natural water color and odor
Relatively abundant and diverse algal (or aquatic plant), benthic macroinvertebrate and fish assemblages typical of that region
Presence of animals that derive part of their support from aquatic ecosystem
Peer review - interdisciplinary team, including the research and academic community
Statistical analysis to define the range in the number of reference sites needed

One particularly problematic aspect about the use of minimally impacted sites as references is what to do if an area is extensively degraded. In this case there may be no minimally impacted sites and even the least impacted sites might indicate significant deterioration. In some areas, most of the stream systems are altered through widespread timber harvest, grazing, channelization, urbanization, and other development activities. In these cases, it is possible that no suitable reference streams exist.

E. SELECTING THE PARAMETERS AND EQUIPMENT [1]

The need to improve existing technology, discard inappropriate technology, and develop new technology will continue. Documented procedures should be used for monitoring parameters that reflect the quality of critical components of the habitat and beneficial uses. The capability to determine from a data set whether data variation is due more from changes in the site rather than from inconsistencies in assessment technique implementation has not yet been proven.

1. Short-Term Monitoring

A. Select parameters that directly affect one or more critical components of the life history of a resource at risk or other beneficial use within the target watershed.

B. Select parameters for which assessment techniques have been previously used in similar watersheds or stream reaches.

[1] Taken directly from Rae (1995).

C. Implement assessment techniques for which field procedures have been published and accepted by the professional community.

D. Provide justification for selection of parameters that do not directly affect a critical component of the life history of a resource at risk or other beneficial use.

E. If trained personnel are available and time permits, implement the Rapid Bioassessment Protocol for macroinvertebrate faunal assemblage assessment within all monitoring studies. Include spring and fall sampling with 300 count subsamples. (Note: If qualified personnel are not available, additional funding may be necessary to accomplish sample analysis.)

F. Consider implementing the V^{STAR} protocol for sediment assessment within wadable streams having an overall gradient less than 4%. Do not use the V^{STAR} protocol in streams that are either bedrock dominated or include significant sediment deposits that are not annually mobile. Also, V^{STAR} should not be used in lithologies that do not produce moderate to high concentrations of fine sediments.

G. When appropriate, implement the D_{50} technique for sediment transport assessment. In wadable streams, the technique may be used on either submerged or exposed sediments (riffles or point bars).

H Select and implement canopy coverage assessment to establish cross-walks with forest stand inventory data and linkage with woody debris recruitment and water temperature.

I. Observe water temperature within the stream in critical habitat areas for fish during critical time periods. Utilize submersible recording sensors for continuous records.

J. Generally, monitoring on higher gradient streams should focus on macroinvertebrates (Rapid Bioassessment), temperature, canopy coverage, and the recruitment of large woody debris. However, short-term monitoring projects may not warrant the use of these specific parameters.

K. Generally, monitoring on lower gradient streams should focus on sediment transport and storage (D_{50}), residual pool volume filled with fine sediment (V^{STAR}), the recruitment of large woody debris, temperature, and canopy coverage. These parameters should be selected when appropriate.

2. Long-Term Monitoring

A. Conduct long-term studies to assess the accuracy of assessment techniques to monitor specific parameters under different site conditions.

B. Consider implementing the V^{STAR} protocol within low gradient stream reaches.

C. Conduct paired tests to validate the relevance of reference, or control, data sets drawn from both spatially or temporally separated samples.

D. Implement the Rapid Bioassessment Protocol for macroinvertebrates.

E Determine additional biological parameters and assessment techniques for monitoring that focuses on vertebrate species.

F. Evaluate the effectiveness of vegetation analysis procedures for characterizing plant community structure within the riparian and near-stream corridor. Determine linkages between vegetation analysis procedures and forest stand (commodity-based) type mapping. Evaluate the linkage between canopy coverage data and recruitment of woody debris.

G. Publish the results of evaluating the effectiveness of assessment techniques.

3. Equipment

The use of expensive or fragile equipment and materials may introduce additional costs and time delays. When expensive equipment is needed, however, it should be used by highly trained personnel. The recommended equipment and supplies listed below were used in the Pilot Monitoring Program.

a) Short-Term Monitoring

A. Select field equipment that is relatively inexpensive to acquire or fabricate.

B. Select field equipment that are appropriate for use by field crews with varying levels of training and experience.

C. Avoid the use of equipment subject to breakage during normal use or that requires frequent or expensive calibration. Avoid the use of toxic or hazardous materials (e.g, mercury-based thermometers).

b) Long-Term Monitoring

A. Periodically re-examine the choice of equipment.

B. Revise and develop new equipment and assess its use in field trials.

C. Publish procedures involving the use of revised or new equipment.

D. Develop methods for "un-wadable" streams.

ASSESSMENT TECHNIQUE EQUIPMENT AND SUPPLIES

V^{STAR}

Equipment

V^{STAR} penetration probe - 2 m (3)	(custom fabrication)
V^{STAR} penetration probe -.7m (3)	(custom fabrication)
level or transit	
measuring tape - 50 m	
measuring tape - 10 m	
stadia rod - metric (2)	
waterproof flashlight	

Software

spreadsheet	(Excel™)
V^{STAR} index calculator	(custom application)

Supplies

- waders
- insulated, waterproof gloves (without finger)
- flagging
- field data forms

Riffle Armoring Stability Index and D_{50}

Equipment

Size class templates - (many)	(custom fabrication)

Software

index calculator	(custom application)

Supplies

- plastic rulers - metric (many)
- field data forms (Rite-in-the Rain)

Temperature

Equipment

recording, submersible sensors	(Hobo™ by "Onset")

handheld electronic sensors ("Stowaway")
handheld mercury thermometers

Software
sensor download and data storage (Boxcar by "Onset")
(including special serial cable)
(including additional serial port, if necessary)

Supplies
submersible sensor housings
steel reinforcing bar - 2 m
hose clamps - 1-inch
hose clamps - 2-1/2-inch
socket screwdrivers to fit hose clamps
mallet - 2 lb - short handle
nylon rope
field data forms

<u>Habitat Inventory and Channel Typing Equipment</u>

Equipment
level or transit
measuring tape - 50 m
measuring tape - 10 m
stadia rod - metric (2)
waterproof flashlight Supplies

Supplies
field data forms

<u>Slope</u>

Equipment
clinometer or Abney
compass
Supplies
field data forms

<u>Macroinvertebrates</u>

Equipment
stadia rod - metric (2)
measuring tape - 50 m
D-net - long-handled
sieve set

white enamel pan
plastic alcohol-proof sample containers - 500 ml

Supplies
field data forms
random number table
absolute alcohol
tweezers
waders
insulated, waterproof gloves (without fingers)
alcohol resistant marking pen

Canopy

Equipment
spherical densiometer
sighting tube
basal area estimator
(Cruz-All)
(Sighting prism)
(Relaskope)
compass
clinometer
measuring tape - 50 m
range finder

Supplies
field data forms

F. DATA MANAGEMENT SYSTEMS [1]

During the Pilot Monitoring Program initial data management efforts focused on the design of standardized field data forms. Early designs were based on forms included in descriptive publications or provided by cooperators. These preliminary designs were tested and refined during field training exercises. Examples of final field data collection forms are presented in the appendix to this handbook.

Field team supervisors were responsible for maintaining supplies of blank forms and retaining completed forms. Daily team debriefings assessed the adequacy of each days' effort. Completed survey forms and associated field notes were deposited centrally at the end of the field season.

[1] Taken directly from Rae (1995).

To reduce volume, forms were printed double-sided. Following problems with immersion, forms were printed on Rite-in-the-Rain ^{R} paper, which proved to be very durable.

Separation of team members along the same stream reach sometimes resulted in multiple copies of the same data entry form for the same sampling site with different data. Form collation, comparison, and completion was originally scheduled for evening de-briefings, but usually occurred following each week's field surveys. Data irregularities sometimes were obvious when field forms for the entire reach were evaluated at the end of the week. Completed field survey forms and associated field notes were collated, reconciled, duplicated, and filed at a central location each week.

Electronic files containing field data on fine sediment (V^{STAR}) , RASI, D_{50}, canopy, temperature, habitat type, slope, and macro-invertebrates were created. The data files on V^{STAR}, RASI, D_{50}, and macroinvertebrates also served as the basis for input files for application software packages.

1. Database Structures

The following fields were created to maintain information collected during the implementation of the monitoring parameters according to the protocols described in the Pilot Monitoring Program and are provided as potential database files to be considered for individual programs (Rae 1995).

$\underline{V^{STAR}}$

Individual Transect Data

1. Stream ID
2. Reach Number
3. Pool Number
4. Transect #
5 Pool Riffle Crest
6. Transect Distance From Head of Pool
7. Pool Length
8. Weight Up (weighting value to upstream transect; typically 50%)
9. Weight Down (weighting value to downstream transect; typically 50%)
10 Sample Point Distance From End of Transect
11. Water Depth
12. Scour Depth

(10., 11.,12. concatenated for multiple sample points on each transect)[1]

Summary Data

1. Stream ID

2. Reach Number
3. Pool Number
4. Pool Volume
5. pool V^{STAR} Index
6. Cumulative Reach V^{STAR} Index

RASI and D^{50} Data

I. Stream ID
2. Reach Number
3. Riffle Number
4-33. Depositional Measurements
34. Average Depositional Measurement
35. Pebble Count-Size Class I
36. Pebble Count-Size Class II
37. Pebble Count-Size Class III
38. Pebble Count-Size Class IV
39. Pebble Count-Size Class V
40. Pebble Count-Size Class VI
41. Pebble Count-Size Class VII
42. Pebble Count-Size Class VIII
43. Pebble Count-Size Class IX
44. Pebble Count-Size Class X
45. RASI Index
46. D_{50} Index

Temperature Data

1. Stream ID
2. Reach Number
3. Date
4. Habitat Unit Number
5. Temperature - Air (handheld)
6. Hobo Number
7. Downloaded Data File Name (submersible recording sensor)

Habitat Inventory and Channel Inventory Data

1. Stream ID
2. Reach Number
3. Date

4. Habitat Unit Number
5. Habitat Unit Type
6. Mean Length
7. Gradient
8. Mean Width
9. Mean Depth

10. Maximum Depth
11. Riffle Crest
12. %Unit Shelter
13. %Undercut Banks
14. % Small Woody Debris
15. % Large Woody Debris
16. % Root Mass
17. % Terrestrial Vegetation
18. % Aquatic Vegetation
19. % White Water
20. % Boulders
21. % Bedrock Ledges
22. % Total Canopy
23. Right Bank Dominant Vegetation Type
24. % Right Bank Vegetated
25. Left Bank Dominant Vegetation Type
26. % Left Bank Vegetated

<u>Slope Data</u>

1. Stream ID
2. Reach Number
3. Habitat Unit Number
4. % Slope (right side looking upstream)
5. % Slope (left slope looking upstream)

<u>Canopy Data</u>

1. Stream ID
2. Reach Number
3. Habitat Unit Number
4. Distance from head of unit
5. % Cover - Upstream Quadrant (spherical densiometer)
6. % Cover - Right Quadrant (spherical densiometer)
7. % Cover - Downstream Quadrant (spherical densiometer)
8. % Cover - Left Quadrant (spherical densiometer)

Concatenated data from points 10,11,12, is gathered at each sampling point along the transect. The data for each point is then added sequentially to the end of the record, i.e., 10,11,12,10,11,12,10,11,12.

2. Further Information On Data Record Keeping

Permanent reference sites track changes in stream channels over long periods of time. The measurements must be both available and usable, despite transfers and other changes in personnel staff and organization. Besides local uses for this data, it may be included in regional or State wide databases. Orderly, consistent methods of recording data make the task easier at each level: in the field notebook, in permanent records, in computer databases, and over large internet sites.

3. Electronic Data Collection and Storage

As electronic data loggers and Geographic Information Systems (GIS) or Global Positioning System (GPS) remote loggers become increasingly available, they may replace the sturdy yellow field book, but the principle is the same: data records should be orderly, consistent, and clear to allow broad use and replication. Use consistent file names, with the same system year-to-year. Always back up computer files on a removable medium (floppy disk, tape cartridge, etc.) and store two copies of the back-up in different locations.

4. File Management Use

Active management of files makes stream data available for long-term use. Use up to date computer filing systems to permanently store data by watersheds. If cooperation with adjacent land owners is planned, agree upon common file format procedures. Multiple hard copies are a good idea: one for the forester's file and one for the main office. Never take original records for extended use elsewhere, use copies. Place duplicates in three-ring binders for use at meetings, in the field, etc.

5. Data Networks

Attempts to collect and correlate stream data on levels broader than basin or property boundaries should be designed on a network level. Network sites should be capable of maintaining records of observations for extended periods (Harrelson et al. 1994). Network site files should include:

- location by USGS map township and range and section, with latitude and longitude;
- a tabulated road log of distances from permanently identifiable features;
- a legible copy of a topographic map, or a plane-table or sketch map of the site (sized to fit in a file folder) showing pertinent features and permanent benchmarks found or installed;

- a physical description of the geology, soils, vegetation, climate, and topography; features that lend significance to the site should be described;

- photographs should be identified by date and position of camera, with the location of negatives noted;

- the data sheets that show the benchmark elevations and the initial survey data (units may be either metric or English, but should be consistent throughout a file); and

- references for methods, site information, and supporting information (Harrelson et al. 1994).

G. TRAINING FOR IMPLEMENTATION [1]

The value of the assessment techniques described in this handbook depends on how well they are implemented. The training to facilitate the use of the assessment techniques then focuses on the decision making process. The following training curriculum is based upon the first version of the Watershed Academy core course and technical field module that was presented during August and September of 1995 at Humboldt State University.

Within the context of watershed assessment, participants are presented with basic concepts involving the physical and biological features creating the unique setting of each watershed. Physical factors are presented as they define the habitat of the biological resource of interest. To describe such habitats, participants are introduced to the life histories of species targeted for management. Within the description of the life history, the physical factors that exert major influence during periods when the species is vulnerable are detailed. Then, the possible relationship between upslope and upstream activities and resultant downstream habitat changes are better clarified.

The Watershed Academy is a structured approach to presenting the basics of watershed assessment. The core course is the foundation for later emphasis on specific techniques, depending upon the interest of the participant. The subsequent technical field module is designed around specific field assessment techniques and information analysis systems.

Managers responsible for resource recommendations and those designing field monitoring projects can increase their conceptual and technical competency by attending similar core course and relevant technical modules. Field crew member or data keyers may consider attending only the technical module (or, a portion of the field course). The breadth of training necessary can be based on the degree of responsibility for planning and managing a monitoring program.

[1] Taken directly from Rae (1995).

CHAPTER IV: REVIEW OF THE MONITORING PARAMETERS AND ASSESSMENT PROCEDURES

A. INTRODUCTION

The parameters reviewed in this section relate to the shape of the stream channel, the structural features within the stream channel, and the stability of the stream banks. These channel characteristics can be monitored on different spatial scales and from different perspectives. For example, bed material particle size and embeddedness evaluate the surface of the streambed on a scale of a few centimeters, whereas a thalweg profile evaluates the topography of the deepest part of the streambed on a scale of tens or hundreds of meters. Measurements of habitat type (e.g., pools, riffles, etc.) were pioneered by fish biologists and are used to evaluate the quality of fish habitat, and these units are functionally related to the parameters used by fluvial geomorphologists (e.g., residual pool depth or the number of debris dams caused by large woody debris).

Attribute Descriptions:

Following this introduction and diagrams of in-channel characteristics are descriptions of various parameters used in this Handbook, including information on the importance, objective of measurement, as well as methods for collecting parameter data.

B. CHANNEL CHARACTERISTICS AND MONITORING PARAMETERS [1]

Most of the characteristics of stream channels that might be used for monitoring are controlled by the same basic set of interacting factors. Among the most important of these are the amount and size of sediment, the duration and size of peak flows, slope of the valley bottom, valley bottom width, steepness of the sideslopes, and the local geology. Some of these factors can be considered constant for a given site, while the factors that do vary (discharge and sediment) are relatively difficult to monitor. Stream channel characteristics may be advantageous for monitoring because their temporal variability is relatively low, and direct links can be made between observed changes and some key designated uses such as coldwater fisheries.

The importance of these controlling factors suggests that many of the channel characteristics will have a similar response to management activities. Some of the parameters which are most closely related include channel cross-sections, and channel width/depth ratio; pool parameters, and thalweg profile; and the three parameters relating to bed material (particle size, embeddedness, and surface vs. subsurface bed material particle size). In most cases it is not necessary to monitor each of these closely related parameters, and the selection among these monitoring parameters will depend upon

[1] Taken directly from MacDonald et al.(1991).

the particular combination of management activities, designated uses, and site-specific conditions. General recommendations are difficult because relatively few studies have used channel characteristics as the primary parameters for monitoring management impacts on streams.

The relatively low temporal variability of channel characteristics must be balanced against: (1) the potentially large spatial variability, and (2) the problem of separating man induced changes, past and present, from changes due to natural events. Proper statistical design can help alleviate both of these considerations, and the much lower frequency of sampling will allow more sites or more parameters to be measured. In many cases a combination of several channel parameters may be the best approach to evaluate and understand observed changes in the stream channel (McDonald et al. 1991).

1. Channel Cross-Section

Definition

A channel cross-section is a topographic profile of the stream banks and stream bed along a transect perpendicular to the direction of flow. Cross-sectional data are obtained by measuring distance and surface elevations along the designated transect or cross-section. The end points of the cross section are arbitrary, but they should extend at least above the estimated bankfull stage and preferably beyond the current floodplain. If change over time is to be monitored, the elevation data must be related to a permanent benchmark.

Cross-section data are needed to calculate discharge using any of the velocity-area methods (Buchanan and Somers 1969). Cross-sections often are used as the sampling transect for other instream parameters such as bed material particle size, embeddedness, and the type and amount of large woody debris. A series of cross-sections referenced to a single benchmark is useful to determine the precise slope of the stream channel. Channel slope is a key parameter in most hydraulic calculations and for stream classification.

Relation to Designated Uses

A cross-section of the channel and adjacent floodplain is one of the key pieces of information necessary to predict the velocity and water surface elevation during high flow events. Such predictions are needed for a variety of engineering and management purposes, including structural design, estimation of flood heights, and the stability of channel protection measures.

For these types of engineering purposes, cross-section data typically are collected at a single point in time. At best such data can provide only a qualitative indication of channel condition.

Monitoring of changes in the channel cross-section can provide important insights into channel stability, bank stability, and the relative balance between sediment (particularly bedload) and discharge (Beschta and Platts, 1986). Widening of the stream channel, filling in of the channel thalweg (the deepest portion of the channel), increasing bed elevation (i.e., channel aggradation), and declining cross sectional area all indicate an excess of sediment. Net deposition of sediment usually results in more extreme stream temperatures, a decrease in the amount and quality of fish cover, a change in the quality of the spawning habitat, a possible reduction in habitat space for algae and macroinvertebrates, increased bank erosion, and an increased likelihood of flooding.

Channel incision or bed erosion (i.e., channel degradation) usually indicates a reduction in coarse sediment inputs or an increase in sediment transport capacity due to higher peak flows. This can have beneficial or adverse effects depending upon the initial conditions and the designated use(s). Channel incision will lead to bank steepening and bank instability, and this will increase the sediment load. Bank instability also will lead to a toppling of the riparian woody vegetation immediately adjacent to the stream channel, which can trigger a series of secondary effects. On the other hand, if the channel already has been subjected to increased sediment loads from previous management activities, channel incision may represent a return to "natural" conditions and an improvement in habitat quality and channel capacity (Megahan et al. 1980).

Response to Management Activities

The shape and area of the channel cross-section can change in response to a variety of management activities. Management can alter the size or frequency of peak flows and the sediment load, and these are likely to affect the shape and area of the channel cross-section. A decline in bank slope may be due to grazing impacts. Rapid infilling and an increase in the width-depth ratio suggests an excess of coarse sediment. Erosion at the toe of the bank may lead to a slumping of the over steepened bank, and these changes can be quantified by systematically monitoring selected cross-sections.

In each case additional information on management activities and natural events should be collected. For example, the cause of infilling could be either several years of below-average rainfall or an upstream landslide. In northern California and parts of the Pacific Northwest, an apparent down cutting in certain stream channels is actually part of the long-term recovery from the large sediment deposits associated with the extreme 1964 flood and previous poor land use practices (Lisle 1982).

Measurement Concepts

Cross-sections are surveyed by establishing a line perpendicular to a stream and measuring bed surface elevations either at regular intervals or at pronounced changes in slope. If the cross-section is not perpendicular to the stream channel and flow direction, errors will accumulate in the estimates of cross-sectional area and discharge. Cross-section data always should be plotted for error-checking and improved visualization of channel form.

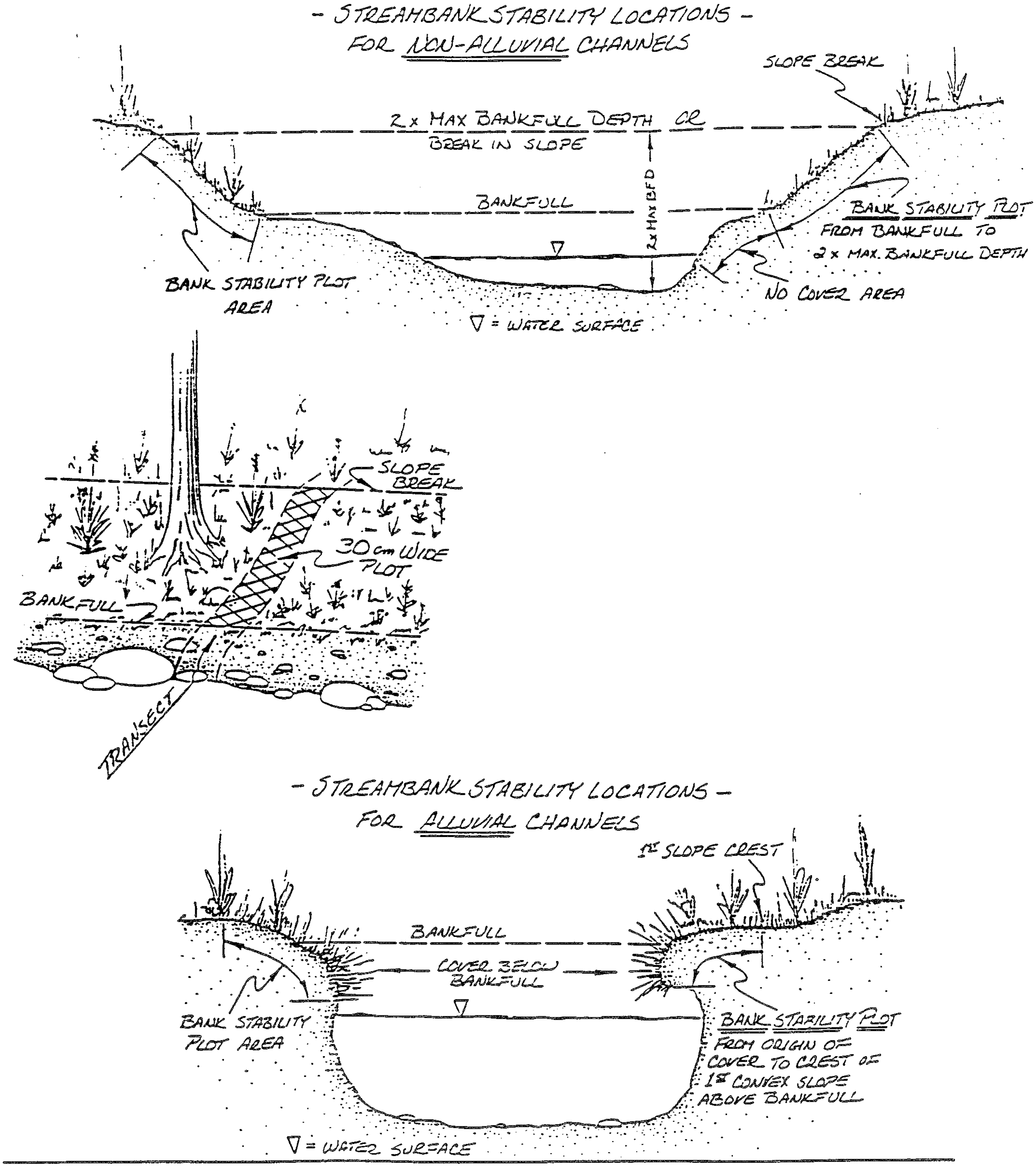
Typically a cross-section is measured by a two-person crew with surveying equipment. However, one person can survey across-section by stretching a tape across the stream and then measuring the height of the tape above the ground surface. Some investigators have found this latter technique to be more efficient (Platts et al. 1983).

Often a series of cross-sections are necessary to characterize a stream reach, establish transects for sampling other parameters, and provide quantitative data for statistical analysis. Groups or clusters of cross-sections can be located by random sampling, stratified random sampling, or systematic placement around random samples. Stratified random sampling can be effective in reducing variability, decreasing sample size, or increasing the ability to detect change if the strata are properly chosen and the user has some prior information on the types and variability of the strata. Either of the two random sampling techniques are acceptable provided the number of samples is large enough to meet the statistical requirements (Platts et al. 1983). Data from cross-sections can be grouped by habitat type to determine general trends.

Current Uses

The most common reason for collecting cross-section data is to calculate discharge using the standard velocity area technique (Buchanan and Somers 1969). Data from multiple cross-sections as depicted in Figure B are used to evaluate fish habitat conditions, estimate net sediment transport within a particular reach, and evaluate changes in channel morphology (e.g., width-depth ratio, bank slope, and bankfull depth). Certain other parameters, such as bed material particle size and embeddedness, can be properly interpreted only if they are referenced to a particular location along a thalweg profile or channel cross-section.

Figure B: Cross-Section of Stream Channel
(USFS 1996)



Cross-section data have been an important component of monitoring the South Fork of the Salmon River and other important watercourses in the Pacific Northwest. In many other monitoring projects, cross-section data have been collected but have not been analyzed to determine the specific changes occurring overtime. The availability of computer software programs and digitizing tables means that comparative analyses can be done more quickly than in the past. Reference cross-sections are being established by the Timber-Fish-Wildlife Ambient Monitoring Program in Washington and by the U.S. Forest Service.

Assessment

Stream cross-sections provide a quick and useful visualization of the stream channel. Repeated measurements of the same cross-section is a relatively simple means to monitor changes in the same channel. Sampling locations for other monitoring parameters often are established on the basis of reference cross-sections.

The sensitivity of a cross-section to change is highly dependent on a variety of site factors. Bedrock can limit scour or lateral migration. In steeper reaches, where the stream has a high sediment transport capacity, there may be no net deposition despite an increase in sediment load. Conversely, in downstream alluvial reaches the channel cross-section may be relatively responsive to changes in both the sediment load and the size of peak flows. This suggests that a series of cross-sections may be needed to assess the overall patterns of channel change within a catchment.

The primary problem with monitoring cross-sections is that it may be very difficult to determine the cause of an observed change. A channel cross-section represents an integrated response to natural events, the physical environment, and management impacts. Separation of these factors requires several different approaches. First, cross-sections should be monitored over a relatively long time period, as short-term changes resulting from unusual climatic events can mask a quite different overall trend. Second, data on parameters, such as bed material particle size or riparian vegetation, are necessary to fully characterize and understand any observed changes in channel morphology. Finally, the data on channel cross-sections must be put in the context of a broader watershed assessment, and this should include data on the type and location of management activities, watershed characteristics, and the historical climate.

In summary, cross-section data are most useful if combined with other monitoring parameters. Cross-section data alone may be difficult to relate directly to the designated uses of the water body of concern. A determination of channel aggradation or degradation, for example, may permit inferences to be made about certain designated uses such as wildlife or fisheries, but are not a direct measure of these uses and may not indicate the cause of an observed change. On the other hand, channel cross-sections are relatively easy and inexpensive to measure, particularly in smaller streams. Thus a combination of channel cross-section data with other parameters more closely linked to the key designated uses (e.g., spawning habitat) can provide the basis for a relatively powerful and inexpensive monitoring procedure (MacDonald et al. 1991).

2. Channel Width and Width To Depth Ratios [1]

Definition

Sediment accumulation in the stream channel reduces stream depth. To maintain the same channel capacity, there usually is a corresponding increase in stream width. These interrelated changes provide the basis for two geomorphic parameters that can be used for monitoring purposes- stream width and the width-depth ratio.

Both stream width and stream depth have to be defined with regard to a certain discharge. This discharge can be specified in absolute terms (e.g., 30 cubic feet per second), in geomorphic terms (e.g., bankfull), or in terms of recurrence interval (e.g., a 5-year event). Because streams almost always are several times wider than they are deep, a small change in depth can greatly affect the width-depth ratio. One must also specify whether the depth is the average depth for the cross-section or the maximum (thalweg) depth.

Relation to Designated Uses

A decrease in channel depth and an increase in channel width can have major adverse effects on the biological community. A decrease in depth tends to reduce the number of pools (Beschta and Platts 1986) and this will reduce certain types of fish habitat. An increase in stream width will lead to an increase in net solar radiation and higher summer water temperatures (Beschta et al. 1987). The combination of shallower pools and increased solar radiation can greatly affect the suitability of the stream for coldwater fisheries. An increase in stream width and an increase in light penetration is likely to increase primary production, although this may be partly offset by a reduced input of organic debris into the aquatic ecosystem from the riparian zone (Gregory et al. 1987).

An increase in channel width is achieved through bank erosion and a corresponding increase in sediment inputs into the stream channel. An increase in bank erosion is particularly important because the sediment is delivered directly into the stream channel. The effects of an increased sediment load can be detrimental to fishery resources.

An increase in the riparian canopy opening due to an increase in stream width can have a series of adverse biological effects. Such an increase is likely to reduce the amount of riparian vegetation, and this will reduce the ability of the riparian zone to capture nutrients and sediment. The riparian zone is also a major source for large woody debris, an important element in pool formation and habitat diversity in most forested streams in the Pacific Northwest.

Response to Management Activities

Road building, road maintenance, forest harvest, and other management activities often increase

[1] Taken directly from MacDonald et al.(1991).

the amount of sediment delivered to the stream channel. Usually an increase in coarse sediment will lead to an accumulation of sediment in the deeper parts of the stream channel. If the runoff remains unchanged, an unconstrained stream generally responds by increasing its width (Lisle 1982, and Grant 1988). The magnitude of this increase in width will be affected by valley shape and the bank materials. Lisle (1982) observed increases in width even in constrained, non-alluvial materials. Thus changes in width or the width depth ratio can be used as an indicator of a change in the relative balance between the sediment load and the sediment transport capacity.

Grant (1988) noted that an increase in channel width also could result from an increase in the size of peak flows. Increases in the size of peak flows due to forest harvest generally are small. This additional mechanism for channel widening does not preclude the use of channel width as a monitoring technique, but it does suggest that additional data are required to understand the cause of any observed changes. Harvest of the riparian vegetation also can decrease bank and channel stability and thereby initiate a cycle of bank erosion and channel widening.

Measurement Concepts

The determination of channel width and channel depth is problematical because both parameters are flow-dependent. Depth tends to increase with flow more rapidly than width (Dunne and Leopold 1978, and Leopold and Maddock 1953), but this relationship may not be constant at a given cross-section. A stream with a wide, flat floodplain, for example, will experience a sudden increase in width when flow overtops the banks and spreads across the floodplain. Thus the monitoring of changes in width and depth should be done at specified discharges and locations. A geomorphically based discharge, such as active channel width at bankfull width, is most commonly used but may be relatively subjective. The resulting uncertainty must be taken into account when drawing inferences from the data.

Cross-section location will affect the width-depth ratio and the sensitivity to change. For example, stream width and width-depth ratios are likely to differ across riffles, sharp bends, and pools. This variation can be minimized by measuring widths and depths at a consistent channel form such as straight riffle reaches, using average depth rather than maximum depth, or by using average values obtained from several different cross-sections.

The sensitivity of stream width and width/depth ratios to management impacts and natural events will vary with stream type and confinement. A bedrock channel in a steep, V-shaped valley will not alter its width in response to an increase in sediment load as easily as a stream in a wide valley with unconsolidated alluvial sediments. Channel shape is also affected by the relative proportions and absolute amounts of bedload and suspended load (Schumm 1960). Streams with cohesive materials tend to have narrow, deep channels, while streams in a sandy or other noncohesive substrate tend to be wide and shallow.

Current Uses

Although a considerable amount of cross-section data can be obtained from gaging stations, stream inventories, and other studies, channel width has not been extensively used as a monitoring technique. Powell (1988) documented the increase in stream width that occurred in both the careful and the intense logging treatments on Carnation Creek in coastal British Columbia.

Channel width and depth data also have been collected in conjunction with the intensive, long-term monitoring efforts on the South Fork of the Salmon River (Torquemada and Platts 1988). Present efforts by agencies such as the U.S. Forest Service to inventory fish habitat and stream channel condition should generate a large amount of stream width and width depth data. It remains to be seen how well these particular parameters can define stream condition and monitor management impacts.

Assessment

On-the-ground measurements of channel widths and width-depth ratios have the potential of being relatively sensitive indicators of changes in the size of peak flows and sediment yields. Channel width and width-depth ratios can be related to the value of streams for fish and recreation.

Defining channel width and depth in the field is not a trivial problem. For this reason it is best to monitor channel width at a series of cross-sections. Use of geomorphic indicators such as bankfull width or active channel width must be done with great care as these tend to be subjective and a major runoff event can alter the channel cross section and make identification of bankfull features questionable. Determining width and depth at a standard discharge may be logistically difficult unless it is done at an existing gaging station. The problem with using gaging seasons as monitoring locations is that they usually are placed at geomorphically stable locations and are relatively insensitive to management related changes in channel form.

Measuring channel width or width/depth ratios also suffers from the same basic limitation as any other instream measure-namely, that it does not provide any information on the cause of an observed change. Hence monitoring data must be combined with information on management activities, storm events, and sediment sources (e.g., roads, debris flows, landslides, or a breakdown of debris dams). As noted earlier, one also has to put the changes observed from a relatively short-term monitoring project into the context of larger changes such as extreme floods or major sediment inputs. Only with this additional information can the effects of forest management begin to be deciphered.

Finally, the magnitude and rate of change in channel width and width-depth ratio will depend on factors such as the slope of the stream, the shape of the valley bottom, the bank and bed materials, and the recent flood history. Although this may make it difficult to establish specific standards, it should not mask general trends. These considerations also indicate that long-term measurements at various locations within the watershed are needed for adequate monitoring (MacDonald et al.1991).

3. Gradient [1]

Importance

Stream channel gradient is an essential element of many stream classification systems and a primary attribute for stratifying sensitive reaches. In addition, knowledge of channel gradient helps provide understanding of the geomorphological processes shaping the channel.

Measuring gradient is essential for characterizing the sensitive reach by its water surface slope. Gradient must be measured in order to compare the reach with other reaches.

Objective of The Measurement

To determine stream channel gradient in percent slope.

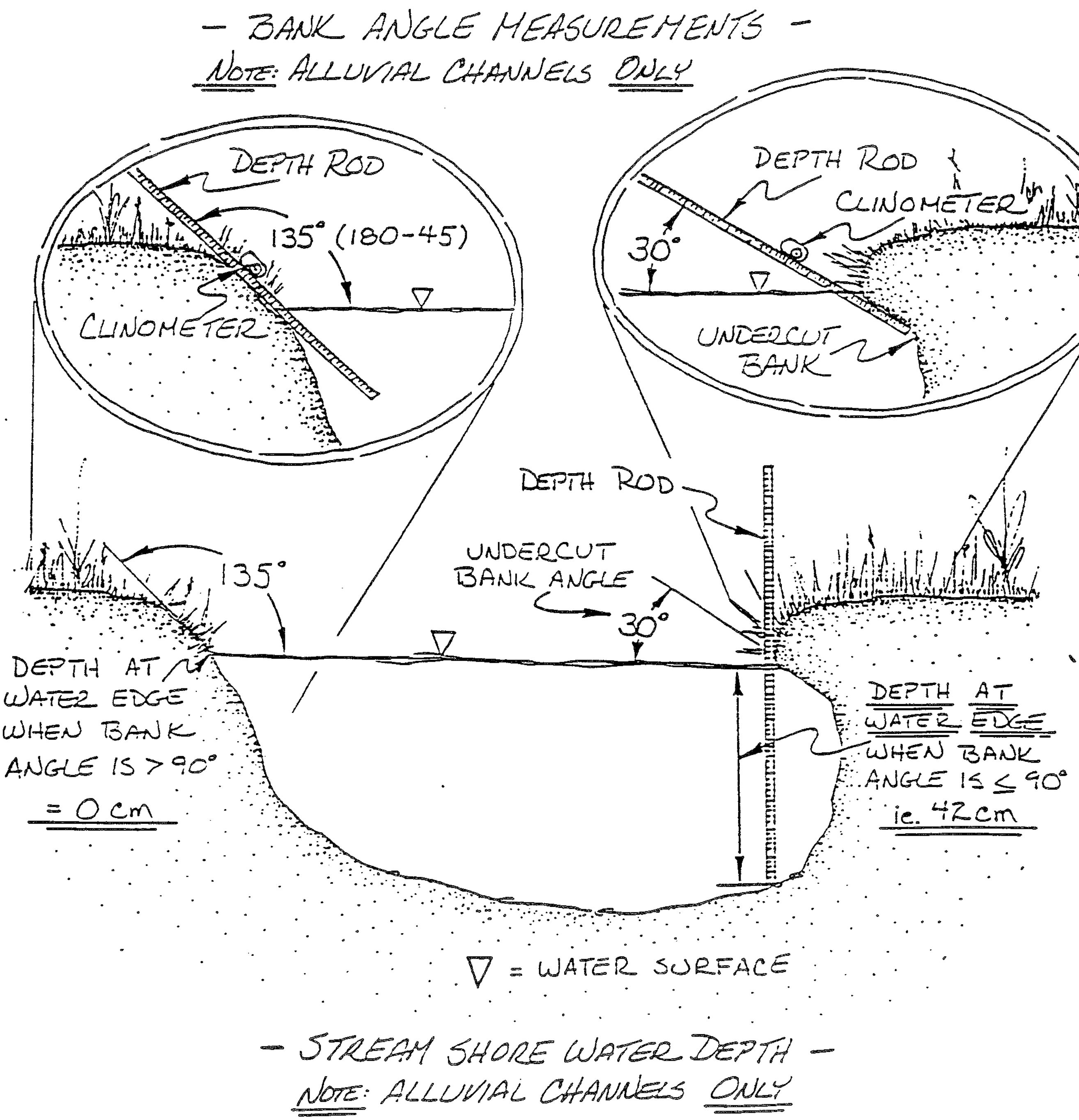
Taking Measurements

The gradient is determined by observing the percent gradient from the unit on the downstream edge to the upstream edge. An observer stands with their feet at water level holding the Abney level centered and balanced on the zero mark, while a cooperator holds the stadia rod with its base at water level directly in front of the person with the level. The cooperator holding the rod then informs the observer of their eye level height on the stadia rod, and marks the level with bright flagging. Next, the cooperator walks to the upstream edge of the habitat unit and places the bottom end of the stadia rod level with the surface of the water. The observer remains at the downstream edge of the habitat unit with their feet level with the surface of the water. The observer looks for the flagging on the stadia. The cooperator may assist in locating the flagging by pointing with a hand and extended finger. The observer centers the bubbles within the Abney level, then aligns the black lines in the level with the eye-level mark on the rod and reads the gradient off the percent scale (Rae 1995). Further gradient measurement techniques are illustrated in Figure C.

Measurements should include the lengths of six pools (P), three riffles (R), and three runs (V) when they exist within 1000m of the study reach.

[1] Taken directly from MacDonald et al.(1991).

Figure C: Measuring Gradient
(USFS 1996)



To measure gradient using the hand level and tripod, the observer at the instrument (hand level) places the tripod in the thalweg and attaches the level to the top of it. The observer records the height of the center of the instrument and the height of the water surface above the streambed. The observer at the instrument sights through the level to an observer with a measuring rod at the other end point of the survey. The observer at the rod notes the height on the rod that is level with the height of the instrument. The observer at the rod records this height and the height of the water surface above the streambed.

To determine gradient first subtract the water-surface height from the height of the instrument. At the rod end, subtract the water-surface height from the level height observed from the instrument. For example, when sighting upstream, if the instrument height is 1.5 m above the streambed and the water-surface height is 0.2 m, the difference is 1.3 m. If the rod level height is 1.1 m and its water-surface height is 0.3 m, the difference is 0.8 m. The water-surface slope elevation change between the survey end points is 0.5 m (1.3 m - 0.8 m), which is called the "rise". The procedure for sighting downstream is the same but note that the rod level height will be greater than the instrument height and the elevation change between survey end points is always a positive number.

To calculate gradient, divide rise by "run" (run is the distance between downstream and upstream measuring points) and multiply by 100 to obtain percent gradient. Using the above example over a 50 m length between end points, 0.5 m/50 m x 100 % =1.0% gradient (Harrelson et al. 1994).

4. Stream Bank Stability [1]

Definition

Stream and river banks limit the lateral movement of water. Typically the bank areas can be identified by a change in substrate and a break in slope between the channel bottom and the stream banks. In many streams the slope of the bank exceeds 45^0 (Platts et al. 1987).

Bank stability is a rather imprecise term that refers to the propensity of the stream bank to change in form or location over time. In alluvial channels the stream and river banks tend towards a dynamic equilibrium with the discharge and sediment load. The bank material, vegetation type, and vegetation density also affect the stability and form of the streambanks (Platts 1984). Change in any one of these factors is likely to be reflected in the size and shape of the stream channel, including the banks.

Even in undisturbed streams some bank instability usually occurs. In valleys with a defined floodplain there is often lateral migration through bank erosion and point bar accretion (Leopold et al. 1964 and Ritter 1978). In V-shaped valleys there is less opportunity for lateral migration, and

[1] Taken directly from MacDonald et al.(1991).

bank instability may stem from the input and eventual removal of obstructions emanating from fallen trees, landslides, or debris flows.

A higher incidence of bank instability can be initiated by natural events that disrupt the quasi-equilibrium of streams or by human disturbance. Extreme floods, wildfires, and landslides are three examples of short-term disturbances likely to affect channel form and bank stability. Climatic and tectonic change are two long-term processes that affect discharge, sediment load, and channel stability, but the time scale of these changes is well beyond the range of current water quality monitoring efforts.

Relation to Designated Uses

Bank stability can be an important indicator of watershed condition and can directly affect several designated uses. Unstable banks contribute sediment to the stream channel by slumps and surface erosion. Because all the material from an eroding streambank is delivered directly into the stream channel, the adverse impact of bank instability can be much greater than the adverse effects of a comparable area of eroding hillslope.

Although in some cases the erosion of one bank will be matched by deposition on the opposite bank, streambank erosion caused by management activities generally will increase stream width. The corresponding increase in stream surface area allows more direct solar radiation to reach the stream surface, and this will raise maximum summer water temperatures. In most cases an eroding streambank will provide little or no cover for fish.

Actively eroding streambanks also support little or no riparian vegetation, and the loss of this vegetation adversely affects a wide range of wildlife species (Raedeke 1988), reduces available forage for wildlife livestock, and reduces the long-term input of organic matter into the aquatic ecosystem. Both the increase in summer water temperatures and the loss of fish cover along an eroding streambank will be exacerbated by the reduction in riparian cover.

Response to Management Activities

The management activity that probably has the greatest impact on streambank stability is grazing (Platts 1981). A reduction in the timing and intensity of grazing in the riparian zone often results in a decrease in channel cross-section area, an increase in channel depth, and an increase in vegetation along the channel banks. All these changes suggest an increase in streambank stability, a reduction in sediment inputs into the stream channel, and an increase in the density of the riparian vegetation.

Increasingly stringent regulations have greatly reduced the direct adverse effects of forest management activities on those streams that have fish, are used for domestic water supply, or otherwise are granted a high level of protection. Small headwater streams and ephemeral channels generally do not have the same level of protection, and this can result in forest harvest and other management activities having a direct, adverse impact on bank stability. A large number of management activities can indirectly affect bank stability, as any change in the size of the larger (channel-forming) flows or in the size and flux of sediment is likely to alter channel morphology and hence bank stability.

Measurement Concepts

Standard procedures to evaluate bank stability have not been developed. Many stream monitoring programs focus on bank instability rather than bank stability, as eroding streambanks are often easier to identify and measure. Different monitoring programs have developed a variety of procedures to evaluate bank stability, and these range from qualitative, visual estimates to detailed measurements of each bank failure. Procedures developed by the USFS to identify sample plots for measuring streambank stability are illustrated in Figure D, and a USFS procedure for locating streambank angle and stream shore depth is depicted in Figure E.

Perhaps the most widely used procedure related to bank stability is the method developed by Pfankuch (1978) to evaluate stream channel condition. This system uses 4-6 parameters to evaluate the condition of the upper stream banks, the lower stream banks, and the channel bottom. These parameters are empirically weighted, and many of them are directly related to bank stability. Summing the scores for all 15 parameters in Table 2 yields an overall rating for the stream channel (Pfankuch, 1978). Its use in the Pacific Northwest is sometimes criticized because it regards large woody debris as a destabilizing factor. Such comments do not demonstrate that the general method is faulty, but suggest that alterations in the parameters and scoring are needed as the technique is transferred to other areas and we gain an improved understanding of fluvial geomorphology.

A simpler procedure focusing solely on streambank stability is described in Platts et al. (1983, 1987). This technique assigns the bank along a specified cross-section one of four stability classes according to the percentage of the bank covered by vegetation and rocks, and the size class of the rock material. The estimated percentage of the bank protected against fluvial erosion by rocks and vegetation provides a numerical rating of streambank stability.

Figure D: Schematic of Sample Plots Along Transect
(USFS 1996)

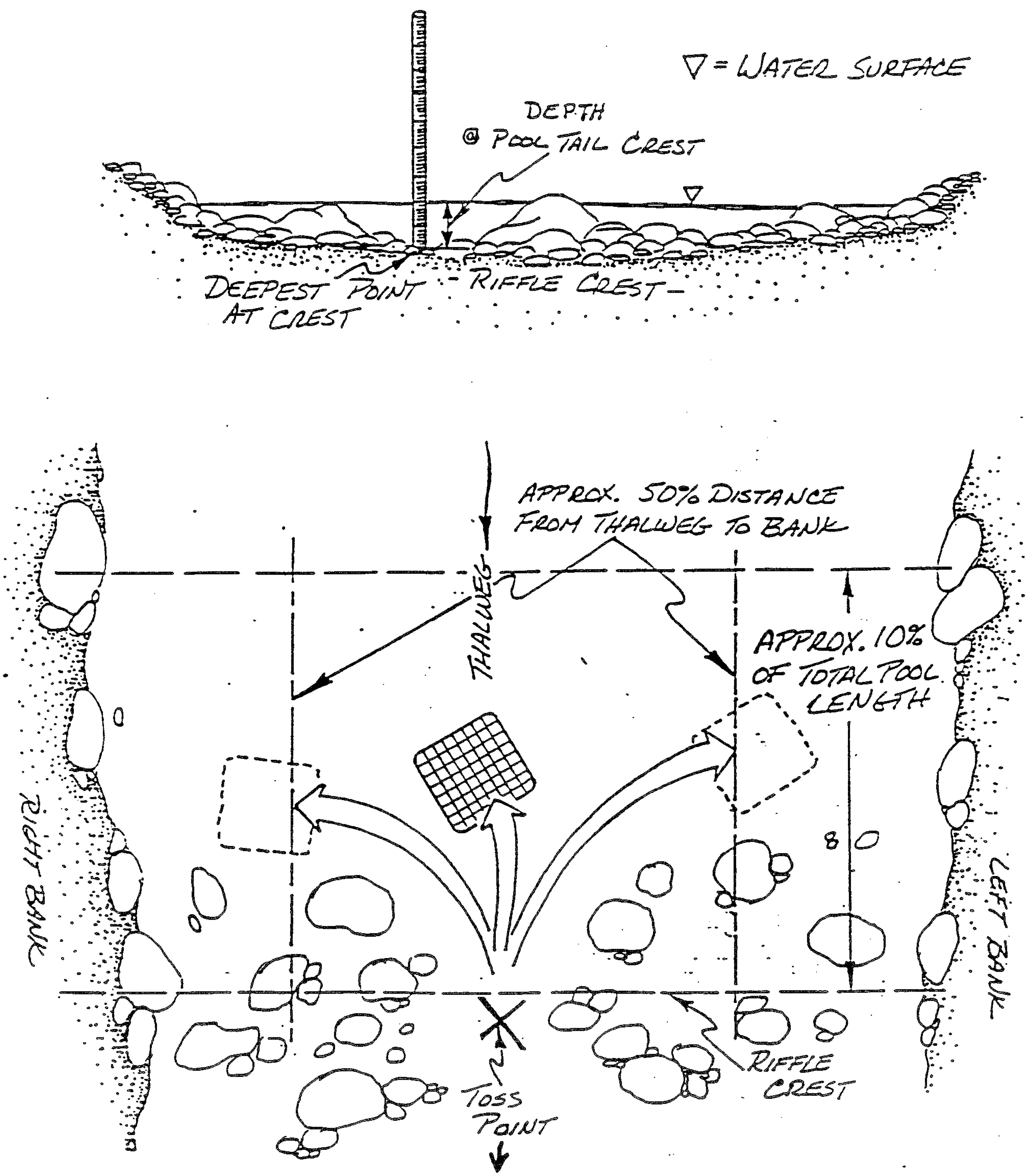


Figure E: Demonstration of Locating Bank Angle and Stream Shore Depth
(USFS 1996)

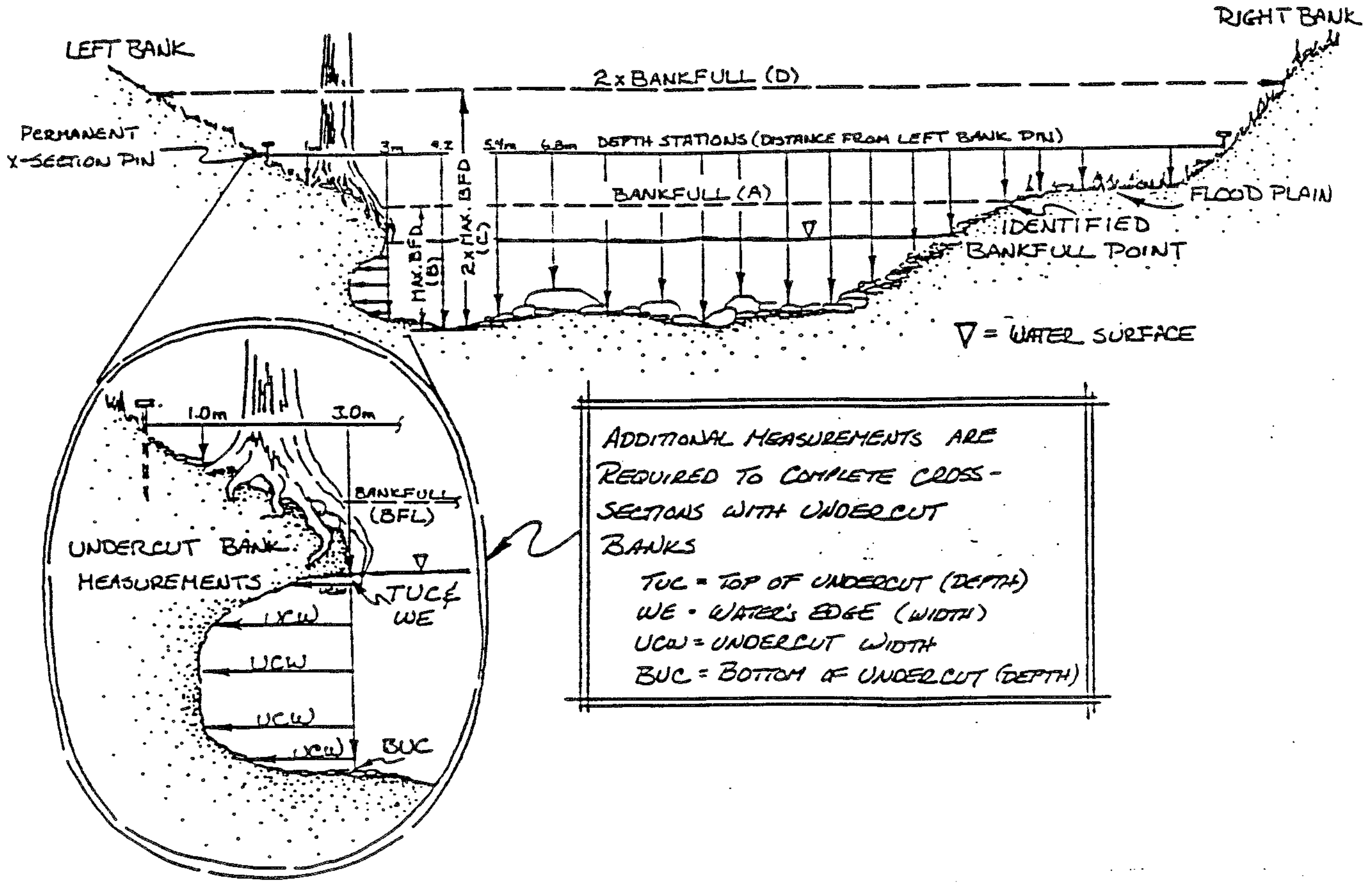


Table 2. Parameters and range of values used for evaluating stream channel condition and stability (Pfankuch 1978).

Channel location / Parameter	Range of values
Upperbank	
Sideslope gradient	0-8
Mass wasting potential	0-12
Debris jam potential	0-8
Vegetative cover	0-12
Lower bank	
Channel capacity	0-4
Bank rock content	0-8
Obstructions and flow deflectors	0-8
Bank cutting	0-16
Sediment deposition	0-16
Channel bottom	
Angularity of bed particles	0-4
Brightness of bed particles	0-4
Consolidation of bed particles	0-8
Stability and size of bed particles	0-16
Amount of scour and deposition	0-24
Aquatic vegetation	0-4

Standards

No standards for bank stability have been established or proposed.

Current Uses

Pfankuch's (1978) channel condition and stability procedure has been widely used by the U.S. Forest Service. Other monitoring programs have also taken elements from this rating system and incorporated them into their own stream evaluation forms (Ralph 1989) and G. Luchetti, pers. comm., King County, WA). Although the selection and weighting of the parameters have never been rigorously tested, the wide use of this procedure suggests a certain level of acceptance. One advantage is its accessibility to people with relatively little technical training, and it seems to provide relatively consistent results (Pfankuch 1978). The arbitrary selection and weighting of parameters means that it should be modified according to local needs and experience, but this is rarely done.

Assessment

Streambank stability is an easily assessed parameter that can be used to indicate whether a particular stream has been disrupted from a quasi-equilibrium state. This disruption could be due to natural causes, or alterations in discharge, sediment load, or vegetative cover caused by management actions (e.g, urbanization, grazing, forest harvest). Some of the major limitations to the use of bank stability include: (l) lack of accuracy and precision (Platts et al.1987), (2) inability to identify specific causes of bank instability (Platts et al. 1987), (3) varying sensitivity among stream reaches, and (4) difficulty of separating natural causes and management impacts.

The lack of accuracy and precision is partly a function of the techniques being used. The visual estimation techniques described by Platts et al. (1983, 1987) are likely to have greater uncertainty then the multi-parameter approach of Pfankuch (1978). One cannot conclude that a change in bank stability has occurred until the observed change significantly exceeds the error in the rating system, but this error is rarely recognized.

The cause of bank instability may be difficult to determine, particularly when there is more than one factor. Grazing has the most direct and obvious impact on bank stability (Platts 1981), and this may mask other management impacts. Discharge and sediment yield tend to be controlled by upslope processes, and so the linkage to bank stability may not be immediately obvious.

Bank stability may be most useful as a quick indicator of a shift in the equilibrium of the stream system. An observed increase in bank instability should then trigger more intensive investigations. By combining an inventory of management activities with specific measurements of other parameters such as the bed material particle size, it is usually possible to determine the primary cause(s) of the observed disequilibrium. Often, however, bank instability may not be the most sensitive indicator of disturbance. Changes in the suspended sediment load, for example, may not immediately trigger bank instability, but could still have a detrimental effect on spawning success. Similarly, grazing impacts are likely to be expressed through the riparian vegetation before they lead to bank instability. Nevertheless, the ease of evaluating bank stability suggests that it can play an important role, particularly when budgets for assessment and monitoring are severely limited (McDonald et al. 1991).

5. Thalweg [1]

Definition

The "thalweg" is defined as the deepest part of the stream channel at any given cross-section. A thalweg profile refers to the topographic variation of the thalweg along the stream axis (i.e., in the upstream-downstream direction). This can be measured with regard to the water surface or surveyed against a fixed elevation. A survey of the thalweg with regard to a benchmark elevation also can be referred to as a longitudinal profile. Sometimes, however, a longitudinal profile can refer to a profile along the streambank or water surface. Thus thalweg profile and longitudinal profile often are synonymous, but this may not always be the case.

Elevation data from a surveyed thalweg profile can be used to calculate an average channel gradient. Thalweg profile data show the variation in bed structure (e.g., pools, riffles, etc.) along the surveyed reach. In particular, a thalweg profile can accurately delineate pools along the main channel and be used to determine residual pool depth. Both a cross-section and a thalweg profile can provide data on the overall degradation/ aggradation of the stream channel, but only a thalweg profile can provide quantitative information on the structure and gradients along the stream axis. The length of the thalweg profile also can be compared with the length of the valley floor to yield the thalweg sinuosity. In most cases the thalweg sinuosity will be similar to the channel sinuosity.

Relation to Designated Uses

The average gradient as determined by a thalweg profile is an important criterion for classifying streams. The channel gradient also is needed for a wide variety of hydraulic calculations and models, including water surface profiles and sediment transport capacity. Local gradients are important for estimating shear stress and small-scale hydraulic behavior.

Thalweg profiles provide detailed and unambiguous data on pool depth and pool length. These pool parameters can be directly related to fish habitat value (Bisson et al. 1982). Changes in flow velocities and stream depths due to changes in the bed profile will affect the number and type of aquatic organisms. An estimate of channel sinuosity is useful for stream classification (Rosgen 1985, and Cupp 1989), and for helping to evaluate one of the ways in which energy is dissipated in streams (Schumm 1977).

Effects of Management Activities

Changes in sediment load or peak runoff can affect the overall elevation of the thalweg profile through aggradation or degradation, and alter the structure and habitat types along the profile (Beschta and Platts 1986). More specifically, an increased sediment load can affect local gradients

[1] Taken directly from MacDonald et al.(1991).

by filling in pools and by reducing the gradient within steep riffles (Sullivan et al. 1987). As discussed previously pool infilling can be a relatively sensitive indicator of adverse management impacts. A decline in sediment tends to result in channel incision, and this has been observed downstream of newly built dams (Shen and Lu 1983, Bradley and Smith 1984), and after a moratorium on timber harvest (Megahan et al. 1980).

A change in the size of peak flows also can be expected to affect the thalweg profile by altering the sediment transport capacity. An increase in peak flows will tend to increase the stream channel width and depth (Schumm 1977), but the interactions among bed material transport, bank erosion, sediment inputs, and discharge often make it difficult to predict the precise effect of a change in one factor on the change in other factors. Beschta and Platts (1986) suggest that stream channel morphology is affected more by management-induced changes in sediment than management-induced changes in flow.

Measurement Concepts

A thalweg profile is a relatively simple monitoring technique, and it is relatively inexpensive to obtain in small streams. Surveying equipment is needed to obtain sufficient accuracy. In areas with dense riparian vegetation, the task becomes more difficult because of the problems associated with obtaining a clear line of sight. Surveying a thalweg profile can be difficult on bends, as the thalweg usually coincides with the area of greatest velocity and may lie beneath an undercut bank. In larger streams a boat and other equipment may be needed to accurately locate and measure the thalweg profile.

No standard length exists for a thalweg profile, but a general rule of thumb is that it should extend for approximately 20-30 channel widths or 2-3 meander segments. In general it should include at least several distinct pools, but the exact location and length will depend upon the objectives of the monitoring and the expected changes in stream channel morphology.

The length of a thalweg profile, when divided by the equivalent length of the valley floor, yields the thalweg sinuosity. The thalweg sinuosity will be similar to, or may slightly overestimate, the channel sinuosity. For short profiles it may be possible to directly measure the valley floor length. Longer thalweg profiles should start and stop at easily defined locations such as bridges so that the valley bottom length can be measured from topographic maps. Thalweg profiles longer than 2-3 meander lengths should be used if an accurate estimate of sinuosity is needed.

Standards

At present no standards or regulations exist regarding a thalweg profile. The state of Idaho, however, is considering the use of thalweg profiles and residual pool depths to monitor sediment production.

Current Uses

In the past thalweg profiles have been measured primarily in the context of research on stream hydraulics and fish habitat. Relatively little long-term monitoring data are available. Nevertheless, surveyed thalweg profiles are attracting increasing interest because of their relative sensitivity to increased sediment inputs, and their ability to quantitatively and unambiguously assess changes in stream channel morphology.

The same studies that support the use of pool parameters as indicators of management effects also can be used to support the use of thalweg profiles. As with any monitoring technique, thalweg profiles are subject to the problem of separating man-induced impacts from natural changes. However, a thalweg profile may have some advantage in that it relies on detailed measurements in a particular location. This enables one to separate individual changes in the stream profiles (e.g., the breakdown of a particular debris dam from the general trend).

Assessment

Thalweg profiles are a specific technique for assessing certain types of changes in stream channel morphology over time. A thalweg profile is complementary to channel cross- sections in that it evaluates changes along the length of a reach, and it offers a possibly more rigorous approach to monitoring the frequency, depth, and length of pools. On the other hand, a thalweg profile cannot provide as much detail on all the different habitat types which are of concern to fisheries biologists (e.g., pocket water, runs, etc.) and which might occur along a typical thalweg profile. Thalweg profiles also can yield data on sinuosity and gradient; both of these are useful for classifying streams and a variety of other purposes.

The disadvantages of thalweg profiles are similar to the other parameters used to monitor channel characteristics. One major problem is how to link an observed change in the stream channel with a particular management activity. This problem is particularly acute for the channel morphology parameters, as their values are the integrated result of a large number of interacting processes. This is why a combination of parameters may be needed to properly evaluate the changes due to management activities and determine the possible cause(s).

Another disadvantage is the problem of setting a threshold or standard for allowable change. In the case of thalweg profiles, one should not just look at an overall change in the gradient, but attempt to interpret all of the smaller changes in bed slope and pool size. Both qualitative and quantitative evaluations may be needed, as streams vary greatly in their sensitivity and response to management impacts (Sullivan et al. 1987). The more recent stream classification schemes (Cupp 1989; Frissell 1986; Montgomery and Buffington 1993, and Rosgen 1985) may help to interpret thalweg profile data by stratifying the data according to stream type. This will facilitate a comparison among streams, and thereby help to determine the expected range of variability for a particular type of stream (MacDonald et al. 1991).

6. Riffle Armor Stability Index- RASI [1]

Introduction

RASI is believed to reflect the amount of sediment in transport relative to a stream's capacity to transport it. RASI is an acronym for Riffle Armor Stability Index. It is a measure of the cumulative percent of the riffle particles (measured using a modified Wolman pebble count) that are less than or equal to the size of the largest annually mobile particles on the riffle. Numbers greater than 80 are believed to indicate unnaturally high sediment loads. Values range from less than 20 to 100. As sediment loads increase, the surface of a riffle exhibits a greater proportion of smaller particle sizes (Platts and Megahan 1975; Lisle 1982, and Dietrich et al. 1989). The size of the largest mobile particles stay constant (or possibly increase if upslope disturbance changes the flow regime). The result is that the proportion of the riffle's surface particles smaller than the largest mobile particles increases. The advantage of RASI over a standard D_{50} measurement is that it allows direct comparison of streams with dissimilar hydraulic properties (Kappesser 1992). A detailed discussion of the sampling methods are discussed below.

The effects that increases in fine sediments have on fish have been studied for decades, although the results remain controversial when applied to natural streams (Chapman 1988, Hicks et al. 1991). The conflicts within the literature probably result from the inherent complexity associated with differences in the morphology of streams, the different requirements of species, and the changing habitat requirements of individuals at various life stages. Much information exists which suggests that high proportions of fine sediments are adverse to fish. Excessive sedimentation has been shown to reduce pool volumes, reduce the oxygen inflow or limit the diffusion of metabolic wastes from redds, and can physically impair the emergence of fry from the gravel (Gangmark and Bakkala 1960; Coble 1961; Koski 1966; Bjornn et al. 1977; Meehan and Swanston 1977; Crouse et al. 1981; Everest et al. 1987; Chapman 1988, and Scrivener and Brownlee 1989). Reductions in intragravel space can also influence the micro habitat for aquatic insects (considered as a primary food source for fish or as a component of biodiversity), or can reduce the diversity of cover for juveniles by burying coarse cobbles (Cordone and Kelley 1961, and Bjornn et al. 1977). Therefore, the composition of stream gravels is an important factor in assessing habitat condition.

RASI represents the surface particle size distribution within a riffle relative to the size of material normally transported by bankful flows (Kappesser 1993). It is the cumulative percent of the riffle substrate that is less than or equal to the size of the largest mobile particle on the riffle's surface. Increased quantities of fine particles on a streambed's surface are thought to represent a channel that is transporting a high sediment load (Platts and Megahan 1975,and Lisle 1982). Dietrich (1989) reported that the surface layer may increase its percent of fine sediments solely as a result of an increased supply of sediment, even when the particle sizes being transported remain constant. Therefore, the amount of fines in the riffle bed compared to the largest mobile particle in the stream

[1] Taken directly from Knopp (1993).

is believed to represent the current dynamics of a channel's sediment transport process, providing a sensitive, quantitative evaluation of whether the stream is aggrading or degrading (Kappasser 1992).

Site selection:

Riffles should be selected to represent a section of stream a minimum of three channel widths long with a uniform bed slope, composition and channel width. Riffle sections with depositional features from dammed pools or mass failures should be avoided. Three riffles per reach should be considered for measurement.

Sampling:

The RASI number is determined by taking two separate measurements:

1) Surface composition is estimated with a modified Wolman pebble count. A riffle transect is established within the bankfull channel and 200 individual measurements of the size of the bed material are made. The particle size data is tallied by Udden-Wentworth size classes. A 200 count is used instead of the more usual 100 count because the RASI method interpolates between categories, which requires a greater reliability within individual classes.

2) The largest particles available for seasonal transport are determined by measuring the 30 largest cobbles found on an adjoining point bar or by measuring the largest mobile particles directly from the riffle. The geometric mean of the sample collected to determine the largest mobile particle is then compared to the riffle distribution to determine what cumulative percent of the riffle is equal to or finer then the largest mobile particle. The percent of the bed that is finer than the bar count's geometric mean is the RASI number. RASI values normally range from 50 to 100, with high range numbers reflecting a riffle with a high surface fine composition (normally considered adverse) and low numbers indicating a bed with few fines. It has been postulated by Kappesser that the bar count represents the largest size transported at bankfull, and that it reflects a unique hydraulic characteristic of the watershed's streams. However, little empirical evidence exists to support or discredit this theory. Data collected in Idaho and in California do result in values that vary with upslope disturbance so as to suggest that this approach is measuring an aspect of the riffle composition that does vary with sediment loads (Knopp 1983). Additional work is needed to develop this concept further.

The RASI method is sensitive to the determination of the largest mobile particle size. Two methods are presented here for it's determination to: 1) quantify in reaches with recent alluvial deposits, and 2) allow quantification in channels with few recent deposits.

1) Determination of the largest mobile substrates from depositional features:

The largest mobile particle size should be collected in a recent depositional feature that is proximate to the riffle used for the pebble counts. Features adjacent to the riffle are ideal. Care must be taken to ensure that the feature contains a blend of size classes in order to allow a meaningful selection of the largest particles available for annual transport. Features that exhibit a confined range of size classes, such as sand bars, should be avoided.

Measure the intermediate axis of the 30 largest sized particles that are clearly part of the recent deposition. In shallow deposits, care must be taken to avoid sampling cobbles that are part of the less mobile bed, or features deposited as a result of major flood events. If 30 particles of approximately the same size class are not present in a deposit, select another proximate feature and continue there. Do not start selecting successively smaller sizes as the largest class is measured. Particles with a flat or platy profile should also be avoided.

2) Determination of the largest mobile substrates from the riffle:

This approach should be used when fresh depositional features are not present in a reach. The objective is to select the largest particles that are annually mobile. Selection of rocks to represent the largest annually mobile substrates should be based upon the following:

- Riffles in Rosgen B or C channels are desirable for sampling. Alluvial reaches with cobble - gravel substrates. Slopes from 1 to 4 percent.

- Sample only within that portion of the riffle that exhibits a uniform slope. Use the same reach sampled for the pebble counts.

- Rocks should be free on the bed surface and not embedded within the substrate. This is best determined by wiggling the rocks by hand. The largest loose rocks are assumed to be annually mobile.

- If some of the substrate are relatively free of algae, moss or lichens, while others are not, select only those rocks that are relatively clean.

- Avoid selecting any unusual rocks that are uncommon in the bed.

- Avoid flat or platy substrate.

Normally the sample should be collected from within the entire riffle and should be fairly uniform in size. Care must be taken to avoid sampling substrate that is too small. A wide variation in sizes indicates inconsistency in your sampling (100 mm to 50 mm is probably too large a range, while 100 mm to 80 mm is acceptable or 80% of your largest sample). The alternate problem is sampling substrate that is too large. Often, in healthy streams large material will exist on the bed which is not mobile during average annual flows. The material is the result of large flood deposits or as the result of the stream cutting through old features, winnowing away the fines, leaving material too large for the stream to transport. These pieces are normally embedded and not loose to the touch. If they can not be easily distinguished by the method mentioned previously, then select another reach. Also, reaches that exhibit an unusually confined geometry (fast runs, rectangular channel cross section, large cobble to small boulder substrates) should also be avoided. A general comment appropriate for consideration is that this parameter is often considered to be highly subjective and not as good as the D_{50} Pebble Count (Knopp 1993).

7. Particle Size Distribution [1]

1. Introduction

The composition of the stream bed and banks is an important facet of stream character, influencing channel form and hydraulics, erosion rates, sediment supply, and other parameters. Each permanent reference site includes a basic characterization of bed and bank material.

The composition of the stream bed (substrate) is an important factor in how streams behave. Observations tell us that steep mountain streams with beds composed of boulders and cobbles act differently from low-gradient streams with beds of sand or silt. It is possible to document this difference with a quantitative description of the bed material, called a pebble count.

2. Definition

The most efficient basic technique is the Wolman Pebble Count (Wolman 1954). This requires an observer with a metric ruler who wades the stream and a note taker who wades or remains on the bank with the field book. Particles are tallied by using Wentworth size classes in which the size doubles with each class (2, 4, 8, 16, 32, etc.) or smaller class intervals based on 1/2 phi values (4, 5, 6, 8, 11, 16, 22, 32, etc.). The latter classes are generally used when detailed particle size data are needed (Harrelson et al.1994).

Procedure

The estimate of the largest particle size moved in the stream is based on measuring one hundred (100) of the largest particles encountered in a fresh bar or other depositional area. Since only recently moved particles should be sampled, particles that are embedded, differ in color from most of their peers, or support epiphytic growth or attachments, should be discarded. The depositional feature is searched thoroughly to locate and measure the largest particles that appear to have been recently moved.

Depositional areas may occur in different locations in the stream (point bars, central bars, or behind

[1] Taken directly from MacDonald et al.(1991).

constrictions. The downstream portion of the point bar should be sampled. For each particle sampled, the intermediate axis is measured and recorded to the nearest millimeter. A flexible, transparent ruler may directly measure the particle size. The intermediate axis is the axis defining a circle which is the smallest through which the particle may fit. Obviously, a shorter axis allows only a portion of the particle to pass while a larger axis passes the particle in several orientations.

Information analysis is performed by use of custom application software created by Kappesser (1992, 1993a, 1993b). The software determines the maximum sediment size transported by the study reach (Rae 1995).

3. Relation to Designated Uses

The particle size of the bed material directly affects the flow resistance in the channel, the stability of the bed, and the amount of aquatic habitat (Beschta and Platts 1986). Because the flow resistance is one part of the overall energy loss in streams, the mean particle size can be related to the other factors that control energy loss in streams such as the stream gradient (Hack 1957) and the sinuosity.

Although a direct relationship exists between the size of the bed material and the stability of the bed, other factors such as the slope, depth, local turbulence, and bank characteristics will affect whether a particular particle will be moved. The frequency of bedload transport is of critical importance for fish spawning and the other organisms utilizing the stream bottom for cover, foraging, or as a substrate.

The size of the bed material also controls the amount and type of habitat for small fish and invertebrates. If the bed is composed solely of fine materials, the spaces between particles are too small for many organisms. Coarser materials provide a variety of small niches important for small fish- especially juvenile salmonids and benthic invertebrates. Coarser materials also have more interflow through the bed, effectively expanding the suitable habitat for benthic invertebrates and other organisms down into the stream bed, and facilitating salmonid reproduction. Platts et al. (1979) found a close relationship between geometric mean particle size and gravel permeability. Hence a decrease in the median particle size of bed material will decrease the permeability of the bed material, and this will tend to decrease intergravel dissolved oxygen (DO) concentrations. Even a small decline in inter-gravel DO can severely affect the survival of salmonid eggs, alevins, and invertebrates.

4. Effects of Management Activities

One of the most common and probably the most damaging effect of forest management activities is to decrease the median bed material particle size. Forest road building and improper maintenance tend to increase erosion and sediment delivery rates. Most of the material reaching the stream channel as a result of human activities will be sand-sized or smaller, unless landslides are caused The deposition of this material in the stream channel then has a series of adverse effects.

There is some evidence that an increased deposition of fine materials may be partially self-perpetuating. In some cases the onset of bedload transport is delayed when the interstitial spaces are filled with fine sediment A reduced frequency of bedload transport then provides more opportunity for the deposition of fine particles and fewer opportunities for fines to be washed out during high flows (MacDonald et al.1991).

If hillslope monitoring of the management activity traces sediment to the stream and no other source can be identified, then the differences can be attributed to management activity. However, impacts that occurred decades ago prior to management activities must be considered and evaluated. Historical impacts due to natural or man-made events could have been significant and subsequently contributed to the existing conditions within the assessment area.

5. Measurement Concepts

The characterization of bed material has been the subject of considerable study. Pebble counts are used to develop a particle size distribution for the bed surface material, while bulk samplers are used to determine the particle size distribution in the surface or subsurface. The selection of a measurement technique depends on the time and equipment available, as well as on the objectives of the sampling.

Following is one sampling procedure suggested by Rae (1995).

1. Select a reach on or near the cross-section and indicate it on your site map. For stream characterization, sample pools and riffles in the same proportions as they occur in the study reach. For other purposes, it may be appropriate to sample pools and riffles separately. Measure a minimum of 100 particles to obtain a valid count. Use a tally sheet to record the count.

2. Start the transect at a randomly selected point (perhaps by tossing a pebble) at bankfull elevations (not necessarily the present water level). Averting your gaze, pick up the first particle touched by the tip of your index finger at the toe of your wader.

3. Measure the intermediate axis (neither the longest nor shortest of the three mutually perpendicular sides of each particle picked up) . Measure embedded particles or those too large to be moved in place. For these, measure the smaller of the two exposed axes. Call out the measurement. The note taker tallies it by size class and repeats it back for confirmation (Rae 1995).

Pebble counts are a systematic method of sampling the material on the surface of the stream bed (Wolman 1954). Typically a grid or transect as suggested in Figure H is established, and the sizes of 100 or more particles are tabulated to establish a frequency distribution. Since each sampled particle represents a portion of the bed surface, the frequency distribution represents the percent of the stream bed covered by particles of a certain size, and not the percent by volume or weight. Particles smaller than 2-4 mm are difficult to measure in the field and may be classified only as fines (Wolman 1954). Other studies estimate the size of fine particles by feel or comparison to reference samples. Pebble counts are simple and rapid, but there may be some bias against selecting very small or very large particles.

Mc Neil Sampler

A second approach to determining the particle-size distribution of the bed material is by obtaining and sieving bulk samples. A McNeil sampler is the most common means to obtain a bulk sample (Valentine 1995). The McNeil sampler is a metal, tube-shaped device that is driven into the streambed to the desired sampling depth. Coarse material within the sample tube is extracted by hand. By capping the tube when extracting the core, most of the fine sediments are retained (McNeil and Ahnell 1964, and Platts et al. 1983).

Freeze Core Sampling

A third major technique to obtain a bulk sample is to freeze a sample of the bed material using liquid $C0_2$ or liquid nitrogen. The frozen sample is then thawed and sieved in order to obtain the particle size distribution. One major advantage of frozen cores is that they retain the vertical structure in the sample, thereby permitting comparisons between particle-size distributions at different depths. Platts et al. (I983) discuss both these techniques in detail and conclude that (1) neither the McNeil sampler nor the freeze core technique is adequate when substrate particles larger than about 25 cm are present, and (2) neither takes a completely representative sample.

One difficulty with evaluating the extensive literature on bed material particle size is the variation in the systems used to classify particle sizes. Some investigators have used many size classes, while others have used as few as six size classes (Platts et al. 1983,and Chapman and McLeod 1987). Each size class can be associated with a specific term (e.g., sand, gravel, cobbles, boulders), but these terms are not necessarily consistent (Platts et al. 1983). The most common classification system in the U.S. is presented in Table 3.

The selection of the sampling technique should be determined by the objectives of the sampling. Characterization of the bed material can be done most easily by using Wolman pebble counts or by measuring the percent of the bed surface covered by fines. McNeil core samples and freeze cores both are useful in assessing the suitability of the substrate as spawning gravel. Freeze cores can be used to determine the variation in the particle-size distribution with depth. Comparisons between the surface and subsurface samples may indicate a change in the sediment load (Dietrich et al. 1989; MacDonald et al. 1991). Recent research in Wyoming has showed that a 20 cm wide by 24 cm long shovel performed equally well or better than other methods in portraying the known size distribution of gravel in laboratory conditions (Young et al.1991) and field conditions (Grost et al.1991, and Valentine 1995). This technique would be less expensive than the McNeil sampling method.

Figure F: Zig-Zag Pebble Count Procedures
(USFS 1996)

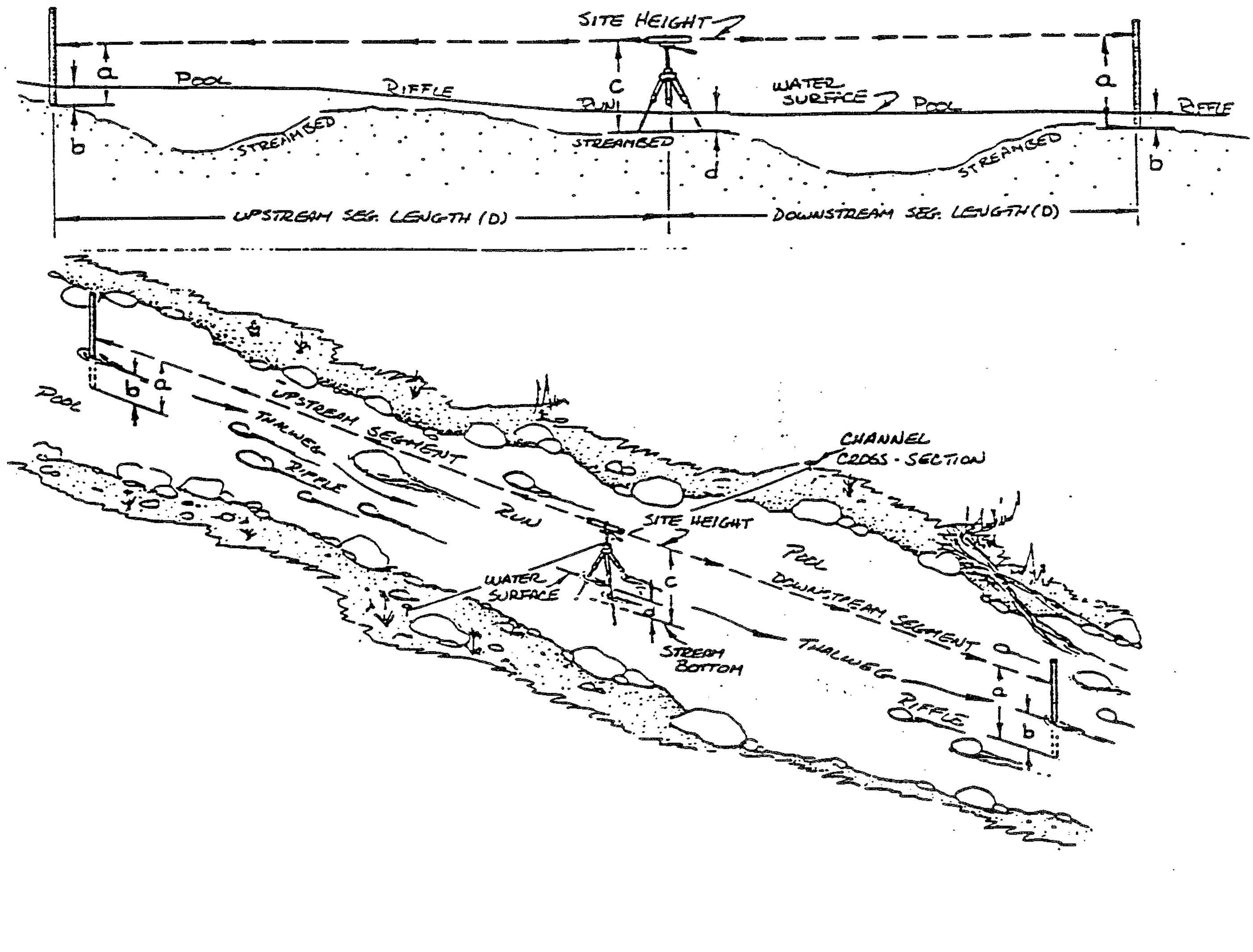


Table 3 Pebble Count Size Classes. Particles smaller than 2 mm in size are placed in a class defined as "<2 mm." Pebble counts can be made using grids, transects, or a random step-toe procedure. A step-toe procedure is used here.

Table 3. Pebble Count Size Classes
(Harrelson et al. 1994)

Size Class	**Size Range** (mm)
Sand	<2
Very Fine Gravel	2-4
Fine Gravel	4-6
Fine Gravel	6-8
Medium Gravel	8-11
Medium Gravel	11-16
Coarse Gravel	16-22
Coarse Gravel	22-32
Very Coarse Gravel	32-45
Very Coarse Gravel	45-64
Small Cobble	64-90
Medium Cobble	90-128
Large Cobble	128-180
Very Large Cobble	180-256
Small Boulder	256-512
Medium Boulder	512-1024
Large Boulder	1024-2048
Very Large Boulder	2048-4096

8. Surface vs. Subsurface -Particle Size Distributions [1]

Definition

The bed material in alluvial stream channels consists of mixed grain sizes. Often the surface of the bed is coarser than the underlying material. This armoring or pavement has been attributed to a settling of the smaller particles down into the bed during active transport (Parker and Klingeman 1982), and selective transport of finer particles when the larger particles are immobile (Sutherland 1987). Surface coarsening has been observed downstream of dams when bedload was eliminated (Shen and Lu 1983, Bradley and Smith 1994).

An alternative to this "equal mobility" explanation for the armoring of gravel-bedded streams and rivers is that armoring is a result of the sediment supply being less than the sediment transport capacity (Kinerson and Dietrich 1989). If one assumes that the subsurface particle size distribution is similar to the particle size distribution of the bedload (Parker et al. 1982) and that the banks are relatively resistant to erosion, then the difference between the surface and subsurface particle size distribution should be quantitatively linked to the sediment supply (Dietrich et al.1989). A dimensionless ratio, q^*, has been defined as the estimated bedload transport rate for the median grain size on the bed surface divided by the estimated bedload transport rate for the median grain size of the subsurface material (Dietrich et al. 1989).

Under this hypothesis streams with a high sediment load and no surface coarsening should have a high q^*, while streams with a low sediment load should have a well developed coarse surface layer and a low q^*. With an increased sediment load, streams that initially had a low q^* would experience a fining of the bed surface material. With a higher q^*, relatively little of an increased sediment load could be accommodated by a fining of the bed surface, and the stream would be more subject to aggradation, pool filling, and overall channel instability. An increased sediment supply also would lead to a greater proportion of the stream bed being occupied by finer materials (Kinerson 1990).

Mean particle size in the bed material is inversely correlated with habitat suitability for aquatic insects and fish (Chapman and McLeod 1987). By reducing pool depth and pool volume, sediment deposition reduces the suitability of a stream for adult fish. Increasing embeddedness and surface fines reduce winter carrying capacity for salmonids in the northern Rockies. Comprehensive reviews of the effects of sediment on aquatic organisms are presented in Chapman and McLeod (1987) and Everest et al. (1987). Scrivener (1988) summarizes the forest management-sediment-fisheries interactions for the Carnation Creek study in coastal British Columbia.

[1] Taken directly from MacDonald et al.(1991).

Effect of Management Activities

The Carnation Creek study in coastal British Columbia monitored changes in particle size distribution in the top (0-15 cm) and bottom (15-30 cm) layers of bed material over a 13-year period. Within and below the area of intense streamside logging, the accumulation and cleansing of fines was highly responsive to both the input of sediment and the occurrence of runoff events. Chronic documentation resulted in fines penetrating deeper into the streambed, and these deeper layers were much slower to recover because scour to these depths was much less frequent. Hence the annual rate of change in the particle-size distribution declined with increasing particle size and increasing depth. Significantly, 8 years after the intensive logging treatment the changes in gravel composition were still accelerating, and fine particles were still accumulating in the deeper layers (Scrivener 1988).

Measurement Concepts

Data on the particle-size distribution in the surface and subsurface layer can be analyzed in several different ways. The simplest method is to compare the median (D_{50}) particle size of the surface and subsurface materials. Since quite different particle-size distributions can have a similar D_{50} (Platts et al. 1983), comparisons generally should incorporate some measure of the variation in the particle-size distribution, such as the D_{84} and the D_{16} (where D is diameter, and the number is the percent of particles that are smaller than the specified percentage). In cases where the particle size distribution of the surface and subsurface layers is known, one should consider developing a statistical measure of the differences between the two distributions.

Standards

No standards for the relationship between surface and sub- surface particle-size distributions have been established or proposed.

Current Uses

Values of q* have been determined for a series of flume experiments (Dietrich et al. 1989) and a number of streams in California with a widely varying sediment supply (Kinerson and Dietrich 1989). The data collected to date shows that rivers and streams with a high sediment supply generally lack a coarse surface layer and have a q* close to 1.0. Considerable local variation occurred within streams reaches. In sediment-rich streams, for example, areas with an armor layer and a low q* could be found immediately downstream of debris jams and other obstructions which functioned as sediment traps (Kinerson and Dietrich 1989). Chapman and McLeod (1987) also noted large differences in particle-size distributions between salmonid egg pockets and immediately adjacent areas. This instream variability should be minimized by selecting relatively straight, featureless reaches with little form roughness.

Assessment

The relationships between sediment supply, sediment transport capacity, and the surface and subsurface particle size distribution are in a state of active investigation. Both theoretical considerations and preliminary field data suggest that differences between the surface and subsurface particle-size distributions can be used to monitor changes in sediment supply. However, characterizing the subsurface particle-size distribution is not a simple task, but is very time consuming and difficult to do and this may ultimately limit the usefulness of q* or an associated measure as a monitoring technique.

The primary advantage of comparing surface and subsurface particle-size distributions is that this appears to provide an immediate assessment of the sediment transport capacity in relation to the sediment supply. The use of q* normalizes the surface conditions against the particle-size distribution and predicted bedload transport capacity of the subsurface layer. This yields a single index for evaluating current conditions and comparing different streams. However, if one is concerned solely with changes over time and has time-trend data available, the surface particle-size distribution could serve as the primary monitoring parameters.

In summary, a variety of studies suggest a direct relationship between an increase in sediment supply due to land use and a change in the surface particle-size distribution. In most cases, however, there already have been some adverse land use impacts, and no data are available on the predisturbance particle-size distribution of the bed surface. Under these circumstances a comparison of the surface and subsurface particle-size distributions may yield a quantitative measure of the sediment supply relative to the sediment transport capacity. The variability of such a measure within a particular stream reach, and the complexity of sediment transport in alluvial channels, mean that additional work will be needed before q* or a similar measure can be adopted as a standard for monitoring management impacts.

9. Embeddedness [1]

Definition

In streams with a large amount of fine sediment, the coarser particles tend to become surrounded or partially buried by the fine sediment. Embeddedness quantitatively measures the extent to which larger particles are embedded or buried by fine sediment (see Figure G). Embeddedness quantitatively measures the extent to which large particles are imbedded or buried by fine sediments. The measure was first used to quantify stream sedimentation in the 1970s and early 1980s (Klamt 1976, and Kelly and Dettman, 1980). Since then the method has undergone a series of modifications and has been used as an indicator of the quality of over-wintering juvenile salmonid

[1] Taken directly from MacDonald et al.(1991).

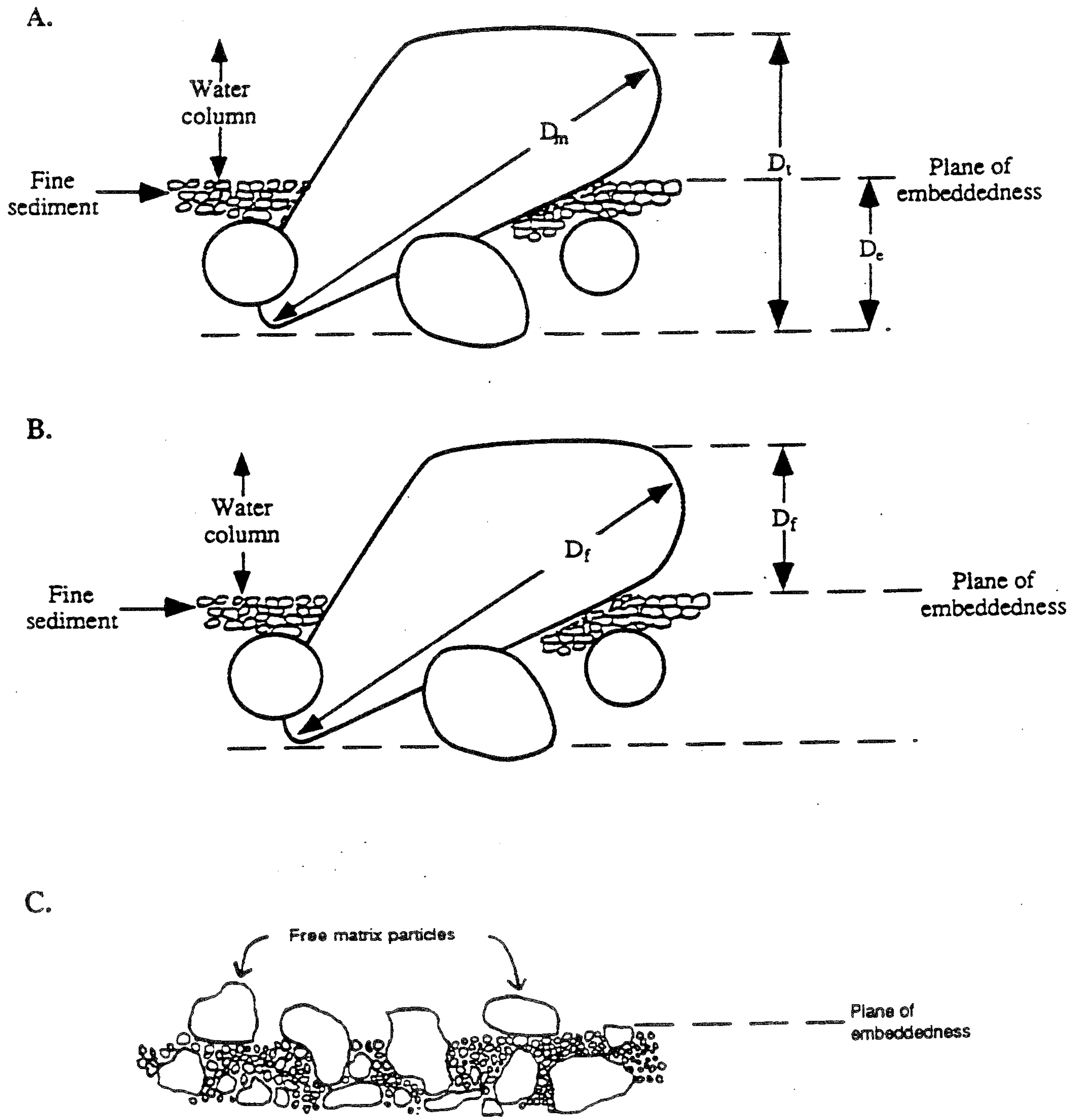
habitat (Munther and Frank 1986; Burns and Edwards 1987; Torquemada and Platts 1988; Potyondy 1988). The method and its application continue to be improved and standardized by researchers in Idaho (Skille and King 1989) and Montana (Kramer 1989).

Currently variation exists in the suggested minimum and maximum size of rocks to be measured and in the specific feature being measured. Most researchers define the technique as cobble embeddedness, even though measurements typically are made on all rocks with a primary axis between 4.5 cm (very coarse gravel) and 30 cm (small boulders). Torquemada and Platts (1988) modified the method to measure rocks as small as 1.0 cm, and the inclusion of these smaller particles led them to use the term embeddedness rather than cobble embeddedness.

The difficulty in measuring cobble embeddedness and the high variability of individual measurements have stimulated research into a series of related measurements. One alternative is to measure the height of the rocks above the bed surface, and this is termed "total free space" (Fig. G. [B]). Conceptually this is similar to bed roughness, and it is an indicator of the area protected from the current. Such areas are important fish rearing and macroinvertebrate habitat. This measurement also has been termed "living space" by Skille and King (1989) and "interstitial space" by Kramer (1989).

A third embeddedness measure (Fig.G. [C]) is the percent of free matrix particles. Free matrix particles are defined as those rocks (typically 4.5-30 cm along the primary axis) having zero embeddedness. Percent free matrix is calculated by dividing the number of free matrix particles by the total number of similarly sized particles within the sampled area. Percent free matrix particles correlates closely w ith percent embeddednes s (Burns and Edwards 1985; Torquemada and Platts, 1988; Munther and Frank 1986,and Potyondy, 1988).

Figure G: Schematic representation of the three main embeddedness measurements-embeddedness, free space, and free matrix particles. D_m represents the length of the primary axis. A. Embeddedness for a single particle is equal to D_e/D_t. B. Free space for a single particle is equal to D_f (note: $D_f = D_t - D_e$). C. Free matrix particles (MacDonald et al. 1991).



Relation to Designated Uses

Cobble embeddedness has both biological and physical significance. Biologically, areas with a high embeddedness have very little space for invertebrates or juvenile fish to hide or seek protection from the current. The accumulation of fines also fills in the spaces between larger particles, and this limits the interstitial habitat. Similarly, the reduction in surface area associated with increasing embeddedness (decreasing total free space) limits the attachment area for periphyton.

The physical effects of embeddedness are similar to the effects of a decrease in bed material particle size. Increasing embeddedness decreases channel roughness, and the resulting reduced bed friction losses will have repercussions on the stream hydraulics and overall channel morphology.

Response to Management Activities

The use of cobble embeddedness for water quality monitoring presumes that increasing embeddedness reflects an increased input of fine sediments to the stream channel. Measurements of embeddedness on 19 tributaries to the South Fork Salmon River in Idaho indicated that streams in heavily roaded and logged watersheds had a significantly higher cobble embeddedness than undisturbed watersheds (Burns and Edwards 1985). No differences were found between undisturbed and partially disturbed watersheds.

Measurement Concepts

The basic procedure for measuring embeddedness is to select a particle, remove it from the streambed while retaining its spatial orientation, and then measure both its total height (Dt) and embedded height (De) perpendicular to the streambed surface (Fig. G. A). Percent embeddedness is calculated for each particle until at least 100 particles are measured. Individual embeddedness values are averaged to yield a mean embeddedness value.

The time required to evaluate embeddedness can be substantially reduced by measuring the height of free matrix particles and counting the remaining embedded particles. Since the relationship between percent cobble embeddedness and percent free matrix particles may vary according to stream order, geology, climate, etc., inferences about percent embeddedness cannot be made from free matrix data until the interrelationship has been defined for that site.

If the monitoring objective is to evaluate changes in the deposition of fine sediments, the interstitial space index (ISI) may be the preferred embeddedness parameter. Both the ISI and percent embeddedness can be calculated from one set of field measurements.

Standards

The State of Idaho Water Quality Bureau currently is proposing a cobble embeddedness criterion. This specifics that cobble embeddedness in fry overwintering habitat should not exceed natural baseline levels at the 95% confidence level. Baseline levels of cobble embeddedness are to be determined in similar watersheds that are unaffected by nonpoint sediment sources (Harvey 1989).

Current Uses

On going, unpublished studies by federal and state agencies are measuring embeddedness as one means to assess the effects of land management activities on streams. Use of the revised measurement techniques and more intensive sampling should allow a better evaluation of the usefulness of embeddedness to monitor the effects of management activities.

Currently embeddedness is being measured in a number of National Forests, particularly in Idaho and Montana. Embeddedness also is part of the Forest Practices BMP Effectiveness Monitoring Program in Idaho. In Washington four classes of embeddedness are being visually estimated in the Timber Fish-Wildlife stream survey program. These field applications will help evaluate the methodology for measuring embeddedness and determine its usefulness for assessing the effects of past and present management activities.

Assessment

The strong interest in embeddedness as a monitoring parameter is due to the recognition that sediment often is the most important pollutant from forest management activities in the Pacific Northwest and Alaska. Hence there is a great need for reliable methods to evaluate sediment inputs and the resultant effects on the designated uses of the water. Embeddedness has shown promise, but the immediate need for a monitoring technique has resulted in widespread use and adaptation before cobble embeddedness could be adequately field-tested and validated. Users should be aware that the various embeddedness techniques are likely to undergo further changes and improvements, and this could severely limit the comparability of data collected over time (MacDonald et al. 1990).

10. V^{STAR} (Pool Sediment) [1]

V^{STAR} measures the relative quantity of fine sediment in pools. The V^{STAR} sampling technique is a way to measure the sediment load in a particular pool between the armor layer on the bottom and the surface of the water. The following discussion is adapted from Knopp (unpublished, 1994) and Lisle (1992).

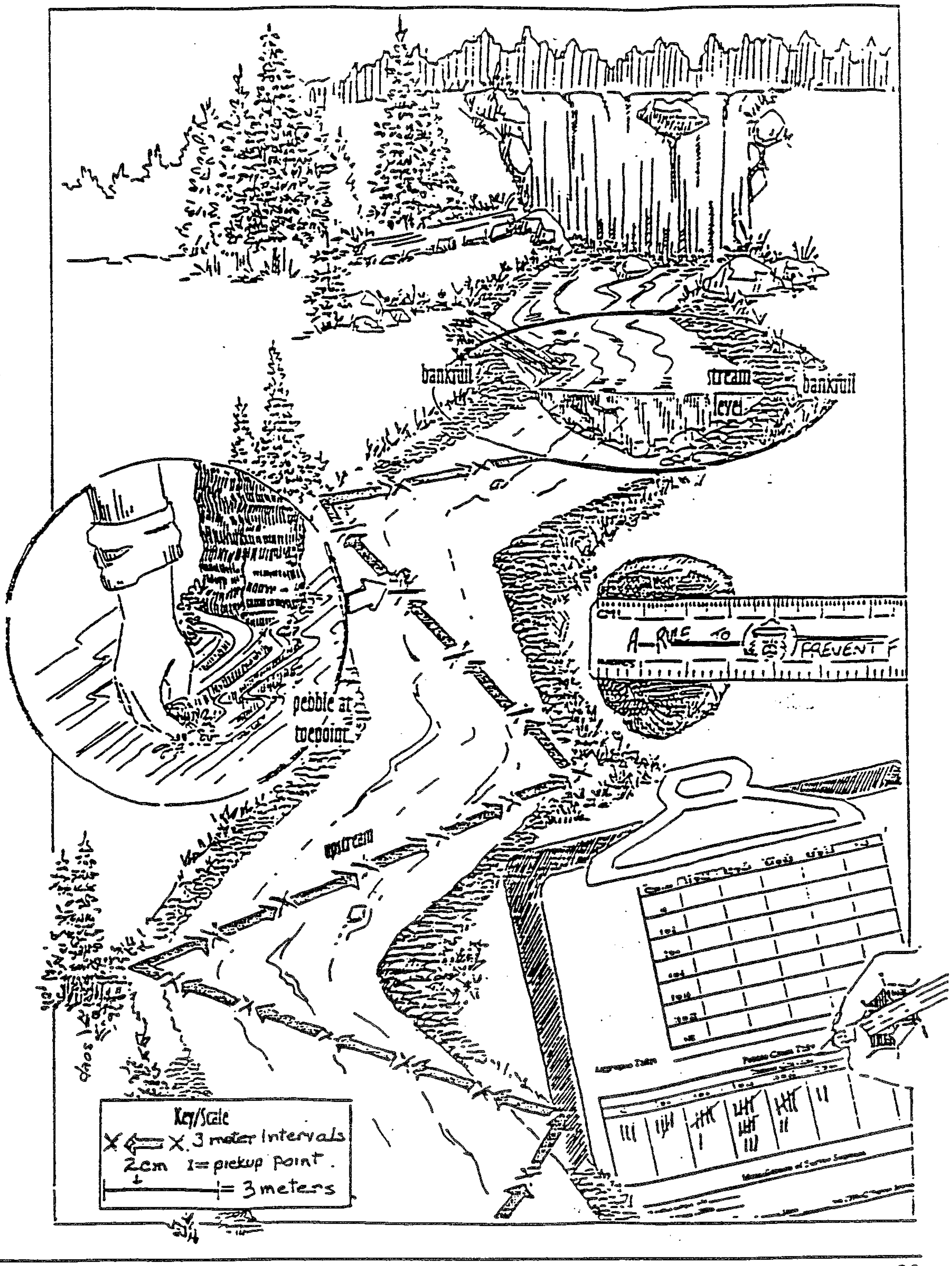
The riffle crest measurement is used to determine the residual depth of a pool, and residual volume

[1] Taken directly from MacDonald et al.(1991).

of a pool (the volume or depth of a pool, including sediment, filled to the bank of spilling). The riffle crest is found usually in an irregular arc at the transition between the lower edge of the pool (end of 0% gradient portion) and the riffle or next inventory unit below the pool. The pool's lip, or riffle crest, is determined by measuring the depth of water at the deepest part of the pool's outflow. If the deepest section is indistinct, then a series of 4 to 6 measurements should be taken along the crest arc, and these averaged to estimate the pool's riffle crest depth. (Refer to Figure H for an illustrated method of locating the pool tail area that is utilized by the USFS.) If the deepest section of the channel is obvious, then determine the riffle crest depth with one or two direct measurements. If the riffle crest occurs in loose, fine sediment, then the measurement must be taken to the bottom of the sediment. Probe the pool tail gravel above and below the apparent riffle crest to estimate the location of the actual buried riffle crest. Four to 6 measurements should be taken. However, the riffle crest should occur on the hard scoured channel, in which case the measurement rod should not be forced into the gravel.

Transects are located to define the morphology and sediment deposited in the pool. Find the most representative locations by initial probing with the V^{STAR} penetration rod. A tape is used to determine the overall pool length and provide a reference for the cross sections. The meter tape should be anchored to the head and tail of the pool. The tape should be left in place while the cross sections are measured. A minimum of 4 transects are required for each pool. More complex pools may require 8 or more transacts. Cross sections are defined with a second tape stretched at right angles to the longitudinal tape or a stadia rod laid perpendicular to the lengthwise tape. If the pool is curved, measurements are taken in distinct segments (the lengthwise tape is always straight, but may be in several sections at successive angles).

Figure H: Locating Pool Tail Area
(USFS 1996)



Penetration rod sampling is at variable intervals of about 0.5 meters so as to measure approximately 10 points across the pool. All measurements start from the same stream bank. Sample points include depth changes in the cross section and as necessary to best define the pool's sediment cross-section. Unusual or peculiar site characteristics are recorded on the areal diagram.

Each measurement along a transect defines the center of a measurement cell defined by 3 numbers: distance from the bank, water depth, and depth to the bottom of the scoured pool from the surface of the water. The cell extends halfway to the next transect (unless a different proportion is specified during data analysis program execution). The cells associated with the first and last transects extend to the start or end of the pool. If the pool narrows at the head or tail, transects should be placed near the ends to minimize measurement error. The largest volume in the pool occurs where the residual depth is greatest. Errors in shallow sections are relatively unimportant.Therefore, place transects to minimize errors resulting from the data analysis program area algorithm and to emphasize water and sediment volumes.

Sediment collected in a pool is measured by probing the pool bottom with a steel rod at several points along several transects. The rod is pushed into the sediments by hand until the firm resistance of the scoured channel (the armor layer) is encountered. The armor layer at the bottom of the sediment column is typically at the limits of rod penetration by hand. Intermediate layers can sometimes be felt, but they should be ignored if the rod can be firmly pushed through. If clay is encountered, the penetration should stop at the depth of the clay. Clay can be easily recognized, both by feel and by the residue it leaves on the V^{STAR} rod. Unlike the resistance of the scoured layer, clay yields slowly but retards rod penetration. After extraction, traces of clay remain on the rod and in the inscribed lines and numbers. Buried wood fragments typically are penetrated by the rod but rod removal is difficult. Wood fragments yield slowly to determined penetration and do not leave material on the extracted rod. Sometimes the rod encounters a rock laying in the sediment but above the scour depth. If a scour depth is grossly less than the two adjacent measurements, another penetration may be placed close by on the transect to determine if the resistance is local and not the anticipated bottom layer.

Measurements are taken through the bank above and away from the surface of the water to a point where the pool depth is less than the riffle crest depth. There often arises the situation in which there is zero water depth, but the probe can still reach water which lies under the surface. This water, and sediment, is considered to be in the pool up to the point where the water measured under the sediment is less than the riffle crest depth.

Undercut banks are difficult to measure. Direct measurements can be made by probing through the bank or using a shorter V^{STAR} penetration rod. If neither of these two options are feasible, measure the horizontal distance of the undercut with the rod, and estimate the water and pool depth by placing the rod in at an angle, measuring the water and pool depth, and then subtracting what was estimated to be the distance gained by placing the rod at an angle. Note that in pools where the undercut volume is insignificant, then no measurement (direct or estimated) may be necessary.

Information analysis is performed by running the custom application software written by Chris Knopp (1994). The software produces a V^{STAR} index for each sampled pool within the stream reach and an index for the entire reach. The software exports a data file which is run through DesignCad-2 for creation of pool transect cross-section diagrams.

11. Turbidity / Suspended Sedimentation Concentration [1]

Definition

Turbidity refers to the amount of light that is scattered or absorbed by a fluid (APHA 1980). Hence turbidity is an optical property of the fluid (Hach 1972), and an increasing turbidity is visually described as an increase in cloudiness. Turbidity in streams is usually due to the presence of suspended particles of silt and clay, but other materials such as finely divided organic matter, colored organic compounds, plankton, and microorganisms can contribute to the turbidity value of a particular water sample.

Prior to about 1970 turbidity was measured primarily in Jackson turbidity units (JTU). Jackson turbidity units are determined by slowly increasing the depth of water in a clear cylinder until a candle flame placed under the bottom of the cylinder disappears into a uniform glow (Hach, 1972). Several problems are associated with JTUs: (1) usable range is 25 JTUs and greater; (2) turbidity due to dark-colored particles cannot be measured as too much light is absorbed; and (3) very fine particles are not measured (APHA, 1980). These problems have led to the widespread replacement of Jackson's candle turbidimeter with photoelectric turbidimeters.

Photoelectric turbidimeters measure turbidity in nephelometric turbidity units (NTU); they are able to accurately measure much lower levels of turbidity, and measurements generally are not affected by particle color (Hach 1972). These properties make photoelectric turbidimeters and NTU units the preferred method for measuring turbidity in streams. The differences in measurement techniques mean that there is no standard conversion between Jackson turbidity units and nephelometric turbidity units (APHA 1980).

Relation to Designated Uses

Most of the biological effects of turbidity are due to the reduced penetration of light in turbid waters. Less light penetration decreases primary productivity, with periphyton and attached algae being most severely affected. Declines in primary productivity can adversely affect the productivity of higher trophic levels (Gregory et al. 1987).

High turbidity levels adversely affect the feeding and growth of salmonids and other fish species.

[1] Taken directly from MacDonald et al.(1991).

Reduced mixing could trigger a series of adverse effects due to the lower concentration of dissolved oxygen in the unmixed deeper portions of rivers and lakes (EPA 1986b). Although this effect is unlikely to occur in the turbulent streams characteristic of most of the Pacific Northwest and Alaska, the increased tendency towards stratification in turbid waters could be significant in reservoirs, lakes, and other downstream areas. Higher turbidity levels also could reduce the solar heating of the streambed materials, but the high absorption of solar radiation in water means that this is applicable only in waters less than about 10 cm deep.

Effects of Management Activities

Most studies of the effects of management activities on streams have measured suspended sediment rather than turbidity, as suspended sediment concentrations are not dependent upon the types of materials in suspension. Suspended sediment also has the advantage of being in units that can be converted to total flux over time and then related to other components of the sediment budget (e.g., erosion processes, in channel sediment storage, and bedload transport). Hence the effects of management activities on turbidity generally have to be inferred from the relatively numerous studies that have monitored suspended sediment concentrations. Extrapolation from these studies is usually possible because of the relationship between the concentration of suspended sediment and turbidity.

In general, the same activities that generate large amounts of suspended sediment will more or less proportionally increase turbidity. However, in watersheds with coarse soils (i.e., little clay or silt), erosion and sediment yield rates can be relatively high while turbidity levels show only a moderate increase. Conversely, watersheds which primarily have clay or clay-like sediment sources could have consistently high turbidity levels but only moderate concentrations of suspended sediment; this is reportedly the case for some of the basalt watersheds in Idaho.

One of the few studies that used both turbidity and suspended sediment to evaluate the effects of road reconstruction and timber harvest was conducted on the east side of the Cascades in Washington. Road reconstruction during the summer of 1979 increased turbidity levels (in NTUs) by a factor of 25 and suspended sediment concentrations by a factor of nearly 50. During the following summer suspended sediment concentrations were elevated by about 50% as compared to the upstream control site, while there was less than a 15% increase in turbidity. In the third post treatment year, both suspended sediment and turbidity concentrations were lower at the downstream site than at the upstream control site. Timber harvest activities using a long span skyline system and variable-width riparian zones had no detectable effect on suspended sediment or turbidity (Fowler et al. 1988). These results suggest that, at least for the above watershed (which was described as having sandy to loamy soils), suspended sediment concentrations appeared to be more sensitive to disturbance than turbidity.

Measurement Concepts

Turbidity measurements are subject to the same considerations as measurements of suspended sediment (Brown 1983) because the most common cause of turbidity in forest streams is suspended sediment. With turbidity, however, there is an additional source of variation due to the different substances that can cause an increase in turbidity. At a particular site, for example, high turbidity levels might be due largely to organic acids at one point in time, while at another time the turbidity might be due primarily to silts and clays from earthflows or bank erosion. This variation in the sources of turbidity complicates comparisons between sites

Typically there is a strong relationship between turbidity and discharge. As in the case of suspended sediment, this relationship will vary by site, within storms (i.e., whether discharge is increasing or decreasing), and between storms.

Turbidity tends to be less sensitive to the sampling location within a stream than suspended sediments as turbidity is primarily a function of the smaller particles (silts, clays, and colloids). Hence the materials causing turbidity tend to be more evenly distributed within the water column and across the cross-section, and grab samples usually are considered to be sufficiently representative. It is recommended that samples be analyzed for turbidity within 24 hours (APHA 1980), as algal growth can cause an increase in turbidity. In forested areas it is often assumed that water temperature and water quality (e.g., paucity of nutrients) will inhibit or restrict algal growth, but protocols for sample collection and storage should consider this possibility. Sediment flocculation also can cause turbidity values to change over time.

Standards

Relative turbidity standards have been established in some states. California, for example, specifies that a timber harvest cannot increase turbidity by more than 20% above background. Alaska and Washington allow an increase of 5 NTU for domestic water supplies when the background turbidity is less than 50 NTU, and no more than a 10% increase in turbidity when the background level is greater than 50 NTU (Harvey 1989). The general criteria for the protection of freshwater fish and other aquatic life is that the depth of the photosynthetic compensation point should not be reduced by more than 10% from the seasonally established norm for aquatic life (EPA 1986b). As suggested above, the basic problem with enforcing these standards is that background levels are seldom defined and difficult to determine. This suggests that only continuing major violations can be unambiguously identified.

Current Uses

Probably the most common use of turbidity measurements is to monitor the quality of domestic water supplies. More frequent sampling is required as the measured turbidity approaches or exceeds the 1 NTU standard.

Turbidity often is used to monitor the effects of a specific management activity (project monitoring). Typically this involves a comparison of measurements taken upstream (control) and downstream (treated) of a particular project, such as the construction of a bridge, with the presumption that any increase in turbidity is due to that activity. This procedure is particularly effective during low flow periods when the background turbidity is both low and consistent. Assessing the effects during storm periods is considerably more difficult (i.e., less sensitive).

Turbidity measurements provide an indication of the amount of suspended material in the water, but the precise relationship between turbidity and the mass of suspended material depends on the size and type of suspended particles. This relationship must be established for each stream or sampling location, and simultaneous measurements of suspended sediment and turbidity must be made over the full range of expected discharges. In some cases a single relationship may apply at several sites, but this must be based on a careful statistical analysis of the data from each site. The relationship between suspended sediment and turbidity cannot be assumed to be stable over time, as changes in sediment sources or transport processes may alter the relative balance between suspended sediment and turbidity.

Assessment

Turbidity is relatively quick and easy to measure. Suspended sediment usually is the primary source of turbidity in forest streams in the Pacific Northwest and Alaska. Simultaneous measurements of suspended sediment and turbidity generally result in a relationship that can predict about 80% of the variation in suspended sediment concentrations from measured turbidity values. Thus turbidity can be used as a surrogate for suspended sediment concentrations. The relative case of measuring turbidity means that qualitative field observations and synoptic sampling can he used to identify specific sediment sources (source-search methodology) (MacDonald et al.1991).

Turbidity is regarded by many as being the single most sensitive measure of the effects of land use on streams. This is due partly to the fact that relatively small amounts of sediment can cause a large change in turbidity, and partly to the estimated accuracy of turbidity measurements (approximately±10%) (APHA 1980, and Brown 1983). Although the variation in turbidity with discharge generally is greater than 10% (Brown 1983), both the accuracy and variability of turbidity measurements compare favorably with other sediment parameters (suspended and bedload) as well as the channel characteristics. Turbidity measurements are particulary effective in the case of project monitoring (samples taken upstream and downstream of a particular management activity (Rae 1995).

Lewis and Eads (1996) conducted an extensive investigation into the effectiveness of turbidity sampling to estimate suspended sediment concentration in Casper Creek Experimental Watershed on the Jackson Demonstration State Forest in California. The following summary is quoted from the Watershed Management Council Networker newsletter dated 1996, volume 6, number 4 titled

"Turbidity-controlled suspended sediment sampling" and provides a brief explanation of some of their results:

"For estimating suspended sediment concentration (SSC) in rivers, turbidity is generally a much better predictor than water discharge, Turbidity is an optical measure of the cloudiness of water caused by light scattering from suspended particles, organics, and dissolved constituents. Although it is now possible to collect continuous turbidity data even at remote sites, sediment sampling and load estimation are still conventionally based on water discharge. With frequent calibration, the relation of turbidity to SSC can be used to estimate suspended loads more efficiently. The sampling can be automated using a programmable data logger which signal a pumping sample to collect SSC specimens, at specific turbidity thresholds. While our focus has been suspended sediment and turbidity, the method could also be applied for solute load estimation, using specific conductance in place of turbidity. The approach has potential for monitoring any water quality constituent whose concentration is better correlated with an easily measured (in situ) parameter, such as turbidity or conductance, than with water discharge.

The efficiency of such a system has been demonstrated (Lewis, 1996) using dense field records of SSC and turbidity collected at 10-minute intervals during five storm events in the Caspar Creek Experimental Watershed on the Jackson Demonstration State Forest in northern California. Caspar Creek is a small, mountainous, coastal watershed that exports predominantly fine sediment. In simulations, samples containing a mean of 4 to I I specimens, depending on storm magnitude, were repeatedly selected from each storm's record and event loads were estimated by predicting SSC from regressions on turbidity. Using simple lines, regression, the five storm loads were estimated with root mean square errors between 1.9 and 7.7%of the known loads, compared to errors of 8.8 to 23.2% from regressions on discharge. Sample sizes of five specimens were generally adequate to estimate the storm loads with root mean square error no greater than 5% of the correct value. For similar accuracy without turbidity, the best available estimation methods require sample sizes 3 to 10 times larger, hence are much more costly in terms of field work and lab processing costs.

In addition to facilitating load estimation, continuous measurement of turbidity provides a more detailed picture of sediment transport than is normally available. Complete records of turbidity and associated estimates of SSC are obtained. Sediment pulses are detected whether or not they are related to water discharge, and the turbidity threshold sampling procedure ensures that at least one SSC specimen will be collected during any significant pulse, The SSC values provide verification that the pulse was real and did not result from temporary fouling of the turbidity probe's optics. Pulses in the turbidity trace are often associated with sudden sediment inputs from events such as bank failures or debris flows. Such pulses provide an alert to watershed problems that may require closer investigation. If turbidity is monitored in nested watersheds, sediment pulses can be tracked as they move downstream.

It is important to remember that turbidity is an optical property, not a direct measure of SSC by volume or mass. A turbidity probe's sensitivity is related to the sensor design and the nature of the suspended material (Gippel 1995). At the Caspar Creek sites, we deploy a backscatter in situ sensor that projects infrared light into the water column. The amount of light reflected back to the sensor is influenced by the quantity of particles, their size, shape, and composition. For instance, sensitivity to clay particles is several orders of magnitude higher than sand. The relation between SSC and turbidity is quite good when particle sizes and types remain nearly constant or are well-related to SSC. Applying storm-by-storm calibrations improves load estimates by accounting for the temporal variability in the relation between SSC and turbidity caused by particle variations, incremental contamination of the sensor's optics, and sensor drift.

The feasibility of the sampling system is being tested at eight gaging stations in Casper Creek, where data have been collected continuously for the past winter. The equipment at each gaging station consists of a stream channel control structure, stilling well, pressure transducer, turbidity probe and housing, pumping sampler, and data logger. The sampling program in the data logger controls the collection of information from the pressure transducer and turbidity probe, and activates the pumping sampler at the appropriate turbidity thresholds. Programming demands on the data logger include calculating median turbidity and mean stage, evaluating rules for specimen collection, and logging data for subsequent retrieval. A high level language, such as BASIC, is desirable for ease of code generation, maintenance, and portability, Because few, if any, commercial data loggers fit these requirements, we built data loggers around a commercially available single-board computer. User interface circuits are designed and added via a stackable board, then all components are housed in a weather-proof enclosure. Data are retrieved from the data logger in the field with a palmtop computer during each site visit. A plotting program allows field personnel to check for valid program operation, examine stage and turbidity data for reasonable values, and detect equipment malfunctions. Although field visits have been reduced from previous studies, it is still desirable to visit sites during storms to check on equipment, remove interfering debris, and make manual measurements. At Caspar Creek, staff plates are read, depth-integrated SSC specimens are collected to calibrate fixed-intake pumped specimens, and discharge is measured to develop or validate stage discharge rating equations.

The position of the turbidity probe in the stream is critical. The probe should remain fully submerged during all flows of interest. We have designed probe housings that protect the sensor from damage, exclude ambient sunlight, and reduce the functional minimum water depth, We are currently evaluating two types of housings and three mounting systems. The design challenge is to maintain hydraulic efficiency and exclude large organics, but not introduce cavitation. Bio-fouling of submerged optic, is a commonly reported problem, typically degrading data 3 to 21 days after cleaning. A simple solution, if only storm data are of interest, is to mount the probe above inter-storm flows thus reducing opportunities for colonization. Another solution is provided by a manufacturer that offers a turbidity probe with an optical wiper that can be activated on command by the data logger.

The channel control structures at the eight gaging stations include two V-notch weirs, one rectangular section (rated by discharge measurements), and five Parshall flumes, each of which provides unique installation challenges. The watersheds vary from 21 to 424 hectares, flumes being sited in the smallest watersheds and weirs in the largest.

The smaller watersheds have very little depth of flow between storm events and present the greatest problem because the turbidity probes require complete submergence in order to function, yet they need to be above the level of bedload transport. To pond the water, funnel-shaped wooden structures were therefore constructed upstream of flumes with inadequate flow depths Astroturf was placed in the throat of the funnels to increase friction and the probes were placed in the converging portion of the funnels where the greatest water depths were observed.

At the gauging station with the rectangular rated section, the turbidity probe is mounted on a depth-proportional intake boom (Eads and Thomas 1983). A float on the surface end of the boom causes the boom to rise and fall, pivoting on the channel bed as the water depth changes and keeping the turbidity probe and pumping sampler intake at a fixed proportion of the water depth. This apparatus was installed with the intent of obtaining a more consistent relation between turbidity and average SSC in the cross-section. Use of a boom is most appropriate in streams where SSC mixing is incomplete.

At the weirs, the probes are mounted on the upstream face with the opening of the housing flush with one side of the V-notch. Holes drilled in the housing permit water to enter through the side and exit at the V-notch end. The higher velocity at the V-notch end creates a pressure differential which seems to be effective in maintaining flow through the housing.

Some experimentation was required this first winter with regard to turbidity thresholds, probe configurations, and software algorithms. For example, one of the tributaries was ch lower turbidity than any of the others and a special set of thresholds was only that gaging station to ensure that enough SSC specimens were collected to estimation. Despite the experimental nature of the operation during the first s look promising, especially at the weirs where the probe is nearly always submerged during flows of interest. Bio-fouling was not a problem at any of our stations, partly because of the type of streams, but also because we routinely cleaned the optics between each storm, and at least once every two weeks. Relations between SSC and turbidity were generally linear and often had remarkably little scatter. We have reduced the number of pumped specimens collected at each gaging station to about one-sixth the number we formerly collected using a discharge driven variable probability sampling method described by Thomas (1985); and the load estimates, at least during larger storm events, are of comparable quality. In addition, we have been able to obtain much more detailed records of sediment transport that have alerted us to active erosion in one of the tributaries" (Lewis and Eads 1996) .

Suspended Sediment Concentration

Definition

Suspended sediment refers to that portion of the sediment load suspended in the water column. This, at least conceptually, is distinct from bedload, which is defined as material rolling along the bed. The relative size of particles transported as bedload and suspended sediment will very with the flow characteristics (e.g., velocity, bed forms, turbulence, gradient) and the characteristics of the material being transported (e.g., density, shape),.

Suspended sediment also should be distinguished from wash load. The latter term refers to particles that are washed into the stream during runoff events, and that are finer than the particles found in the stream bed (Ritter 1978). By definition the wash load is finer than the bed material load, and the wash load is considered to remain suspended in the length of the fluvial system (Linsley et al. 1982).

Relation to Designated Uses

Numerous laboratory studies have documented the adverse impacts of fine sediment on benthic invertebrates as well as salmonid reproduction and growth (Chapman and McLeod 1987).

Reduced gravel permeability can inhibit salmonid reproduction by reducing the concentration of dissolved oxygen and by entrapping alevins or fry. Also an excess of fine sediment can adversely affect habitat availability.

Direct effects of suspended sediment on salmonids occur only at relatively high concentrations. For example, Noggle (1978) found that the ability of coho salmon fingerlings to capture prey was reduced at suspended sediment concentrations of 300-400 mg L^{-1}. Mortality of salmonids occurs only at concentrations greater than 20,000 mg L^{-1} (Everest et al. 1987).

An increase in suspended sediment concentration will reduce the penetration of light, and a sustained high concentration of suspended sediment could reduce primary production if other factors are not limiting (Gregory et al. 1987). The effect of suspended sediment on water temperature has not been well documented. EPA's *Quality Criteria for Water* notes that suspended materials will increase heat absorption, particularly in the surface layer, and inhibit mixing between the warmer surface layer and the cooler underlying waters (EPA 1986b).

Suspended sediment will settle out in still or slow moving waters, and this can result in clogged irrigation canals and reduced reservoir storage capacity. In some cases, however, the deposition of suspended sediment can be regarded as beneficial. For example, deposition during high flow events provides additional nutrients and soil materials. This regular deposition is a major reason why alluvial valleys often are among the most productive and fertile farmlands

Effects of Management Activities

Forest management activities can affect the amount of suspended sediment in streams by altering both the erosion rate and the rate of transport into the stream channel. The range of management activities, and the number of erosion and transport processes, have resulted in an extensive literature on the relationship between forest management and sediment yield. However, recent changes in forest management practices may make it impossible to directly extrapolate from previous studies, even if they were conducted in a comparable environment (Everest et al. 1987). The following paragraphs provide a brief summary rather than a comprehensive overview.

Most comprehensive studies of the effects of forest management have found road-building and road maintenance to be a primary source of sediment (e.g., Brown and Krygier 1971; Megahan and Kidd 1972). This sediment can be eroded from the road surface (e.g., Reid and Dunne 1984), from road fills (e.g., Megahan 1978), or from slope failures associated with road construction and drainage (e.g., Duncan et al. 1987; Megahan and Bohn 1989). In most cases there is a sharp increase in sediment yield associated with road-building activities, and a rapid decline as roads stabilize (e.g., Beschta 1978). Increased sediment yields tend to be more persistent if the erosion stems from slope failures or surface runoff associated with continued heavy traffic.

Forest harvest can increase sediment yields by a variety of processes: surface erosion from landings, skid trails, and other compacted areas; slope failures triggered by removal of the tree cover, and surface erosion from burned areas or areas disturbed by site preparation activities (Swanson et al. 1987). Surface erosion can include both fluvial detachment and transport as well as dry ravel and surface creep (Swanson et al. 1987). Historic practices of disturbing the stream channel and removing large woody debris also have been shown to increase the amount of fine sedimentation in the stream channel (Bilby 1981; Megahan 1982). Removal of, or a reduction in, the riparian vegetation is a another mechanism by which forest management activities can increase the amount of fine sediments (e.g., Platts 1981). Grazing often exacerbates the effect of reducing the vegetative cover by simultaneously trampling the vegetation, compacting the soil. and trampling the stream banks (Gifford 1981).

Measurement Concepts

Suspended sediment concentrations are determined by obtaining a water sample, drying or filtering the sample, and then weighing the residual sediment. Concentrations are typically expressed in milligrams per liter (mg L^{-1}), and this usually is equivalent to parts per million (ppm) because 1 L of water has a mass of approximately 1 million milligrams. As sediment concentrations increase, however, the density of water exceeds 1000 g L^{-1}, and this causes an increasing divergence between milligrams per liter and parts per million.

The primary problem with measuring suspended sediment is how to sample in time and space. Estimates of the total amount of suspended sediment over time often are based on a presumed relationship between the concentration of suspended sediment and scream discharge, but this is by no means constant or reliable (e.g., Ferguson 1986). For example, suspended sediment concentrations for a specified storm event typically are much higher after a dry period than after an earlier, but recent, storm. Often suspended sediment concentrations are higher during periods of increasing discharge (i.e., the rising limb of the hydrograph) and lower during periods of decreasing discharge (i.e., the falling limb of the hydrograph).

Calculating the sediment load or sediment flux requires continuous discharge measurements. Porterfield (1972) provides detailed information an the procedures to obtain fluvial sediment discharge data, and provides a series of plots illustrating the variation in suspended sediment concentration over individual runoff events. Recent work by Cohn et al. (1989) and Walling and Webb (I982) illustrates the difficulties of accurately predicting suspended sediment concentrations from discharge data.

Most sampling schemes take individual or composite samples at regular time intervals (e.g., daily). Since high flow events are relatively rare, a sampling system based on equal time intervals will result in a large number of samples at relatively low flows, when suspended sediment concentrations are low, and very few samples at high flows, which is when most of the suspended sediment transport takes place. This is both inefficient and results in a high level of uncertainty with regard to the total sediment load. A stage activated system can greatly increase sampling efficiency by sampling only the higher flows.

Thomas (1985) suggests linking a microprocessor to a stream gage recorder and an automated sediment sampler in order to sample on a volume basis. This increases the number of high flow samples and reduces the number of low-flow samples, with a significant improvement in both efficiency and accuracy. While such systems illustrate the potential for improved sampling procedures, they may be too costly for most monitoring applications.

Standards

Water quality standards usually are set in turbidity units rather than the concentration of suspended sediment. The general criteria established by EPA is that "settleable and suspended solids should not reduce the depth of the compensation point for photosynthetic activity by more than 10 percent from the seasonally established norm for aquatic life" (EPA 1986b).

Current Uses

The importance and intuitive appeal of suspended sediment make it one of the more commonly used parameters for water quality monitoring. However, in most cases discharge also must be measured at the same time. In general, sampling should also focus on the high discharge events when the majority of suspended sediment is being transported. The unpredictable and short-term nature of most high runoff events suggests that if an automatic sampler is being used to take samples at constant time intervals, it may be best to take relatively frequent samples, and then discard those that do not correspond to any runoff event. Continuous discharge data are needed to interpret the suspended sediment data and estimate sediment loads and fluxes.

Simultaneous discharge measurements may not be necessary if the monitoring objectives are relatively limited. For example, construction of a bridge during summer baseflow periods may be monitored by comparing upstream and downstream suspended sediment concentrations. Such measurements will provide some indication of the effects of the management activity on suspended sediment concentrations, but in the absence of discharge data there will be no data on the total amount of sediment released by the project, or how the total load might compare to the total suspended sediment load during different storm events.

As previously discussed, the rigorous assessment of management impacts on suspended sediment requires data from replicated treated and untreated sites. Ideally data collected over time are used to determine the changes due to management, while data from matched sites are necessary to account for changes in the frequency and intensity of runoff events during the monitoring period. The tremendous temporal variability in suspended sediment concentrations suggests that paired (i.e., treated and untreated) sites are necessary to detect even relatively large changes.

Assessment

Suspended sediment is a very useful indicator of active erosion in a particular basin. However, the multiple processes involved in sediment storage and delivery preclude the use of suspended sediment concentrations as a quantitative measure of specific hillslope and channel processes. On the other hand, suspended sediment concentrations are very sensitive to landscape disturbance, and its conceptual simplicity gives it broad appeal.

The primary problem with using suspended sediment as a monitoring tool is its inherent variability. Representative samples are difficult to obtain, and suspended sediment concentrations vary tremendously over time and space. Thus it is often difficult to determine if there has been a significant increase in suspended sediment, and whether an observed increase is due to management activities or natural causes. These problems are exacerbated as one moves farther downstream because the impact of individual management activities is diluted and the amount of suspended sediment from other sources becomes larger.

Suspended sediment can and should be included in a monitoring plan provided it is recognized *a priori* that (1) identifying an increase in suspended sediment due to forest management requires several years of background data from the basin or site where management will occur and a similar set of data from comparable, unmanaged site(s); and (2) calculating suspended sediment fluxes and loads results in an inherent uncertainty of at least 25-50% (MacDonald et al. 1991).

12. Large Woody Debris [1]

Definition

Large pieces of wood in streams have been referred to by a variety of names including large organic debris (LOD), coarse woody debris (CWM), and large woody debris (LWD). The type and size of material included in this designation has varied according to the objectives of the person measuring the debris. Studies on the energetics of stream systems have included material as small as 2.5 cm in diameter as LWD (Harmon et al. 1986. However, studies of the effects of woody debris on channel morphology typically use a much larger minimum size for LWD -usually 10 cm in diameter and 2 m in length.

The amount of LWD in stream channels depends on a variety of factors. Stream size is an important determinant, with smaller streams usually containing more wood than larger systems (Swanson et al. 1982, and Bilby and Ward 1987). Riparian tree density is positively related to LWD amount in streams in eastern Washington (Bilby and Wasserman 1989). Bed characteristics also have been shown to influence LWD amount, as streams with boulder or bedrock substrates typically contain only about half the LWD compared to streams with finer substrates (Bilby and Wasserman 1989). Catastrophic events, such as major windstorms or landslides, also have a major impact on the amount and location of LWD in some stream channels (Keller and Swanson 1979, Bisson et al. 1987).

Stream size plays a major role in determining the size of LWD in stream channels as well as the amount of LWD. Generally, the average size (diameter, length, or volume) of LWD in a stream channel increases with increasing stream size (Bilby and Ward 1987). This increase is caused by the increased capacity of larger channels to move material downstream. Thus, in larger channels, smaller wood is selectively flushed from the system or deposited on the floodplains, leaving only the larger pieces. This causes a decrease in the amount of LWD, but an increase in average piece size. Pieces of wood with a low probability of being moved by the stream are the most important in influencing channel morphology (Bilby and Ward 1987). In general, pieces as long as bank full width in length or longer are regarded as being relatively stable (Bisson et al. 1987).

Relation to Designated Uses

LWD influences stream systems and their biota in a number of ways. Large wood has a major impact on channel form in smaller streams (Sullivan et al. 1987). The location and orientation of LWD can influence channel meandering and bank stability (Swanson and Lienkaemper 1978, Cherry and Beschta 1989). LWD tends to cause both a greater variability in channel width and an increase in average channel width (Keller and Swanson 1979). LWD also forms and stabilizes gravel bars (Lisle 1986).

[1] Taken directly from MacDonald et al.(1991).

LWD is often the most important structural agent forming pools in smalls streams. Bilby (1984b) reported that over 80% of the pools in a small stream in southwest Washington were associated with wood. Similarly, Rainville et al. (1985) found that 80% of the pools in a series of small streams in the Idaho Panhandle were wood-associated. While the relative importance of LWD in pool formation decreases with increasing channel width, wood in large rivers forms pools along the channel margins or in secondary channels, and these pools may be very important for fish populations (Bisson et al. 1987).

Another way in which wood affects channel shape is by forming waterfalls. Waterfalls form plunge pools and also influence sediment transport in streams. The greater the proportion of the drop in elevation of a stream caused by waterfalls the less efficient the system is at moving sediment downslope (Heede 1972). The proportion of channel drop accounted for by summing the heights of LWD-caused waterfalls ranged from 30 to 80% in streams in the western Oregon Cascades (Keller and Swanson 1979). In streams in the Oregon Coast Range, wood caused 6% of the total fall (Marston 1982). In western Washington the proportion of elevation drop caused by LWD was found to decrease with increasing stream size. LWD accounted for >15% of the elevation drop in stream channels <10 m wide, but <5% of the elevation drop in channels 10-20 m wide.

LWD also influences sediment transport in streams by forming depositional sites. Wood was responsible for storing half the sediments in several small streams in Idaho (Megahan and Nowlin 1976). The importance of wood in retaining sediment in small streams has been demonstrated by the release of very large amounts of material after removal or disturbance of LWD (Baker 1979, Beschta 1979).

LWD also can provide storage sites for leaves, twigs, and other organic material. In small streams in forested areas, this fine organic material can provide the bulk of the energy and materials entering into the aquatic food web. In the absence of LWD, much of the terrestrial organic matter entering the stream is flushed rapidly downstream with little opportunity for the biota to utilize this material (Bilby and Likens 1980).

LWD is one of the most important sources of habitat and cover for fish populations in streams. Most of the work documenting this function of LWD has been done on salmonids in the Pacific Northwest (Sedell et al. 1984; Bisson et al. 1987,and Sedell et al. 1988). Generally there appears to be a direct relationship between the amount of LWD and salmoid production; no known data indicate an upper end to this relationship (Bisson et al. 1987). One of the key functions of LWD with regard to fish production is to increase habitat complexity, and this helps ensure that cover and suitable habitat can be found over a wide range of flow and climatic conditions. LWD also may allow a finer partitioning of the available habitat. Pools formed by LWD, for example, are favored habitat by certain species and age groups of salmonids (Bisson et al. 1982). More complex wood structures, such as rootwads or small debris jams, attract more fish than single logs (Sedell et al. 1994, McMahon and Hartman 1989). In a number of experiments, wood removal has been demonstrated to reduce fish population densities (Lestelle 1978; Bryant 1983; Dolloff 1986; Elliott 1986; Bisson et al. 1987).

Several potentially detrimental effects are associated with LWD in streams. Historically, massive wood accumulations on larger rivers impeded navigation. Most of these accumulations were removed around the turn of the century (Sedell and Luchessa 1982). In most large rivers today, wood is found primarily along the channel margins or in off channel areas (Bisson et al. 1987) and therefore poses little hazard to navigation.

Large wood accumulations may form blockages to the passage of anadromous fishes. For many years this was perceived as a serious problem, and wood was removed from channels to prevent the formation of blockages. Extensive clearing of wood from smaller streams was conducted during the early 1960's to 1998's to reduce bank and bed scour and provide upstream passage for anadromous fish (Bilby 1984b, and Sedell et al. 1988). After channel clearing, much of the residual debris is unstable and is flushed from the stream channel, further reducing the amount of LWD (Bilby 1984b). However, many LWD accumulations which appear to be blockages at low flows are passable at higher discharges. In addition, these blockages normally occur in steeper channels where spawning and rearing habitat for anadromous fish is limited. Historical estimates suggest only 5-20% of available anadromous fish habitat was inaccessible because of debris blockages (Sedell et al.1994). Excess wood removal has been very detrimental to fishery habitat conditions.

Response to Management Activities

The length of time needed for riparian areas to produce LWD after harvest depends upon the size of the stream. Measurable contributions of wood from second-growth riparian areas did not occur until 60 years after harvest for third-order channels on the Olympic Peninsula (Grette 1985). Bilby and Wasserman (1989) indicate that it takes longer than 70 years for streamside vegetation to provide stable material to streams wider than 15 m in southwestern Washington. Thus larger streams are likely to be deficient in LWD for a longer period of time after timber harvest than smaller streams.

Measurement Concepts

Platts et al. (1987) provide a review of techniques to measure and map LWD. Selecting a methodology depends upon the objectives of the monitoring. Measurement techniques vary widely in terms of effort required, and they range from a simple enumeration of pieces to a detailed description of the characteristics and location of each piece. More detailed descriptions might include measuring the size of each piece, mapping the associated channel characteristics, and noting the location and orientation of each piece relative to a permanent benchmark. An alternative procedure for monitoring the stability of LWD is to tag and relocate each piece on an annual or storm basis.

Various criteria have been employed to delineate those pieces of wood to be included in an LWD survey. Most surveys include only those pieces which extend below the waterline at bankfull discharge and exceed some minimum dimensions. Surveys measuring the biomass of organic material in stream systems will use a smaller minimum size than studies of the influences of LWD on channel morphology or fish habitat (Harmon et al. 1986).

The cost of monitoring LWD increases considerably if volume or biomass estimates are needed, as this requires at least the length and diameter of each piece. Length measurements may include the entire piece or just that portion extending below the bankfull channel. Diameter may be measured at the mid-point of the piece or by averaging the diameter at both ends. Probably the most efficient procedure to determine volume or biomass is to visually estimate the length and character and then correct the visual estimates by measuring a subsample of the pieces (Hankin and Reeves 1988). Biomass of LWD also can be estimated with techniques derived from inventories of forest residues (Van Wagner 1968). This procedure inventories all LWD intersected by a series of cross-sections across the stream (Froelich et al. 1972, Lammel 1972), and is most applicable when the minimum piece size is relatively small. Special procedures or categories may be needed for measuring debris jams, standing trees, and snags within the stream channel (Platts et al. 1987).

Information on channel features associated with LWD is sometimes collected during surveys. Data may include the following:

- type of habitat unit or channel feature
- surface area, or volume of wood-associated pools
- surface area or volume of sediment stored behind LWD
- number and heights of waterfalls; and
- volume or biomass of fine organic matter

(Bisson et al. 1982,1987; Platts et al. 1983,1987; Bilby and Ward 1987)

<u>Standards</u>

Standards for LWD in streams have not been established for any state, although an attempt was made in the development of Washington's forest practice regulations to maintain wood levels at those seen in old-growth stands (Bilby and Wasserman 1989). However, LWD amounts and characteristics vary as a function of stream size, vegetation type, and other factors, thus inhibiting the establishment of strict numerical standards.

Most Pacific Northwest states have established Best Management Practices (BMPS) to control the adverse effects of forest management on streams channels and riparian areas. The most recent revisions of these BMPs have incorporated provisions for retaining LWD in streams and ensuring a continuing supply from the riparian area. Approaches currently in use or being considered included defining strips along the stream in which no harvest is permitted (e.g.,Oregon and Alaska), establishing specific numbers of trees to be left along the stream (e.g., Washington), or establishing a minimum basal area which must be retained along the stream (e.g., Oregon).

Generally, the regulations applying to larger, fish-bearing waters are more stringent than those used on smaller streams. On larger streams the disturbance of in-channel debris, or removal of standing timber from the riparian area, is generally prohibited or restricted. Thus LWD in the channel is protected, slash introduction during timber harvest is reduced, and the future source of LWD for the channel is retained.

Although some states have developed regulations to restrict forest management activities near smaller streams, frequently slash is introduced to the smaller channels during timber harvest. In cases where the amount of slash entering the channel is considered to pose a threat to down stream resources, cleaning of the channel may be required. Factors considered in deciding whether or not to remove a piece of wood from the channel include the size of the woody debris and the extent to which it deflects stream flow towards the banks.

Current Uses

Recent programs to inventory stream condition and fish habitat on forest lands usually include some measurements of LWD. Generally the LWD measurements focus on the number and size of LWD pieces and their association with various channel features. As most of these programs are of recent origin, relatively little of the resulting data have been used to develop management prescriptions (Bilby and Wasserman 1989).

When possible, comparable surveys should be conducted on similar, unmanaged streams. For example, upstream wilderness areas can provide reference data on the natural loading, recruitment rate, and downstream transport of LWD.

Such comparisons of logged and unlogged reaches can provide insights into management impacts on LWD. However, the long residence time of LWD in streams suggests that the ultimate impact of forest harvest on amounts, characteristics, and functions of LWD may not be evident for years or decades.

Assessment

Large woody debris (LWD) performs a variety of functions critical to the maintenance of productive fish habitat in stream systems. Various management activities, including timber harvest, alter the amount and characteristics of LWD in Pacific Northwest streams; therefore, monitoring activities evaluating stream conditions on forest lands should incorporate measurements of LWD. This need to monitor LWD is increasingly recognized, but monitoring programs with a LWD component are only now being established. The type of measurements which should be taken will depend upon the objectives of the specific monitoring project, but should include, as a minimum, wood abundance and piece size.

Logging and fish habitat improvement projects are the two activities most likely to alter the amount of large woody debris in stream channels. On-site measurements of wood frequency and piece size can be a relatively sensitive indicator of management impacts. In downstream locations changes in the LWD size and frequency usually occur more slowly and may not be easily detectable.

The long time required for a tree to mature and enter into the stream channel suggests that one should monitor the vegetation in the riparian zone and plan for future recruitment. Hence long-term monitoring of large woody debris in stream channels is needed to fully assess the adequacy of present practices, whereas a simple inventory may suffice for evaluating conditions with regard to fish habitat, channel morphology, and sediment storage.

The extensive changes in forest practice regulations over the last twenty years means that long-term trends in LWD must be evaluated in the context of the regulations in force at the time of the management activity. Hence the data from long-term monitoring projects may not be directly applicable to current practices, but they can provide some guidance to the formulation of future regulations (MacDonald et al.1991).

Large woody debris has been an essential component of stream habitat restoration projects conducted in northwestern California by the Department of Fish and Game to enhance summer and winter salmonid fish habitat. The methods and specifications for using logs and log structures were developed and documented by Flossi and Reynolds (1994). Following are some specific applications that have been utilized successfully to improve instream fish habitat.

Logs

Logs can be used individually, or in combination with other logs, root wads, or boulders. Longevity is highly dependent on the tree species and percentage of time that the log is saturated. Redwood, western red cedar, Port Orford cedar, and Douglas fir can be expected to last the longest. Spruce, hemlock, white fir, pine, and hardwoods are least durable. The longevity of most logs can also be increased by removing their bark. Logs are buoyant and will float if not secured or weighted down adequately.

Logs can be used for a variety of applications: weirs, wing-deflectors, digger logs, cover structures, cribbing, and bank armor. Full-channel log structures are susceptible to washout or destabilization during periods of high stream flow if not adequately secured.

Root Wads

A root wad with an extensive root network can provide complex fish habitat throughout the year depending on where it is placed. Root wads can be anchored in a variety of locations including mid-channel, at the stream margins, or in pools, to enhance summer and winter habitat. Root wads with a long section of log intact are most valuable since they are easier to secure in place. Root wads must be well-secured, preferably to bedrock, boulders, or stable logs.

Log Structures

Applications for log structures are similar to those for boulder structures. Logs may be used to provide instream cover for juvenile salmonids and spawning adults, to scour pools for rearing habitat, to recruit spawning gravel, and to stabilize eroding stream banks.

Log structures have a variety of shapes and uses. These include straight log weirs, downstream-V weirs, diagonal weirs, upstream-V weirs, upsurge weirs, wing-deflectors, divide logs, digger logs, and Hewitt ramps. The various structures have specific purposes which often dictate the specifications to which they are built, Many of these structures serve the dual purpose of trapping, sorting, and stabilizing gravel for spawning habitat as well as creating scour pools which act as rearing habitat for juvenile salmonids and escape cover or resting areas for spawning adults.

Cover Structures

A study on the effectiveness of placing tree bundles of fir, alder, maple and myrtlewood was conducted on five different Oregon streams. Juvenile coho and steelhead populations were sampled in 16 pools before and after tree bundles were added. Before the tree bundles were added the pools sampled were holding 12 percent of their summer coho population during the winter. The following year, after tree bundles were added, these same pools contained 74 percent of their summer coho population during the winter sampling. The sampling showed an increase in steelhead populations between the summer and winter populations during the winter after tree bundles were added.

Quality of a pool can be increased by adding cover structures. Amount of effective cover and the complexity of habitat is at least as important as the physical amount of pool created. Strategically placed cover can help keep pools scoured, while improperly placed cover will cause deposition of sediment. The following principles when implemented were found to be successful for enhancing instream fish habitat.

Riparian vegetation is a highly important source of cover. Overhanging vegetation or undercut banks, along with the associated roots, provide excellent, effective cover.

Logs, root wads, tree bundles, and boulders are the primary cover elements added to pools. Some guidelines concerning construction and installation of cover structures in a stream are:

Cover should be incorporated with other stream enhancement structures such a, log and boulder weirs, boulder clusters, and single and opposing wing-deflectors.

Cover structures are often placed over pools, backwater areas, or along meanders to provide overhead protection.

Logs, tree bundles, or root wads can be cabled against the banks. Secure logs or root wads to a stump, a bedrock outcropping, large boulders, or use a deadman. Cover can also be cabled to instream boulders using polyester resin adhesive.

Cable all log and root wad cover structures tightly.

Protect the upstream end of logs from direct flow of the stream.

Two examples of cover structures are spider logs and log, root wad, and boulder combinations.

Spider Logs

Spider logs, also called mini logjams, are a jumble of several logs placed at random angles to mimic a log or debris jam. They provide cover for juvenile rearing and adult spawning and collect woody debris to increase diversity. Their use is restricted to areas where there is no danger of causing bank failure or channel migration. Backwater eddy areas on the stream channel margins are the best locations for these structures.

The structures are composed of several logs placed across each other to imitate a natural debris or log jam. They are cabled together and secured to bedrock or large boulders in the channel with cable and polyester resin adhesive. Two or three main structure logs can be anchored into bedrock or to boulders. Several other logs with branches and root wads attached are then fastened to these structure logs with cable or threaded rebar.

Extreme caution must be used in locating these structures as the potential for an adverse effect is great. Before placing spider logs, it is necessary to determine channel capacity and bank full discharge that can be expected. Log structures should not reduce channel capacity below flood stage needs or a massive logjam and sediment trap could develop.

Log, Root Wad, and Boulder Combinations

Log, root wad, and boulder combinations combine the two main forms of structure added to a stream to enhance habitat. The longevity of boulders combined with the overhead cover provided by logs can create habitat that is superior to that offered by either element individually.

Log, root wad, and boulder combinations are used to create cover for juvenile rearing. These structures also act as resting areas and escape cover for spawning salmonids. By creating velocity shear zones they create areas of deposition as well as scour, thereby enhancing spawning through gravel sorting.

Log, root wad, boulder combinations are usually used in mid-channel areas. In addition to creating cover and sorting gravel, they may provide a visual barrier between spawning areas, which can increase the number of spawners that will use an area,

Methods used to install log, root wads, boulder combination structures are similar to those used for installing log or boulder structures. Wire rope is run through holes drilled through the logs. One cable may pass through several logs. Ends are set into holes which have been drilled into the boulders and filled with polyester resin adhesive. The cable is drawn as tight as possible, to leave a minimum amount of slack in the cable.

Log Jams

Log or debris jams can be either human-induced or a natural feature. It is sometimes difficult to establish whether or not a log jam is blocking migration, Often, a log jam which appears impassable has stable underwater passages for migrating fish. Careful surveys for salmonids, especially fry, above suspected jams should be conducted prior to any treatment. Large woody debris accumulations are preferred rearing habitat for steelhead trout and coho salmon because of the excellent cover they afford. Large stable pools created by log jams also provide important holding areas for adult salmonids.

Log and debris jams which become plugged with silt, gravel, fine debris, or other materials can form an impassable barrier or block flow and create a waterfall. In some cases, water diverting around log jams can create detrimental bank erosion. If a jam is creating an impassable barrier or creating erosion, modification of the log jam is desirable. In all instances, only the minimum amount of wood necessary to facilitate fish passage, or to eliminate a stream channel problem, should be manipulated.

The fastest and most efficient way to modify a log barrier is with heavy equipment. A self-propelled logging yarder, with a high lead, is most desirable. Hydraulic excavators are -also useful. When equipment is not available and access into the site is poor, manual labor, combined with a chain saw and griphoist operation, can satisfactorily modify log jams (Flossi and Reynolds 1994).

13. Pool Parameters [1]

Definition

Pools can be defined as sections of the stream channel that have a concave profile along the

[1] Taken directly from MacDonald et al.(1991).

longitudinal axis of the stream, or as areas of the stream channel that would contain water even if there were no flow. This means that the maximum depth of pools is deeper than the average thalweg depth, and water velocities at low flows often are lower than the average velocity. Pools are an important component of the aquatic habitat, and they can be classified and measured in several different ways.

Pools usually are classified by the process that created the pool (e.g., undercut bank, debris dam, beaver dam, plunge pool, etc.). This classification is useful for evaluating the abundance and type of fish habitat (Bisson et al. 1982), although the various categories of pools and other habitat types have not been standardized (Platts et al. 1983). Nevertheless, the number and type of Pools in a particular reach could be enumerated, and changes over time could be monitored.

More commonly the depth, residual depth, volume, or area of pools are measured, and these measurements can be used as monitoring parameters. Pool depth can be either average depth or maximum depth. Residual pool depth refers to the depth of the pool below the downstream lip of the pool (i.e., the depth of the water which would be trapped in the pool if there was no discharge) (Lisle 1987). Pool area refers to the total surface area of the pool. Both pool depth and pool area will vary with discharge, whereas residual pool depth is not discharge-dependent.

Relation to Designated Uses

Pools are an important morphological feature in stream channels and an essential type of fish habitat. In general, a variety of pool types are needed to provide the range of habitat needed by different species and age classes of fish. Slow-moving dammed or backwater pools may be necessary for salmonid survival under harsh winter conditions. Deep undercut pools may provide protection from high temperatures. Young fish may require shallow, low-quality pools to avoid predation. Particularly in smaller streams, pools provide the majority of the summer rearing habitat (Beschta and Platts 1986). Pools also may be important sites for recreational activities such as fishing and swimming.

Response to Management Activities

Those pools characterized by low flow velocities (e.g., backwater or dammed pools) are particularly susceptible to infilling with sediment. Hence the depth, area, or volume of these pools can serve as a relatively sensitive indicator of changes in the coarse sediment load due to forest harvest road building and maintenance, mining, or other management activities.

Changes in pool area, pool volume, or residual pool depth also can be caused by changes in the features that create pools. Thus a reduction in the input of large woody debris may lead to a reduction in the number and size of pools. Similarly, a change in the size or frequency of peak flows will alter the ability of the stream to transport coarse sediment, and this may alter pool measurements.

Measurement Concepts

Pool depth, pool area, and pool volume are all direct physical measurements, and they are relatively simple to make in small streams. Recent publications have encouraged the use of visually estimating the width, depth, or area of pools within a stream reach, and then adjusting these visual estimates for any systematic bias by measuring a certain percentage of the pools (Hankin and Reeves, 1988). In larger streams with deeper pools, direct measurements are considerably more difficult Also, a series of conceptual problems in making pool measurements must be considered before embarking on a classification or monitoring program.

First, it may be difficult to determine exactly what constitutes a pool. Large, still pools are easy to classify, but the change from pools to runs or glides is one point on a continuum. Platts et al. (1983) found a consistent observer bias when measuring pool areas along stream cross-sections. This consistent bias resulted in a relatively narrow 95% confidence interval for the data (±10%), but poor year- to year accuracy and precision.

A second problem associated with pool measurements is that pool depth, pool area, and pool volume are all flow dependent. An increase in stage will increase the value of these parameters. Although this may not be a problem in streams with a consistent summer baseflow, it does mean that stage or water depth must be recorded and taken into account when analyzing the data. The advantage of residual pool depth is that it is independent of discharge (Lisle 1987).

Standards

No standards for any pool parameters have been established or proposed.

Current Uses

Most surveys of fish habitat or stream channel condition have utilized some measure of pool area, length, depth, or volume. Many of these surveys also identify the primary cause of each pool. These data are then used to generate summary statistics on the pool-riffle ratio, pool area, or pool volume per unit length of stream channel. The expectation is that subsequent surveys should be able to determine whether substantial shifts have occurred in these values.

Assessment

In many streams, pool parameters have considerable potential for monitoring. Decreases in pool depth or pool volume may be relatively sensitive indicators of logging induced changes in the coarse sediment load or the size of peak flows. Since pool parameters have not been extensively monitored in the past, there is little documentation to guide the selection of a particular parameter. Residual pool depth does have the advantage of being independent of discharge. Residual pool depth also may be the most sensitive pool parameter, as an increase in coarse sediment is likely to first affect pool depth. Monitoring pool parameters will be most useful in low or moderate gradient streams in alluvial valleys.

To be useful, any monitoring of pool parameter should be combined with data on the pool-forming features. Logging in or near the riparian zone, for example, may alter the type and amount of large woody debris in the stream channel, and this will directly affect the number and size of pools. This suggests that the sample size should be large enough to allow for random changes in pool-creating structures, or the pools should be stratified by pool type.

Pool measurements are most likely to be useful when combined with discharge and other morphological data. Bed material particle size can be extremely useful parameter in interpreting the cause and significance of a change in pool depth or pool volume. Flood history and local discharge data are important because large storms can reduce the size or number of pools, and this effect must be distinguished from forest management activities. Additional long-term data are needed to better assess the value of pool parameters for monitoring, but pool parameters promise some significant conceptual and practical advantages in monitoring forest activities (MacDonald et al. 1991).

C. CANOPY [1]

Introduction

Characteristics of the riparian zone canopy are rarely considered as water quality parameters, yet this canopy directly affects many of the designated uses of water. The type and amount of riparian vegetation is an important controlling factor for stream temperatures and bank erosion, and both temperature and bank erosion can be directly related to the quality of fish habitat. The riparian zone also plays a key role in defining channel morphology and creating fish rearing habitat through the input of large woody debris. Finally, the riparian zone is believed to be important in controlling the amount of sediment and nutrients reaching the stream channel from upslope sources.

Over the past 25 years, several major studies have documented the effects of forest harvest in the riparian zone on streams and water quality. The results of these studies have led to more stringent regulation of forest management activities adjacent to certain classes of streams (e.g., perennial streams with fish present or providing domestic water supply). The documented effects of management activities on the stability and vegetation of riparian zones, and the established linkages between the riparian zone and various designated uses, provides the rational for including riparian parameters in the handbook.

The first parameter is the width of the riparian canopy opening. Changes in the width of the riparian canopy opening generally result from changes in the balance between sediment and discharge.

[1] Taken directly from MacDonald et al.(1991).

Hence the width of the riparian canopy opening may be a useful parameter for quickly determining historical trends in stream condition over large areas using aerial photographs (Grant 1988).

The second parameter, riparian vegetation, is much more broadly defined. A variety of measurements can be made regarding the type and condition of the riparian vegetation, and these measurements may differ widely in their purpose, the amount of effort required, their sensitivity to different management activities, and their relation to the designated uses. The point is that the riparian vegetation and the width of the riparian canopy opening are important components of stream condition, and they can be useful parameters for monitoring the effects of management activities on streams.

Definition

The riparian canopy opening refers to the gap between the canopy of the riparian vegetation on opposite banks of a stream or river. Often the canopy of small streams are completely shaded by woody vegetation and hence have no riparian canopy opening in their undisturbed state. In steep, narrow, V-shaped valleys, considerable shading can result from the dominant upslope species rather than riparian vegetation. In lower-gradient and higher-order streams, the stream channel by definition is wider and there commonly is a gap or opening between the parallel stands of the riparian vegetation. Streams with an alluvial valley floor tend to have more extensive and complex stands of riparian vegetation that develop in response to periodic flooding and high water tables.

These riparian and upslope forests that shade undisturbed stream channels can be altered by both natural disturbances (e.g., landslides, debris flows, and stream channel erosion) and forest management activities. Often a highly interactive response exists between changes in channel morphology and changes in the riparian forest (Wissmar and Swanson 1990). For example, channel or bank erosion often changes the size and location of the stream channels, which results in a corresponding loss of the stream side vegetation and an increase in the width of the riparian canopy opening.

Monitoring of the riparian canopy opening offers a relatively rapid means of assessing the influences of a variety of management activities on both the streamside vegetation and the stream channel. Identification of the source areas and quantitative mapping of the changes in the riparian canopy opening over time can help determine the primary cause(s) of adverse change (Grant 1988).

Relation to Designated Uses

An increase in the width of the riparian canopy opening will allow more direct radiation to reach the stream and raise peak summer water temperatures. Less shading also will result in greater temperature fluctuations on both a seasonal and a daily basis. A reduction in canopy cover may increase the amount of reradiated long-wave radiation, thereby allowing more heat loss at night

Heat loss can be crucial to the icing up and formation of anchor ice in colder environments (Beschta et al. 1987).

In light-limited forest streams, an increase in the width of the riparian canopy opening can increase primary production (Gregory et al. 1987). This may induce a corresponding increase in invertebrate and fish production. However, increased primary productivity may be offset by decreased inputs of detrital food subsidies, leaves, and other organic material from the riparian zone. The net balance between the increased primary production and the decreased detrital inputs will depend on the size of the stream and the presence or absence of other limiting factors, such as plant-available nutrients.

Changes in the size and structure of the riparian canopy will adversely affect a wide range of animal species dependent on riparian habitats (Deusen and Adams 1989). A reduction in the width of the riparian zone may reduce the purported ability of the riparian zone to trap excess nutrient and sediments coming from upslope (Green and Kaufmann 1989). An increase in the riparian canopy opening is likely to reduce the long-term delivery of large woody debris (LWD) into the stream channel (Grant 1988). In many forested streams LWD is an extremely important element in channel morphology, sediment transport, and quality of aquatic habitat (Bisson et al. 1987).

Effects of Management Activities

Changes in the size of the riparian canopy opening can result from a variety of interacting fluvial and geomorphic processes. Probably the most common cause is an increase in coarse sediment. This can increase channel width through bank erosion, with a corresponding loss of the riparian vegetation. Recolonization of the enlarged streambed by riparian species will proceed slowly at best until the source of the excess sediment is removed.

Grant (1988) noted that an increase in channel width and the riparian canopy opening also can result from an increase in the size of peak flows. Peak flow increases from management activities usually are small or are limited to the smaller, more frequent storms (Ziemer 1981). In general, peak flows probably are less likely to enlarge the size of the riparian canopy opening and initiate channel morphological changes than increases in the amount of coarse sediment (i.e., bedload). Other possible causes of fluvial disturbance that can increase the riparian canopy opening include debris flows, extreme discharge events, entrainment and transport of large woody debris in flood plain areas, and increased lateral migration of stream channels.

Measurement Concepts

Although riparian vegetation affects many aquatic habitat and water quality parameters, generally it is more effective to monitor these other parameters directly rather than monitoring the riparian vegetation. Estimates of cover or rearing habitat for juvenile salmonids, for example, focuses on the type and abundance of cover in the stream, and not the potential cover, such as dead branches and snags, which may fall in to the stream. Similarly, water quality parameters such as nitrate, conductivity, and turbidity are measured directly, and the influence of the riparian vegetation is difficult to assess. A notable exception is the increase in water temperature caused by removal of the riparian canopy. In short reaches with negligible groundwater flow, the increase in summer maximum temperatures is a direct function of the additional exposure of the stream surface to incoming solar radiation, and this effect can be predicted (Beschta et al.1987).

It follows that, with the exception of temperature, any precise measurement or characterization of the riparian vegetation provides an accuracy which cannot be translated into a more precise assessment of water quality or the impairment of designated uses. Thus relatively simple techniques that are repeatable over long time periods usually provide the best approach to monitor the condition of the riparian vegetation, and to evaluate the likely effects of the riparian vegetation on water quality (Platts et al. 1983).

More often than not, however, stream inventory and water quality monitoring programs have developed ad hoc techniques for monitoring the riparian vegetation according to their particular objectives and conditions. The choice of qualitative or quantitative methods is determined by the parameter being measured, the anticipated use of the data, and the cost of collecting that data. Some of the most commonly measured parameters include vegetation type, vegetation cover, and vegetation density. Vegetation type is usually a qualitative categorization which can be as simple as tree, shrub, grass or bare ground (Platts et al. 1983). More commonly the vegetation type is based on the dominant overstory species or specified plant communities (Platts and Nelson 1989).

Assessment

Riparian vegetation is of critical importance to water quality because of its proximity to, and interactions with, aquatic ecosystems. In small streams the riparian vegetation usually is the largest source of organic material and hence a critical source of detritus for aquatic food webs. The riparian zone is also the primary source of large woody debris. The amount of shade cast by riparian vegetation is an important factor in determining maximum stream temperatures and may also influence winter minima. Low overhanging riparian vegetation provides cover for salmonids and other fish (Platts et al. 1983). A reduction in the riparian vegetation through overgrazing, logging, or intensive recreational use can lead to bank erosion and instability. Bank erosion can have a disproportionate effect on water quality and the designated uses of water because the sediment is delivered directly into the stream channel.

Monitoring of the riparian vegetation is another means of assessing management impacts in the riparian zone and evaluating whether certain designated uses are impaired. However, riparian vegetation cannot be used as a direct indicator of water quality except in the case of stream temperatures. For this reason most water quality monitoring programs use relatively simple, qualitative indicators to assess the density, and cover of the riparian vegetation. Detailed quantitative monitoring is most appropriate for:

1. assessing stream shading and predicting the thermal effects of changes in the riparian canopy,
2. predicting the size and future recruitment of large organic debris,
3. measuring the amount of cover for fisheries, and
4. assessing bank stability and bank erosion as a function of vegetative cover.

Only the first of these cases can be classified as a traditional water quality parameter, even though the other three have clear linkages to water quality and some designated uses of water.

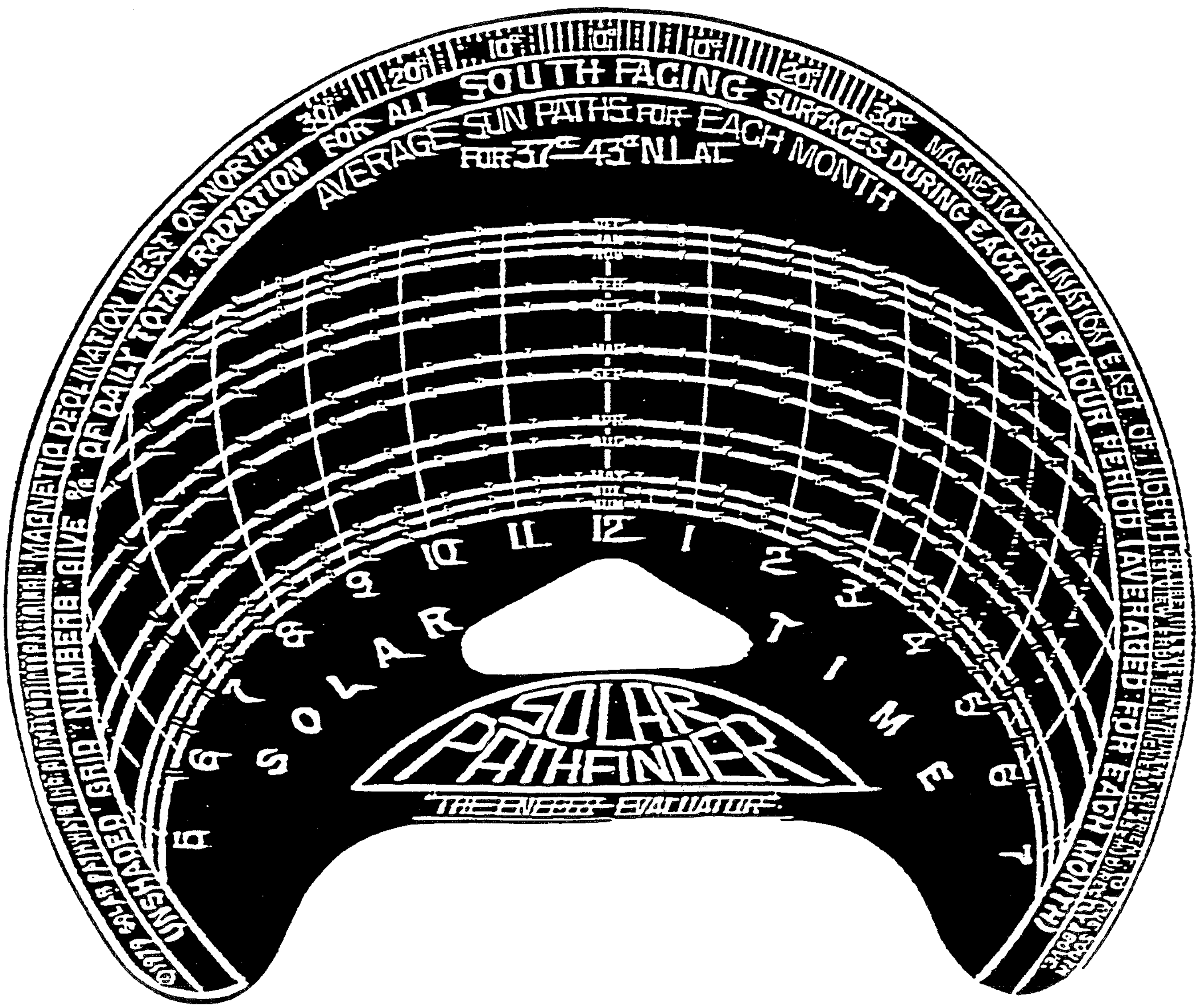
Management goals and the type of vegetation will largely determine the type of monitoring. In cool forested areas the emphasis should be on maintaining a healthy riparian canopy and ensuring adequate future inputs of large organic debris. In warmer areas stream surface shading is more likely to be the primary concern, and measurements of the riparian canopy can guide the intensity of management in the riparian zone (MacDonald et al.1991).

Data on canopy cover and stream shading can be obtained by several different methods. Sampling procedures for the spherical densiometer in large and small streams are discussed in Platts et al. (1987). Stream surface shading can be determined by measuring the height, density, crown width, and offset of the riparian vegetation. The Solar Pathfinder Chart is depicted in Figure I. The Solar Pathfinder provides a simple technique for measuring the amount of solar radiation blocked by vegetation or topography. It directly maps the extent of shading on the specified month (Platts et al. 1987). Each of these techniques produces data useful for assessing changes in the riparian canopy over time, or for predicting the effect of riparian canopy removal on stream temperature.

Changes in the riparian vegetation due to logging, or other management activities can be assessed by each of the above techniques. Cover, density, and biomass are more likely to reflect short-term management impacts than vegetation type (McDonald et al.1991).

During the PMP, direct canopy measurements were taken by use of the spherical densiometer (observation of shade intercepting subdivisions of reflected sky) (Lemmon 1956,1957), and with the sighting tube (overhead line-intercept observation). Another indirect measure of canopy coverage includes basal area measurement by the Cruz-All. (See Bell and Dilworth (1993) for the mathematical basis for canopy measurements). Portions of the sky blocked by the proximity and height of watercourse channels or ridges are measured by observing adjacent hillside slopes.

Figure I: View of Solar Pathfinder Chart Used to Record Shading
(USFS 1996)



The spherical densiometer, a small hand held-device, is a mirrored lens with twenty-four equal-area etched squares on a concave mirror (Model A). The lens is set into a wooden carrying case with hinged lid and small bubble level. The etched squares form a grid delineating a plot of the area over a sampling site. The observer levels the densiometer and notes the squares that include canopy. Care must be taken to keep the device level in front of the observer, but without introducing the shadow of the observer into the sampled area. Each square is visually divided into four sections, thus creating a total of 96 sampling quadrants. Recorded average numbers are corrected in the office by applying the appropriate ratio (N x .96 or N x 1.04). The .96 factor is applied when canopy covered squares are counted. The 1.04 factor is applied to squares counted that do not have canopy cover.

The presence of any living plant material within the sampling quadrant constitutes a 'hit' and is counted. Each of the intercepted or empty quadrants are counted and recorded onto the data sheet. For relatively open canopies, the intercepted quadrants may be quickly counted. Within closed canopies, counting the open quadrants is easier. The number of quadrants counted and whether they were 'open' or 'closed' is noted. At each sampling site, observations are taken in four opposite directions (facing upstream, turning to the right, facing downstream, and turning right again). <u>The first observation is always taken facing upstream</u>, and all subsequent readings proceed to the right (clockwise). Since the observations are a measure of density, the four samples should be taken directly over the same spot by the observer rotating around the densiometer. A series of observations is taken for each pool starting at five meters above the top of the pool, at the top of the pool, in the middle of the pool, at the bottom of the pool, and five meters below the bottom of the pool. All observations should be taken in the center of the stream channel. At the 95 percent probability level, Lemmon (1956) showed that average measurements of the same overstory area can be expected to be within + 2.4 per cent of the mean. For more discussion on the spherical densiometer, see Lemmon (1956,1957).

The sighting tube, another small hand-held device, is a PVC 'L' fitting containing mirrors, and two levels. The sighting tube is used to obtain a point-intercept measure of canopy directly overhead of the middle of the stream channel. The observer views the canopy through the mirrors within the tube, while leveling both horizontally and vertically. A set of wire cross hairs and a dot on a mirror permits the observer to maintain the level and observe at a specific point. When these dots are centered on the horizontal axis, the cross hairs in the sighting tube show the point directly above the observer's head. Depending on the available light, the observer may be able to note both an intercept and the species of tree seen. Under lower light levels and where footing is uncertain, a recorder may note the intercept and determine the species. These measurements are taken at five meters above the pool, half way to the top of the pool, at the top of the pool, at two places equidistant between the top and middle of the pool, at the middle of the pool, at two places equidistant between the middle and bottom of the pool, at the bottom of the pool, half way between the bottom of the pool and five meters below the bottom of the pool, and at five meters below the bottom of the pool. Again, the observer should stand in the center of the stream channel.

Basal area (standing crop of trees) can be measured by the use of the Cruz-All^{Tm}. A small, hand-held diecut aluminum plate attached to a string, the Cruz-All^{TM} has slots of different widths cut through it which represent four size classes. A tree is noted as being within one of the four size classes (5, 10, 20, and 40). If it is wider than the class in question, or narrower, then the next larger class is selected. A valid sample is taken when the Cruz-All^{TM} is held a set distance away from the eye of the observer (the length of the string attached by the manufacturer to the Cruz-All^{TM}) and the observer rotates about a fixed spot. The observer then compares the trunk (at DBH) of each tree visible from the sampling site through the Cruz-All^{TM} openings. The observer does not move in order to better see trees located behind others. Trees hidden behind other trees are not recorded. The Cruz-All^{TM} is kept above the same spot for all samples at a single site. Observations are taken at the top, middle, and bottom of each pool.

The canopy coverage which results from sun interception by ridge lines and channel sides is measured as the hillslope on the right and left banks (looking upstream). Slope can be estimated by using a clinometer, a small hand held device which measures both percent and degree angles (other scales may be included on the clinometer). The observer holds the clinometer near an eye and looks upslope to a point at an equal height above the ground surface. By looking at the point with the uncovered eye, and centering the line in the clinometer on this point with the eye behind the clinometer, the observer is able to read the percent slope off of the right side of the scale in the clinometer. The hillside slopes are measured at the bottom of each pool.

During canopy data collection, photographs are taken (35 mm color transparencies are commonly used). For each pool and riffle, views should include the view of the unit from downstream, a view of the right bank riparian zone looking upstream, a view of the left bank riparian zone looking upstream, a view of the unit from the top looking downstream, and a picture of each the right and left bank riparian zones from upstream looking downstream. Consistency is important when photographing the features; if some views are not possible or do not present the desired information, record the circumstances and omit the picture. Unique features which may help explain a problem, a certain technique, or verify the specific sampling site should also be photographed.

Data analysis consists of incorporating field data within text descriptions of study reaches. The canopy information should provide a quantitative basis for the description of canopy strata and overstory species composition. The comparison of data produced with spherical densiometers and sighting tubes suggests differences between canopy coverage directly over the stream and coverage which may produce shade on the stream at different times. It should be made clear that the Solar Pathfinder is used to determine shading and predicting temperatures, while the sighting tube and the densiometer are used to estimate canopy density (Rae 1993).

D. TEMPERATURE [1]

Introduction

Temperature is a key parameter that can be significantly altered as a result of timber harvest immediately adjacent to the stream channel. Increases in peak summer water temperatures can directly affect coldwater fishes.

Water temperature strongly influences the function of biological systems, and individual organisms and species. Stream temperature has impacts an health, behavior and survival of aquatic organisms. Manipulation of riparian vegetation that provides shade is a key management concern.

Water temperature is an easily measured parameter that has considerable chemical and biological significance. It is measured on a linear scale in either degrees Fahrenheit (°F) or degrees Celsius (°C). Celsius is increasingly preferred and can be obtained easily from °F by the equation:
°C = 5/9 (°F - 32), or if desired from Celsius to Fahrenheit by the equation ^{0}F = (1.8 x C) +32.

Relation to Designated Uses

Increased water temperatures are known to increase biological activity. A rough rule of thumb is that a 10°C increase in temperature will double the metabolic rate of cold-blooded organisms (Keeton 1967). Salmonid egg and alevin development, and subsequent timing of emergence from gravel, have been shown to be closely associated with stream temperatures (Alderdice and Velsen 1978). A rise in summertime water temperature resulting from forest harvest may increase the growth rate and productivity of many aquatic organisms (Beschta et al. 1987).

The optimal temperature range for most salmonid species is approximately 12-14°C. Lethal levels for adult salmonids will vary according to factors such as the acclimation temperature and the duration of the temperature increase, but they generally are in the range of 20-25°C in the laboratory. Salmonid eggs and juveniles are much more sensitive to high temperature. Combs (1965) found the lethal limit of sockeye salmon eggs to be 13.5°C. Spawning coho and steelhead may be intolerant of temperatures above 10°C (Beschta et al. 1987).

Acute effects of high temperatures on fish have been well documented in laboratory studies, but little information is available on the long-term exposure of salmonids to sub-lethal temperatures. Similarly, the sub-lethal effects of altered thermal regimes due to forest harvest have seldom been documented for salmonid species. Recent studies by Holtby (1988) and Berman and Quinn (1990) are beginning to address these sub-lethal effects.

[1] Taken directly from MacDonald et al.(1991).

Stream temperature also can affect the behavior of aquatic organisms, but these behavioral effects generally are poorly understood or have been documented for only a few species. For example, at temperatures below about 5°C, juvenile salmonids tend to move into the gravel or other protected areas. This behavioral thermoregulation allows salmon and other fish to minimize body temperature fluctuations despite wide variations in stream temperatures (Coutant 1969).

Temperature controls the rate of many chemical reactions. A general rule of thumb is that the rate of a chemical reaction proceeding at room temperature will double with a 10°C increase in temperature (Eastman, 1970). The equilibrium between ammonium and unionized ammonia, for example, is highly dependent upon temperature and can have a series of repercussions with regard to nitrogen cycling and water quality. In contrast, the equilibrium concentration of dissolved carbon dioxide and oxygen in water is inversely proportional to water temperature (MacDonald et al. 1991).

Effects of Management Activities

In many areas of the Pacific Northwest and Alaska, forest cover provides substantial shade to streams and other water bodies. A reduction in forest cover along streams can increase the incident solar radiation and hence peak summer temperatures. Complete removal of the forest canopy in the Pacific Northwest has been shown to increase the highest daily stream temperatures in the summer by 3-8° C, although daily summer minima are increased by only 1-2 ° C (Beschta et al. 1987).

These temperature increases are due almost entirely to the additional input of incoming shortwave radiation. Hence elevated stream temperatures may not return to pre-logging levels until the stream banks become revegetated and the input of shortwave radiation has been reduced to prelogging levels (Moring 1975, Holtby 1988). The thermal energy in streams is not easily lost through reradiation, convection, advection, and conduction. This means that increases in stream temperature generally are additive, and an alternation of shaded and unshaded reaches is not an effective strategy to minimize increased summer temperatures due to forest harvest (Beschta et al. 1987).

Removal of the forest canopy may decrease the minimum nighttime temperature in winter by allowing more radiation heat loss. In coastal areas this possible effect is likely to be minimal, but in colder locations clearing the riparian zone may cause increased incidence of anchor ice or freeze-up (Beschta et al. 1987). The largest changes in winter minima will occur in small, shallow, slow-flowing streams that do not have significant groundwater inflow.

Although the greatest effect of forest harvest is on summer maxima, smaller temperature changes in other seasons can have greater biological significance. On Carnation Creek in coastal British Columbia, for example, coho smolt numbers, size, and migration were affected more by small changes in late winter and spring temperature than by a larger changes in summer temperatures (Hartman et al. 1987). Both this research and recent models indicate that alterations in stream temperatures can have a series of complex, interacting effects that we are only beginning to unravel for single-species systems. Holtby (1988) and Holtby et al. (1989) reported that habitat changes, like temperature elevation, can affect more than one life history stage and persist throughout the life cycle.

Measurement Concepts

Temperature can be measured by either a thermometer or an electronic sensor. Thermometers are relatively inexpensive but should be calibrated if accurate measurements (e.g., within 1°C) are required. Inexpensive thermometers may have measurement errors as large as 3°C (APRA 1976). Electronic sensors have the advantage of allowing continuous monitoring.

To obtain average stream temperatures, measurements should be made in more turbulent reaches. Water temperatures near the bottom of pools can be 5-10°C cooler than the surface water (Bilby 1984a). Usually thermal variations within a stream result from inflows of cool water sources, such as groundwater or intergravel water, into slow-moving reaches, pools, or backwater areas. In such cases a single surface temperature can be misleading. The daily fluctuations in stream water temperature also must be considered if instantaneous rather than continuous temperature measurements are being made.

EPA has established a general national criteria for coldwater fisheries. This guideline states that the weekly average warm season temperature should (1) meet site-specific requirements for successful migration, spawning, egg incubation, fry rearing, and other reproductive functions of important species; (2) preserve normal species diversity or prevent appearance of nuisance organisms; and (3) not exceed a value more than one-third of the difference between the optimum and the lethal temperature for sensitive species (EPA 1986b). Specific temperature standards to satisfy these criteria are left to the individual states.

Many aquatic organisms respond more to the magnitude of temperature variations and amount of time spent at a particular temperature than to an average value. For this reason temperature criteria should not only specify the maximum allowable increase in the weekly average, but also the maximum increase for shorter periods of time.

Thermographs are used to collect and record stream temperatures during low flow long day length periods, when maximum temperatures are likely. The objective of the measurement is to determine mean maximum temperature for a specific period(i.e., July 1-August 31). Temperature range for the time period is also monitored. Maximum temperatures could be determined for comparison with other watershed projects or biological standards, or water quality objectives. A minimum of 1468 measurements (hourly for 62 days) should be taken when using a thermograph (USFS 1996).

Assessment

Measurement of summer and winter water temperatures is a useful approach to assessing the thermal suitability of a stream for fish. In contrast to most of the other parameters discussed in this Handbook, temperature monitoring is relatively straightforward and inexpensive and can be Project Monitoring. In turbulent forest streams that are well shaded by riparian vegetation, relatively few measurements may be required because of the limited spatial and temporal variability. In pools and backwater areas, however, additional measurements may be necessary to determine whether these areas which experience thermal stratification are subject to cool-water inputs. Similarly, the timing and frequency of temperature measurements should be determined only after data have been collected on the diurnal fluctuations in temperature and the sensitivity of daily peaks stream temperature to short-term fluctuations in air temperature. Use of continuous recording devices eliminate the sampling problems caused by temporal variability.

Beschta et al. (1987) concluded that logging-related temperature increases generally have not resulted in significant mortality of resident salmonids. However, research has suggested that a variety of sub-lethal adverse effects may occur as a result of forest harvest, and this suggests that continued efforts to monitor stream temperature changes may be desirable. The difficulty is not in monitoring these changes, but in predicting the biological effects in complex ecosystems.

Similarly, the postulated decline in nighttime winter stream temperatures due to forest harvest have not been verified. Although the magnitude of the change is likely to be relatively small in most cases, it may have important implications for stream icing in colder locations.

The additive nature of temperature increases and the likely importance of sub-lethal effects suggest that monitoring is needed when (1) the potential exists for large changes in water temperatures due to management activities, (2) water temperatures already are in the upper range of the acceptable temperatures, and (3) there is a potential for significant temperature increases due to the additive effects of numerous smaller increases. Care also needs to be taken in distinguishing temperature effects on aquatic organisms from other changes due to opening up the forest canopy such as increased light, increased nutrients, greater primary productivity, and alterations in the amount of large woody debris (MacDonald et al.1991).

E. MACROINVERTEBRATES

Introduction

The following discussion is taken from MacDonald et al. (1991). The procedure developed by the California Department of Fish and Game is also included subsequent to this discussion.

Macroinvertebrates are animals without backbones that are large enough to be seen with the naked eye. The lower size limit is arbitrary. The U.S. Geological Survey has adopted a mesh size of 0.21mm as the most suitable for sampling macroinvertebrates in flowing waters (Platts et al. 1983), while APHA (1989) defines macroinvertebrates as those invertebrates on a U.S. Standard No. 30 sieve (0.595 mm openings).

Definition

A wide variety of taxonomic groups are found in freshwater environments, and these include annelids, crustaceans, flatworms, mollusks, and insects. Benthic macroinvertebrates, which live on the stream bottom, are the group most amenable to systematic study. It follows that most freshwater monitoring programs have been directed towards benthic aquatic insects, and these organisms are the primary focus of this protocol technique.

Relation to Designated Uses

Macroinvertebrates play several major roles in aquatic ecosystems. They graze on periphyton (attached algae) and feed on the terrestrial organic material that falls into the stream. Other invertebrates act as predators and filter feeders. Macroinvertebrates are a major food source for most fish species in forested areas (Gregory et al. 1987). Much of the ecological importance of macroinvertebrates stems from their position as an intermediate trophic level between microorganisms and fish (Hynes 1970).

Benthic macroinvertebrates have several characteristics which make them potentially useful as indicators of water quality. First, many macroinvertebrates have either limited migration patterns or a sessile mode of life, and this makes them well suited for assessing site-specific impacts. Second, their life spans of several months to a few years allow them to be used as indicators of past environmental conditions (Platts et al. 1983). Third, benthic macroinvertebrates are abundant in most streams. Fourth, sampling is relatively easy and inexpensive in terms of time and equipment (EPA 1989). Finally, the sensitivity of aquatic insects to habitat and water quality changes often make them more effective indicators of stream impairment than chemical measurements (EPA 1990). In Ohio, for example, 36% of impaired stream segments detected with biosurveys could not be detected using chemical criteria alone (EPA 1988).

Disadvantages of monitoring macroinvertebrates include a relatively high degree of variability within or between sites (Minshall and Andrews 1973), local or regional variations in the sensitivity of a given organism to stress (Winget and Mangum 1979), the need for specialized taxonomic expertise, and the cost of processing (sorting and identifying invertebrates) samples containing numerous organisms. Much of the variability between samples is due to the highly heterogeneous distribution of macroinvertebrates with depth, current speed, and substratum (Platts et al. 1983, Morin 1985). This means that sampling locations must be carefully selected and that sampling usually should be stratified by habitat type.

Most monitoring techniques require macroinvertebrate identification to genus or species. Interpretation of the results requires knowledge of the habitat requirements of the identified taxa and familiarity with the typical macroinvertebrate community in the study area. In some sampling techniques, considerable effort may be needed to separate organisms from the substrate. The difficulties associated with the separation, identification, and enumeration of taxa may produce inadequate sampling programs (Jackson and Resh 1988).

Effects From Management Activities

The effects of forest activities on macroinvertebrate communities vary. Increases in the riparian canopy opening or the amount of organic material in the streams generally enhance aquatic insect populations. An increase in fine sediment usually has the opposite effect (Gregory et al. 1987; Section 3.1). Removing the riparian canopy decreases the input of terrestrial organic material and the number of detritivores. However, this decline often is overwhelmed by the corresponding increase in primary production and herbivorous insects (Gregory et al. 1987). Several studies have documented an increase in primary productivity after partial or complete removal of the riparian canopy (Hansmann and Phinney 1973, and Murphy et al. 1981). However no increase was found in Camadon Creek in coastal British Columbia, where phosphorus was found to be the limiting factor (Stockner and Shortreed 1988). Logging-induced increases in aquatic insects have been observed in northern California (Erman et al. 1977) and the Oregon Cascades (Murphy et al. 1981). While logging activities may increase total abundance, species diversity is usually reduced (Gregory et al. 1987).

Invertebrate communities also are affected by management practices on forest lands. Buffer strips 30 m wide appeared to protect vertebrate communities from logging induced changes (Erman et al. 1997,Newbold et al. 1980), but buffer strips 10m wide still resulted in a decrease in detrital inputs and macroinvertebrate densities (Culp1988). The net effect of logging on aquatic macroinvertebrates depends on the relative balance among all the controlling factors.

Measurement Concepts

A variety of sampling and data analysis techniques can be used to monitor macroinvertebrate communities. Some of the more common parameters include presence or absence data, functional feeding group analysis, and community parameters. Sample collection techniques can be equally varied, ranging from the placement of uncolonized substrates to kick nets, drift nets, and fixed-area substrate samples.

Sampling Techniques

Sampling techniques for macroinvertebrate can be classified as qualitative, semiquantitive, or quantitative (Platts et al. 1983). Qualitative techniques rely on indicator species or an evaluation of selected functional or taxonomic groups. Generally the samples for qualitative evaluation are not collected on the basis of a specified area or collection effort, and this severely limits any numerical analyses.

Sampling procedures that use uniform substrates or a specified amount of collection effort (e.g., a 3-hour drift net sample, or 50 sweeps with a dip net) are termed semiquantitative techniques (Platts et al. 1983). Data from these samples can be used for qualitative purposes, such as the presence or absence of particular taxa, or for estimating population characteristics such as diversity, total numbers, or biomass. The primary limitation of semiquantitative methods is that results are on a per sample basis rather than per unit area (Platts et al. 1983).

Quantitative techniques involve complete sampling in a specified area. The resulting density data are on an absolute basis (e.g., number of organisms per unit area), and this allows a comparison of populations over time or space. Data collected using quantitative techniques can be used to estimate productivity as well as population characteristics.

Although qualitative techniques typically are quicker and easier than semiquantitative or quantitative procedures, they yield less specific information. This generally makes qualitative techniques less sensitive and less reliable. Since a similar level of expertise is needed to analyze the samples and interpret the results, most projects should use semiquantitative or quantitative sampling methods (Platts et al. 1983).

This range of sampling procedures indicates that a wide variety of sampling techniques have been developed to accommodate varying study objectives and locations. The composition of the substrate, water depth, and current velocity largely determines the most appropriate technique. The most common methods include various types of nets, substrate sampling techniques, and the placement and subsequent retrieval of artificial substrates (Greeson et al. 1977). Each technique has a different set of errors and bias, making comparisons of data from different sampling techniques difficult (Platts et al. 1983). For this reason monitoring studies should select and utilize one of the better known techniques and apply this as widely as possible to ensure comparable data.

Drift nets are used to sample macroinvertebrates that have been dislodged or are migrating, and typically they are left in place for at least several hours. However, the nets can become clogged if they are not regularly cleared, and this will reduce the number of organisms captured in the nets. Drift net data are expressed as numbers and biomass of organisms per unit discharge (APRA 1989).

Dip nets are used to qualitatively collect organisms associated with backwater arm, nearshore areas, and deposits of organic debris. Collection techniques can be specified by area and effort in order to obtain semiquantitative data. In deep waters and in areas with fine substrates, a variety of grab samplers, such as Eckman or Peterson dredges, may prove most effective.

In small forested streams, Surber (Surber 1937) and modified Hess (Waters and Knapp 1961, Jacobi 1978) samplers are most often used for quantitative sampling (Platts et al. 1983). Both of these samplers utilize a frame to delineate a specific area of stream bottom and a net to capture the benthic fauna as the substrate is disturbed to a depth of 5 or 10 cm. The primary difference is that the modified Hess sampler uses a closed frame, while the Surber sampler relies on the current to carry dislodged organisms into the attached net. The mesh size of the net must be large enough to allow the free flow of water and fine sediments, but small enough to capture most of the benthic invertebrates. APHA (1989) suggests a mesh size of 0.595 mm, but in forest streams with little or no fine sediments a smaller mesh size may be preferable. For qualitative or semiquantitative samples, a kick-net typically is used. Kick- nets can be made by attaching a fine meshed screen between two rods. The net is held vertically in the stream while the substrate immediately upstream is disturbed. The current then carries the dislodged organisms into the net. By specifying the area and effort sampled, semiquantilative data can be obtained (Platts et al. 1983).

Sampling methods must take into account the time of year, number of samples per site, and habitat to be sampled. Significant changes in invertebrate populations occur during the year because of natural life cycle processes (Minshall and Andrews 1973). To account for these changes, sampling programs must define which season(s) will be sampled and maintain this sampling period throughout the life of the study. Collecting samples in more than one season is preferable, but when this is not possible the optimal sampling season is the period when most macroinvertebrates are both large enough to be retained during sieving and sorting, and identifiable with the most confidence (EPA 1989). In the Northcoast region this is typically late winter and early spring. However, sampling effectiveness is reduced during or just after periods of high water. This suggests that the optimal sampling time in streams with snowmelt runoff will be just prior to spring snowmell, while rain-dominated streams should be sampled after winter storms when the flow regime is relatively stable.

The number of samples that should be collected at each site is a function of the size of the site to be sampled and the variability between replicate samples. Quantitative methods generally require more samples per site than semiquantitative methods because of the greater variability in invertebrate densities compared to relative abundances (APRA 1976). In general, quantitative methods will require at least 5-10 samples per site in order to detect statistically significant differences (Platts et al. 1983).

The habitat selected for sampling will greatly affect the type of invertebrate community observed. The most diverse invertebrate communities generally occur in riffle/run habitats with gravel and cobble bottoms (EPA 1989). Since areas with the greatest diversity will provide the most sensitive indicators to environmental changes, riffle/run habitats are usually preferred for sampling when they are available. Sampling methods developed in North Carolina take qualitative samples from five microhabitats (riffles, macrophytes, logs, sand, and leaf packs) from each site to document invertebrate populations (Lenat 1988).

Data Analysis:

A variety of community and population indices can be used to characterize benthic macroinvertebrates, although the choice will be somewhat constrained by the particular sampling technique used to collect the sample. One useful approach is to divide benthic aquatic insects into functional feeding groups such as shredders, collectors, scrapers, and predators (Cummins 1973). Changes in the relative abundance of the different functional feeding groups can indicate habitat change. For example, an increase in the number of scrapers as compared to shredders suggests an increase in the production of attached algae due to a reduction in the riparian canopy or an increase in stream width. Considerable care is needed in the separation of organisms, as closely related species can fall into different functional feeding groups. Platts et al. (1983) conclude that this approach shows promise, but still must be regarded as experimental. They recommend that the functional feeding group approach be used in conjunction with more conventional community analysis techniques.

Some of the more commonly used community parameters include abundance, species richness, diversity indices, and biotic indices. Each of these parameters considers only a part of the overall invertebrate population characteristics, and each has certain drawbacks in terms of representing the complex assemblage of organisms present at any given site (Elliott 1977). It is therefore beneficial to use more than one community measure for assessing invertebrate populations.

Abundance can be expressed in absolute terms as the number of individuals per unit area present, or in relative terms as a percentage of total numbers. The absolute abundance is a useful indicator of the overall productivity at a site. Relative abundance values, such as percent contribution of the dominant taxon, indicate the community balance. Communities dominated by just a few taxa indicate environmental stress (EPA 1989).

Rapid Bioassessment Protocol II (RBP II) is a more intensive and systematic procedure intended to distinguish among three categories of water quality (non-impaired, moderately impaired, and severely impaired). Separate collections of macroinvertebrates are obtained from riffle/ run areas and coarse particulate organic matter. To reduce sample processing time, a 100-organism subsample is randomly sorted from the composited riffle/run samples. Each organism in this subsample is classified to the lowest taxonomic unit (order, family or genus) and functionally by feeding group, Larger subsamples (200 or 300 organisms) can be sorted, but they have not been shown to increase the sensitivity of the procedure (EPA 1989). The macroinvertebrates collected from coarse particulate organic matter are classified as shredders or non-shredders. From these data eight community, population, and functional feeding group parameters are calculated. These are combined to yield a single evaluation of "biotic integrity," and this is compared to the biotic integrity of a comparable, unimpaired site ("reference station") (EPA 1989). The particular combination and valuation of parameters in RBP II were developed from a single field study in North Carolina (EPA 1989), although several of the individual parameters have been derived from previous studies.

RBP III, a more detailed protocol for benthic macroinvertebrates, is very similar to RBP II, but requires identification to the genus or species level. The more precise valuation of the eight metrics allows four levels of impairment (severe, moderate, slight, and no impairment) to be distinguished. Again validation is based on a field study in North Carolina and the use of similar procedures in other studies (EPA 1989).

Standards

The principal objectives of the Clean Water Act are "to restore and maintain the chemical, physical and biological integrity of the Nation's waters" (Section 101). Current water quality programs focus on chemical integrity and, to a lesser degree, on physical integrity (EPA 1990). It is becoming apparent, however, that chemical criteria do not always protect biological integrity, even though the water quality criteria for parameters such as pH and dissolved oxygen are based in part on the sensitivity of aquatic macroinvertebrates (EPA 1986b). The inadequacy of chemical and physical criteria to protect biological integrity is particularly true for nonpoint source pollution and habitat degradation. To achieve the goals of the Clean Water Act and protect biological integrity, EPA is requiring the incorporation of narrative biological criteria into state water quality standards (EPA 1990).

The Rapid Bioassessment Protocols (EPA 1989) are an important step towards establishing sampling procedures and measurement parameters for assessing water quality using macroinvertebrates. Additional work will be needed to establish and verify these assessment procedures for the different ecoregions. Currently the applicability and reliability of the methodology is being studied in several watersheds in Oregon and Washington (R. Hafele, Oregon Dep. Environ. Qual., pers. comm.).

An important limitation of the Rapid Bioassessment Protocols is that they were not designed for quantitative water quality monitoring. The original intent was to develop inexpensive screening tools, and the maximum resolution of the current protocols is for qualitative levels of water quality (EPA 1989). Quantitative field data may allow additional inferences to be made.

In summary, aquatic macroinvertebrate monitoring is a useful tool for evaluating general water quality condition and the extent to which designated uses are impaired or supported. Biological measurements often are less expensive then detailed chemical analyses, as a trained entomologist can use aquatic insect data to infer a great deal about the site under consideration. To be most effective and reliable, however, biological studies need to be integrated into a monitoring plan that includes both physical and chemical evaluations (MacDonald et al. 1991).

California Department of Fish and Game macroinvertebrate procedure.

The following is a sample procedure developed by the California Department of Fish and Game, Water Pollution Control Laboratory, for macroinvertebrate assessments that was utilized in the Pilot Monitoring Program. The CDFG Water Pollution Control Laboratory (WPCL) has developed biological assessment techniques for measuring impacts to aquatic systems caused by contaminated water and sediments and altered physical habitat. Some of the techniques include acute and chronic toxicity testing, stream gravel quality assessment, water chemical analyses, stream habitat measurement and aquatic macroinvertebrate survey. The following procedure describes the specific biological assessment technique which will be used for a "Water Quality Field Assessment Techniques Evaluation Study" (Harrington 1993a).

These procedures closely follow RBP III for macroinvertebrates as outlined by the U.S. Environmental Protection Agency in Rapid Bioassessment Protocols for use in Streams and Rivers EPA/4441489-001 (Plafkin et al. 1989). The purpose of rapid bioassessment protocols is to provide States with a practical technical reference for conducting biological assessments of lotic systems.

Sample Site Location

Sites for macroinvertebrate sampling sites will be located above and below particular timber harvest units and at least one relatively undisturbed stream reach (control) within the same watershed. Each site must include at least 100 feet of riffle/run habitat with relatively fast currents and cobble and gravel substrates.

Field Procedures

Macroinvertebrate samples will be collected from three randomly chosen riffle sections within each sample reach by using the following procedures:

1. A longitudinal grid is produced by placing a measuring tape along the bank of all riffle sections in the sample site.

2. Three transects along the longitudinal grid are selected using a table of random numbers.

3. Starting from the downstream transect, macroinvertebrates are collected from three locations along the transect using a D-shaped kick-net. The three locations are usually at the side margins and the center (thalweg) of the stream. The macroinvertebrates are collected by placing the kicknet on the substrate and disturbing approximately one square foot of substrate upstream of the kick-net. The three collections are composited within the kick-net.

4. The content of the kick-net are placed in a 500 um mesh sieve for cleaning. The large organic material is removed by hand while carefully inspecting for clinging organisms.The remaining material is placed in a glass jar, labeled and filled with 90% ethanol.

5. Field Procedures 3 and 4 are repeated on the three transects to produce three replicate samples for each sample reach.

6. The samples are submitted to WPCL in Rancho Cordova by UPS or personal delivery or to other laboratories. Each shipment of samples is accompanied with a Chain of Custody document and stored in the WPCL Sample Depository (according to CDFG Laboratory Quality Assurance Procedures) until processing.

Laboratory Procedures

Each preserved sample is sampled again in the laboratory and analyzed using the following procedures:

1. The jar is opened and the contents placed in a gridded (2 in) white enameled tray. The sample material is then evenly distributed on the bottom of the tray.

2. At least five grids are chosen using a table of random numbers. Starting with the first grid, macroinvertebrates are removed and placed in a clean labeled jar. Additional grids are used until 100 macroinvertebrates are removed from the original sample.

3. The remainder of the sample material is redeposited into the sample jar and retained in the WPCL Sample Depository.

4. This subsampling procedure is repeated for all three replicate samples from each site.

5. All macroinvertebrates in each of the three replicate subsamples are identified to lowest taxonomic level, assigned to a Functional Feeding Group, and enumerated. Functional Feeding Groups are determined using Merritt and Cummins (1984) and other published and unpublished information on regional aquatic macroinvertebrates.

6. Each taxon of identified macroinvertabrates are retained in individual glass vials and maintained as a reference collection in the WPCL Sample Depository.

7. The following eight bioassessment metrics, as described in Plafkin at al. (1989), are calculated for each of the three replicate subsamples:

1. species richness;
2. modified Hilsenhoff Biotic Index;
3. ratio of scraper and filtering collector functional feeding groups;
4. ratio of ephemeroptera, plecoptera and trichoptera (EPT) and chironomidae abundances;

5. percent contribution of dominant taxon;
6. EPT index;
7. community similarity indices;
8. ratio of shredder functional feeding group and total number of individuals collected.

8. Mean and variance of the eight bioassessment metrics are calculated for each site using the three replicate subsamples.

9. Given the variances are homogeneous, analysis of variance are performed using the eight bioassessment metrics for those sites of concern (usually above and below a timber harvest unit and the reference or control site). Data transformation or a qualitative interpretation of the bioassessment metrics is normally performed if statistics were not appropriate.

10. Habitat and physicochemical assessment data are used to interpret results of the bioassessment metrics.

11. All data generated is maintained in a biological data management system similar to that developed by the U.S. EPA (BIOS). The data is also used to establish Biological criteria for California streams as described in U.S. EPA document EPA-440/5-90-004 (EPA 1990).

Quality control (intra-laboratory) is performed on ten percent of the samples using the following procedures:

1. The sample jars used for quality control are selected randomly from each group of samples delivered to WPCL.

2. The contents of the jars are then processed as described in Laboratory Procedure 1 and 2 except that in addition to 100 macroinvertebrates, 200, 300 and 500 are removed, identified to lowest taxonomic level, and enumerated.

3. The remainder of the contents are then identified, enumerated and placed in the WPCL Sample Depository.

F. METHODS FOR COLLECTING INSTREAM FIELD DATA [1]

This handbook has been developed for personnel who will have the responsibility for managing streams and riparian areas. The approach has been practical but specific with a concentration on

[1] Taken directly from Rae (1995).

taking consistently accurate measurements in order to replicate those instream measurements in the future. The techniques in this handbook provide a minimum set of procedures for collecting field data, and they should be accepted with the understanding that revisions will be necessary to address the broad range of physical conditions that will be encountered and the technical changes for taking those measurements.

The following is a suggested procedure that was developed for the Pilot Monitoring Program and implemented during the data collection stage of the program.

The preliminary stream survey should begin at the downstream end point and proceed upstream. Avoid walking in the stream as much as possible to minimize disturbance or damage to the existing natural conditions. This is particularly important for the macroinvertebrate sampling that should be completed prior to the initiation of other instream sampling in order to gather the mobile creatures that would otherwise evade collection nets once water disturbance begins.

The survey team should consist of at least three people with a designated team leader. A team of five members is the most that would be needed. The total reach should be surveyed from one end to the other on the first pass to minimize channel disturbance and field time. (Subsequent reentry to inspect sites omitted will result in considerable time being expended for this initial reconnaissance.) If the necessary forms and worksheets are available, and the assignment of duties with all of the team members has been completed, the following inspection sequence can begin for a selected stream channel reach of 1000 meters:

Step	Reconnaissance and Resource Assessment
1	All team members assemble at the downstream end point of the selected stream channel.

A. Install permanent marker in a stable bank. Place second marker near trail or road. Record the necessary data that will identify the site for future location using photographs, compass bearings, GPS instrumentation, site diagram, distance from land features, or text description.

B. Continue walking upstream on both sides of the stream. For consistency when referencing the streambanks, they are referred to as "right bank" and "left bank" when facing upstream.

(1) Measure the stream distance using a hip chain and record the location of erosion events, man made, or natural. Note possible future erosion sources.

(2) Type stream side habitat.

% canopy
% undercut bank
% bank cover and stability
% buffer zone disturbance (riparian corridor health)

(3) Count all large woody debris (LWD) located in the stream and on the banks.

(4) Locate pools and riffles that meet criteria and mark them on the bank with permanent identification (use survey tape on an R-bar, or flag a nearby tree.

(5) Flag fast water habitat for channel cross section measurements.

2. Designate one team member to go upstream ahead of the others to continue with preliminary surveys and assessments. The remaining members of the team will continue surveying and conduct the following assessments:

(1) Begin macroinvertebrate collection in the selected riffles.

(2) Sample the first of six pools and riffles.

(3) Conduct pebble count (D^{50}).

(4) Install HOBO™.

(5) Take temperature readings at V^{STAR} transects of air, soil, sediment, and water.

(6) Take density readings of riparian canopy at each V^{STAR} transect and over each macroinvertebrate sampling transect.

(7) Take the channel cross-sectional area measurements.
-bankfull width & depth
-present water width and depth
-flood plain width and depth
-use water-depth measurements from same transects used at velocity gradients (in riffles/runs) or V^{STAR} (in pools)

(8) Measure the stream gradient at the channel cross-section transects.

(9) Measure the entrenchment at each channel cross-section.

3. The designated team member that proceeded ahead of the team will continue upstream surveying the steam channel for a distance of 1000 meters, measured from the down stream end point, and collect the following information:

(1) Record written comments regarding the habitat types and stream characteristics observed in the channel.

(2) Locate remaining pools, and riffles. Flag with location markers.

(3) Take photographs of stream habitat conditions and channel characteristics.

(4) Prepare written comments regarding observations of channel conditions and unusual geologic formations.

(5) Count and record all deposits of LWD.

(6) At the end point of the reach, take bearings and place an R-bars.

-Place first marker in the stable bank of the stream.
-Place second marker near a trail or road and take a compass reading.
-Photograph markers and local land marks.

4. On the return walk through of the stream channel designate a transect every 20 meters (a total of 50 for the entire reach) and record the following attribute information:

(1) Streambank stability
(2) Stream shading
(3) Stream shore water depth (alluvial streams)
(4) Bank angle (alluvial streams)

(5) Aquatic fauna
(6) Width-to-depth measurement every 5^{th} transect

The sequence of tasks as they are shown above in steps one through four can be rearranged when a time savings can obviously be accomplished and personnel expertise can better be used (Rae 1993).

CHAPTER V: STATISTICAL CONSIDERATIONS IN WATER QUALITY MONITORING

A. RELEVANCE OF STATISTICS TO WATER QUALITY MONITORING [1]

Statistics are an inherent component of nearly all water quality monitoring programs. In most cases a precise formulation of the monitoring objectives results in a question that is best answered on a statistical basis. For example, a common objective of water quality monitoring plans is to determine if a particular management activity is causing an adverse change in water quality. To answer this question in a quantitative manner, it is necessary to acquire data and make a comparison either to other site(s), or to data from the same site prior to the management activity. If the monitoring plan is properly designed and replicated, data analysis will yield specific conclusions with an identified level of risk (Mac Donald et al. 1991).

Other common monitoring objectives include the characterization of a parameter (baseline monitoring), determination of trends (trend monitoring), evaluation of models and standards (validation monitoring), and assessment with regard to a set standard (compliance monitoring). Each of these requires collecting and analyzing data. Statistics provides the scientific basis and procedures for studying numerical data and making inferences about a population based on a sample of that population (Mendenhall 1971, Sokal and Rohlf 1981).

By its very nature, water quality monitoring is a sampling procedure. It simply is not possible to make continuous measurements of all parameters at all locations. This means that before any data are collected one must address questions such as:

- How many samples are likely to be needed to characterize a parameter with a specified degree of uncertainty?
- How many samples are likely to be needed to determine if there is a difference between locations, or a change over time?
- Where and when should samples be taken?
- Which parameters should be measured?
- How will the precision and accuracy of the data be assured?

As the monitoring plan develops and data are collected, there is a continuing need to analyze the data, evaluate whether the data are meeting the objectives, and determine whether the timing and location of sampling is optimal. All these aspects of a monitoring program either require or involve statistics.

Many people react negatively to the use of statistics. Typically this is due to a lack of understanding

[1] Taken directly from MacDonald et al.(1991).

about the role of statistics in water quality monitoring, or past experiences in which the application of statistics led to unexpected conflict or uncertainty. Statistics can make a strong positive contribution to water quality monitoring programs by:

- providing an overall design for collecting and analyzing data;
- facilitating the precise specification of objectives, including an explicit recognition of the uncertainty and potential errors;
- providing a quantitative means to optimize the location and times of sampling, and thereby reduce costs;
- providing a rigorous set of procedures for analyzing the data collected in a water quality monitoring program; and
- providing a quantitative basis for making inferences about the characteristics and response of the populations being sampled.

To take full advantage of these potential benefits, those responsible for preparing monitoring plans should consult with a statistician both early and often. **Too often a statistician is consulted after the data have been collected, and the statistician's tools are unable to salvage inconsistent or unreplicated data.**

These five contributions imply that statistical procedures are critical tools in water quality monitoring, but they are not a substitute for decision-making. Averett (1979) states "data interpretation is an intellectual activity; statistical applications are a mechanical activity." Those responsible for a water quality monitoring program still must decide how much uncertainty can be tolerated and balance the relative risks and costs associated with different types of errors. The managers and technical staff must also determine what type of monitoring design is most appropriate, which parameters to measure, and the initial times and locations for sampling (Mac Donald et al. 1991).

This chapter presents some of the key statistical principles which must be considered in developing a water quality monitoring program. The overall goal is to demystify the role of statistics and statisticians in water quality monitoring programs. The specific objectives are to: (1) explain how statistical considerations should be taken into account in designing and implementing water quality monitoring programs; and (2) explicitly discuss the trade-offs between sample size, inherent variability, level of significance, statistical power, and the minimum detectable effect.

Specific guidance on the selection and use of statistical tests is not addressed in this handbook, as a number of texts provide a much more extensive review of experimental design and data analysis (Gilbert 1987; Green 1989; Sanders et al. 1987; Zar 1984). The books by Gilbert and Sanders are particularly noteworthy because they focus on the statistical methods for monitoring environmental pollution and the design of water quality monitoring networks, respectively. A series of papers by the U.S. Forest Service provides a particularly clear and simple explanation of the statistical aspects of water quality monitoring in forested areas (Ponce 1980a,b), but these may not be as readily available. Two books that focus on nonparametric statistics are recommended: the classic, easily understood text by Siegel (1956) and the recent more rigorous treatment by Daniel (1990).

1. General Design and Replication

The overall design of a monitoring project is largely determined by the monitoring objectives and closely tied to the type of monitoring. In many cases the design of the monitoring plan will determine the statistical procedures used to analyze the data.

Standard statistical designs are based upon a series of experimental units. Experimental units are defined as the objects upon which measurements are made Mendenhall (1971). In an idealized, simple experiment, the experimental units would be randomly selected and half assigned to some treatment, while the other half would be left as untreated controls. Both the treated and the untreated experimental units usually are considered to be representative samples of much larger populations. Repeated measurements on the experimental units generate the data used to describe the sampled populations, and to draw inferences about the larger population from which the experimental units were drawn.

The idealized simple experiment outlined above illustrates several key elements common to all statistical designs. First a population is defined, and samples are drawn from that population. The population might be defined as a particular fish species in a stream reach, in pools of a certain size, or in a certain type of stream. Second, some treatment is applied to the designated experimental units, and this might be timber harvest, forest fertilization, or gravel extraction. Third, this treatment is applied to two or more experimental units, and two or more experimental units are left as controls. Fourth, a series of measurements are made, and these provide the raw data for the statistical analysis.

Unfortunately most water quality monitoring plans do not fit this idealized design. A typical objective of water quality monitoring plans is to determine whether the value of a parameter has changed over time at a particular site. The two most common approaches used to address this question are (1) to measure the selected parameter over time at the site of interest, as in trend monitoring; and (2) to compare data from a treated site with an untreated site, as in project monitoring.

With regard to the first case, there is only one experimental unit, and the data collected are samples of all possible measurements in time. In some cases the onset of a management activity can be used to separate the data into two groups (i.e., before and after), and one can test for significant change over time by comparing the means and variances over the initial period (baseline data) to the means and variances following the onset of the management activity. Often, however, this straightforward approach is not valid because the data should only be serially correlated (i.e., the value of any given data point is related to the previous value), or the data vary according to season, discharge, or other variables.

The approach to detecting trends will depend on the number of data points available and the type of trends or correlations present in the data. Graphing the data is the first and probably most important step in identifying the complicating factors and determining the appropriate statistical approach (Gilbert 1987). A basic choice is either to attempt to remove the trend or correlation and then use parametric statistics, or use nonparametric statistics on the original data. Gilbert (1987) provides a useful guide to trend analysis techniques, and he references Harned et al. (1981) for analyzing discharge-related parameters and Montgomery and Reckhow (1984) for analyzing serially correlated data (Mac Donald et al.1991).

The first and most common design to evaluate changes over time is to monitor a single site. This approach is useful to detect seasonal or other trends, but a basic problem is that statistical inferences cannot be made either about the cause of any observed change at the monitoring site or about the cause of similar changes observed at other sites. Data from other sites are necessary for making inferences about other locations (Hurlbert 1994).

The paired-site approach is the second design which often is used to evaluate change. In this design two sites are monitored, and a statistical relationship between the sites is established for the parameter(s) of interest. After this initial calibration period, one site is subjected to a treatment (e.g., timber harvest), and the other is left as a control. A significant change in the statistical relationship between the sites is used to indicate a treatment effect. This is the basic concept behind paired-watershed experiments (Bosch and Hewlett 1982). For an example this approach has been used in the Casper Creek watershed study on the North Coast of California (Rice et al. 1979).

The advantage of the paired-site approach is that the untreated or control site provides a basis for separating the treatment effect from other extraneous factors (e.g., climatic events). Nevertheless, this design still shares the same major flaw as the single-site approach, namely the lack of replication. In the absence of replicated treated and control sites, there is no information on the spatial variability of the parameter being measured. An estimate of the variability is necessary to make any statistically based inference about the cause of an observed difference between the treated and control sites. Since in most cases sites are not replicated, claims of cause and effect must be based on other information and not statistical testing (Hurlbert 1984). Ideally data should be collected to document the processes responsible for the observed change.

The paired-site approach is commonly used in project monitoring. Typically water quality is measured upstream and downstream of a particular activity, and the observed differences between sites are presumed to be due to particular project or activity. However, the known differences in water quality and stream characteristics between upstream and downstream locations (Naiman et al.1991) means that a pre-project calibration period is essential for unreplicated sites. As in the paired-site approach, the absence of multiple treated (downstream) and control (upstream) sites means that the inference of cause-and-effect must be based on qualitative evaluation rather than statistical testing.

As suggested above, neither the single-site nor the paired-site approach fit into the traditional randomized designs described in statistics texts. In most water quality monitoring plans, the experimental units are streams, lakes, or sampling sites, and these cannot be randomly allocated among treatments such as clear cutting or road building. Typically the experimental units and treatment(s) are already specified, and the objective of the monitoring program is to determine if change has occurred. Sampling sites are often fixed by the presence of a bridge or other structure from which samples can be safely taken at high flows, or by access to the drainage network.

The randomized block design may be the most relevant to water quality monitoring. Each block includes all of the treatments as well as a control. Treatments are randomly assigned to the experimental units within a block. Analysis of variance procedures are used to evaluate the differences between treatments in one or more blocks, regardless of the variation among the different blocks. Thus the primary advantage of this design is to exclude extraneous factors (such as site differences, which occur between blocks) and focus on the differences between treatments within blocks. This makes the design statistically more robust (i.e., the results are reliable over a wider range of conditions).

Paired watersheds and upstream-downstream comparisons represent two of the simplest forms of a block design. The combination of a watershed and a control watershed form one, unreplicated block. Additional paired watersheds undergoing identical treatments result in additional blocks. To the extent that treatments are randomly assigned to each experimental watershed within a block, this yields a randomized block design, and statistical inferences can be made regarding (1) the cause of any observed differences, and (2) the likely result of a similar treatment on other unmonitored sites that are part of the same population.

In the case of upstream-downstream comparisons, the upstream site usually acts as the control, and the downstream site usually serves as the treated site. Again the addition of paired upstream-downstream sites generates additional blocks. The problem with this design is that the treatments are not randomly assigned within each block, but are set according to a pre-determined and recognized site difference. The statistical design to resolve this problem is to replicate pairs without any treatment or project and compare the upstream-downstream differences between these untreated pairs to the differences for the pairs where there actually is a management activity. Alternatively, a relationship between each upstream and downstream location could be established during a calibration period, and a change in this relationship following management activities would indicate a treatment effect rather than a site difference.

In practice it is often assumed that natural variability overwhelms any consistent site effect between the upstream and downstream locations. In this case, a calibration period might not be necessary, and any difference between the sites should be due solely to the treatment being studied. Such an approach is inconsistent with basic statistical principles as indicated above.

The problem of separating site differences from treatment differences is particularly acute for many of the channel parameters. Channel cross-sections, pool parameters, and bed material particle size are all sensitive to environmental factors such as the local geology and landforms, and they may exhibit considerable variation over relatively short distances. As previously discussed, the problem of spatial variation can at least be alleviated by carefully identifying the sites to be monitored, and monitoring prior to initiating management activities. This availability of pre-project data is critical to inferring management effects, and also influences the choice of statistical test(s).

2. Benefits of a Proper Statistical Design

The importance of the statistical design can be illustrated by an example. Suppose a land manager needed to determine if clearcutting increases the number of landslides. The staff reviewed a recent set of aerial photos and determined that there were 25 landslides on 5,000 acres of clearcuts, and 50 landslides on 20,000 acres of mature forest. Although the number of landslides per unit area proportionally was twice as high on clearcuts as mature forest. it is not possible to make any generalizations or statistical conclusions because data on the variability of the number of landslides on clearcut and forested areas was unavailable. Statistical analyses require multiple measurements in time or space, but the results cited above are from a single survey of one control and one treated experimental unit.

One might argue that statistical rigor may not be important in cases where the difference is relatively large, but what is the certainty associated with the statement that clearcutting increases landslides if there were 70, 80, or 90 landslides in the uncut form? The overall trend in land management is towards increasing regulation to eliminate the obvious adverse impacts. Hence increasingly sensitive techniques will be required to evaluate future management effects, and this will require proper statistical designs.

Collection of essentially the same data in the context of an overall statistical design can greatly increase the value of the data. In the above example, instead of treating the entire area as one experimental unit with two treatments (clearcut and forested), the staff should have identified the population of clearcuts units and potentially harvestable forested units. Then data on the area and number of landslides in each clearcut and each forested unit should have been collected. This procedure would yield a data set consisting of the number of landslides per unit area for each potentially harvestable forested unit and each clearcut unit. Since these data represent a sample of a much larger population of clearcut and potentially harvestable forested areas, statistical techniques can be used to determine the following:

- the mean and variance of the number of landslides in each land use type;
- the approximate shape of the underlying distribution of the data (e.g., normal, binomial, Poisson, lognormal);
- the significance probability associated with the observed difference in the number of landslides between the two land use types; and
- the likelihood of obtaining a false conclusion.

A proper statistical design can greatly improve the efficiency of data collection. For example, if the staff thought that the difference in the number of landslides in the clearcut and forested units was relatively large, measurements might only be made on a random sample of 10% of the units. If this sample indicated a statistically significant difference, measuring the remaining units might be unnecessary, and a substantial savings in the cost of the study would be realized.

The potential benefits of an adequate statistical design are even more apparent if there are several sources of variation. In the above example, the frequency of landslides might be strongly influenced by slope steepness, amount of roading, or the type of bedrock. If the sample size is sufficiently large, statistical procedures can be used to separate these factors. Such information is extremely useful for developing practical management procedures, such as identifying high-risk areas or predicting sediment input to streams from landslides (MacDonald et al.1991).

B. PRINCIPLES OF SAMPLING [1]

Many of the most important principles of sampling are similar to the principles of statistical design, and these are discussed in most statistical texts. The three basic types of sampling are random, systematic, and stratified, and each can be applied in space or over time (MacDonald et al. 1991).

The procedure for simple random sampling is to clearly identify the universe of potential sampling times or locations, and then select individual times or locations for sampling according to a random number table or any random procedure. If information on the variability of the parameter is known, then the number of samples needed to achieve a certain confidence interval can be calculated. For example, simple random sampling might be used to select the particular day for measuring pH in a large river.

Using simple random sampling to select monitoring sites may prove difficult in practice because it requires identifying all possible sampling sites (i.e., the sampling frame). This may not be a problem if the precise location of the sample is not important. The sites for monitoring many water column parameters, for example, could be randomly selected from the population of river miles. Simple random sampling could be very time-consuming if one wishes to sample only certain habitat types (Hankin and Reeves 1988).

Systematic sampling consists of randomly selecting the first sample, and then selecting all subsequent samples by applying a constant interval. Systematic sampling can result in a biased sample if there is a systematic variation in the population being measured. For example, if the timing of the first sample in a given year was determined randomly, and subsequent samples were taken at exactly 6-month intervals, this might not represent a true long-term average because all the samples would be taken in two different seasons. Hankin and Reeves (1988) discuss the merits of different sampling schemes to estimate fish abundance and habitat areas in small streams. They advocate systematic

[1] Taken directly from MacDonald et al.(1991).

sampling of individual habitat units (e.g., measuring the area of every tenth glide, or counting the fish in every fifth plunge pool) because it is the most practical and is unlikely to significantly bias the results. Systematic sampling along a river or stream can be an efficient means to detect distinct but unknown sources of pollution (Gilbert 1987).

Stratified random sampling involves some grouping of the population of interest, and then randomly sampling each group or stratum (Ponce 1980a). This procedure is often used in water quality sampling because certain parameters are known to vary by the time of day, season, discharge, or some other factor. The different strata can be sampled at different frequencies according to the estimated size of the population (proportional sampling) or the variability within the different strata (optimal sampling). Optimal sampling generally is preferable for flow-dependent parameters, whereas proportional sampling may be equally efficient for time-dependent (e.g., seasonally varying) parameters.

The advantages of stratified random sampling are similar to the advantages of a randomized block design, in that it can (1) improve the efficiency of sampling, (2) provide separate data on each stratum, and (3) enhance the sensitivity of statistical tests by separating the variability among strata from the variation within strata. The information needed to construct the strata and estimate the sampling frequency must either be known prior to sampling or obtained through a pilot study.

Seasonal strata are often used for sampling invertebrates and fish, while discharge is often used to establish strata for sampling sediment and the other physical and chemical constituents of water. Stratification by discharge also helps ensure that high flows are sufficiently sampled.

For water quality programs the decision regarding where to sample is largely determined by the objectives of the monitoring program, location of the management activities, layout of the catchment(s) to be monitored, access to the monitoring sites, and the design of the monitoring program. These issues are discussed in greater detail in Gilbert (1987); Kunkle et al. (1987); Ponce (1980a,b); Sanders et al. (1987). For project monitoring the general principle is to locate the sampling sites as close to the actual project as practicable, as the largest water quality impact will be immediately downstream of the activity. Minimizing the distance between the upstream (control) and downstream (treated) sites will help minimize confounding site differences.

Empirical knowledge of the basin to be monitored (derived possibly from a watershed assessment) is extremely helpful in developing a monitoring program (Ponce 1980a). Even a cursory inspection can indicate the types of adverse change that are likely to be encountered and the spatial distribution of management activities. This type of spatial data provides much of the guidance needed to establish sites and direct the monitoring activities towards the problem areas.

Monitoring of channel characteristics or water quality within a particular basin or region may best be achieved with a spatial stratified sampling scheme. In keeping with the principles of stratified random sampling, the best approach is to classify stream segments and subsample. Rosgen (1985) and Cupp

(1989) are probably the two most widely used stream classifications systems at this time. Once the stream segments have been identified, an additional stratification into habitat units may be desirable (Hankin and Reeves 1988). Specific details for laying out such nested sampling schemes are beyond the scope of this Handbook, but the principles and references cited in this chapter can provide the necessary guidance.

In turbulent streams many of the physical and chemical constituents of water are relatively insensitive to the precise monitoring location. For these parameters a general site description, such as just upstream of a particular tributary, usually is sufficient. In less turbulent reaches, some parameters, such as suspended sediment, can vary considerably with depth, and the reader should refer to the appropriate U.S. Geological Survey publication for detailed sampling guidelines.

Other parameters, particularly those that pertain to channel geomorphology, may exhibit a great deal of variation over a few meters. For these parameters a more precise site description is needed, and this usually is based on prior knowledge. Bed material particle size, for example, might be evaluated in certain geomorphologically determined locations, like the downstream edge of a point bar. Embeddedness often is measured in riffles with certain characteristics, although the precise location of each sample is random.

Even after determining the general time and location of sampling, another series of sampling questions must be addressed. Is a grab sample close to the bank adequate, or should a series of depth-integrated samples be taken across a particular cross-section? Is one sample in time adequate, or should several samples be taken? If several samples are taken across a channel or over a relatively short time, should these samples be kept separate or combined?

The answer to these questions largely depends on the objectives of the study, the parameter being measured, and the site characteristics. Certainly the same statistical principles apply to these fine-scale questions of sampling as they do to the larger-scale questions of location and timing discussed above. Composite samples over time or space can represent a substantial saving in analytic costs, but this reduces the resolution of the data. Samples for analyzing bacterial contamination should never be composited. If only a single grab sample can be taken, this should be taken in the middle of the stream at the 0.6 depth (Ponce 1980a). Specific recommendations for sampling various parameters can be found in APHA (1989); Gresson et al.(1977); Guy (1970), and Guy and Norman (1970). Once a monitoring project has been initiated, any change in sampling procedure should be undertaken very cautiously, as this may preclude any comparisons to data collected using any other procedure (Dissmeyer 1994).

1. Frequency of Monitoring [1]

An important constraint in developing a monitoring plan is the anticipated cost of obtaining the necessary data. In this section the cost of acquiring data is analyzed in terms of the typical frequency

of sampling and the range of flow conditions that need to be sampled. The time required to obtain a sample, the equipment required to obtain a sample, and the cost of analyzing the sample or field data. All of these factors must be evaluated before one can estimate the cost of acquiring data on a particular monitoring parameter (Mac Donald et al. 1991).

As discussed previously, the sampling frequency is a function of the statistical objectives of the monitoring project. Any change in the desired accuracy or reliability of the results directly affects the sample size and the choice of parameters. All the parameters discussed in these guidelines also are subject to spatial and temporal variability, and this again affects their relative precision and ability to detect change.

A monitoring project that is attempting to detect a relatively small change with a high degree of certainty will be more costly than a monitoring program with a lower standard for identifying a statistically significant change. More measurements will increase the precision and hence the ability to detect change, but the marginal cost and benefit of each additional measurement will vary according to the parameter.

In the first column of Table 1, (Frequency and Cost of Data or Sample Collection by Monitoring Parameters), the monitoring parameters are grouped according to the typical frequency and timing of measurements. Parameters that need to be measured only annually, seasonally or more frequently over a relatively short time period (e.g., daily for 2 weeks in mid-summer) are rated as having a low sampling frequency. These include most of the geomorphic and riparian parameters, as well as the forest chemicals such as herbicides and pesticides. Those parameters rated as having a high frequency of monitoring, such as the sediment parameters, must either be measured over all flow conditions or be intensively monitored over a series of high flow events.

The frequency of sampling for most of the water column parameters cannot be easily defined because of the large range of monitoring objectives. Low flow, baseline, or trend data might be obtained with relatively few measurements, while monitoring total nutrient loads (e.g., to protect downstream oligotrophic lakes) requires much more frequent sampling.

The second column in Table 1 indicates the flows over which sampling should be carried out in order to properly characterize the parameter of interest. For many parameters, such as those relating to channel characteristics and riparian conditions, the measurements can be made whenever it is practical and safe. Other parameters must be measured at high flows, and this can be an important constraint

[1] Taken directly from MacDonald et al.(1991).

when access to the sampling is difficult, or when there is no bridge or other structure from which samples can be safely taken.

The channel and riparian parameters generally have the lowest measurement frequency and are the least restrictive with regard to the timing of measurements. This is due to the fact that they are with the exception of habitat types not flow-dependent. Although large discharge events can have a major effect, the parameters listed under channel characteristics usually are monitored on an annual basis.

In contrast, the three sediment parameters-turbidity, suspended sediment, and bedload-are highly dependent on discharge. Since virtually all of the sediment transport occurs during high flow events, and there can be considerable variation in sediment transport within a given storm event, frequent sampling is needed during high discharge events. A similar logic applies to the monitoring of changes in water yield and the size of peak flows.

The other biologic parameters such as algae, invertebrates, and fish exhibit seasonal variation. The optimal time and frequency of sampling will vary with location and objective, but at a minimum the invertebrate populations should be sampled in the spring and fall (EPA 1989b), and the resident fish population in spring and summer.

2. Amount of Data Collected [1]

The amount and type of data needed vary significantly among monitoring levels, reflecting the number and complexity of methods used. It is important at all levels of monitoring that data be collected systematically according to a plan that specifies parameters. The observers must be properly trained to ensure consistent interpretation of conditions, measurements, and sample collection. Field, laboratory, and analysis forms need to be developed to ensure nothing is overlooked. Simple forms will suffice for low levels of monitoring, but will increase in complexity and detail with higher levels. Recording data on forms facilitates entry into a database. Data have lasting value only if stored in a database and can be readily accessed and analyzed. Analysis of a monitoring database can identify BMPs that are consistently effective, those that are only effective in specific situations, and those that need modification, and can reveal in-stream responses to BMPs implemented in various ecoregions.

A quality assurance/quality control (QA/QC) program is needed at all levels of monitoring to ensure consistency of interpretation and accuracy of data. This includes checking performance of observers. It will vary by monitoring level and the variables being assessed.

[1] Taken directly from Dissmeyer (1994).

3. Quality Assurance and Quality Control [1]

Laboratory Analytical Procedures: Methods of sample and data analysis should be specified. For EPA-approved or standard methods, pertinent literature should be referenced. For nonstandard or modified methods, detailed operating procedures should be provided, including sample preparation and analytical procedures.

Field Sampling Procedures: Field sampling procedures should include steps to be taken to assure the quality of samples and sample data. The sampling procedures will vary by variable. The following are examples of procedures to documented:

a. Specific physical, chemical, biological and habitat variables to sample
b. For biological variables, identify target assemblages
c. Sampling methodology
d. Habitat-assessment methodology
e. Details of sample preservation
f. Use and calibration of instruments
g. Replication and QC requirements
h. Sampling site selection

Sample Custody: A chain-of-custody procedure should be developed to ensure a written record traces the possession of the sample from the time of collection through data analysis.

Calibration Procedures and Frequency: A program of calibration procedures should be written to assure that field and laboratory equipment is functioning at an optimal level.

Preventive Maintenance: A plan for routine inspection and preventive maintenance should be developed for all field and laboratory equipment and facilities to ensure data of consistently high quality.

Data Reduction, Validation, and Reporting: This part of the QA plan is designed to ensure good data by maintaining data quality throughout data reduction, transfer, storage, retrieval, and reporting. For example, biotic samples should be checked for proper taxonomic identification and forms checked for completeness, recording errors, plausibility, and consistency.

Internal Quality Control Checks: All personnel participating in monitoring activities must be trained in the proper use and maintenance of sampling equipment. They must be aware of the limitations of each piece of equipment. Internal quality-control checks can include replicate samples at stations to check consistency of collection, repeat field collections by separate crews, etc.

[1] Taken directly from Dissmeyer (1994).

Data Precision and Accuracy Procedures: The best approach to ensure precision and accuracy is ensure that project personnel have received adequate training and gained the necessary experience to conduct the project. Adequate training of personnel in methods application is the best way to ensure consistency, repeatability, and precision.

Performance Audits and Systems Audits: Quality control checks on the procedures used by field personnel should be done periodically during the field season. If any problems are found, corrective action must be taken immediately.

Corrective Action: A corrective-action program should be developed capable of detecting errors at any point in the project implementation process. The program must be able to identify problems and their source, implement action to correct them, document results of corrective action, and continue the process until each problem is eliminated.

Quality Assurance Reports: A formal report should be written to inform appropriate managers about the performance and progress of the monitoring plan.

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APPENDICES:

APPENDIX A.
COHO SALMON

The coho salmon (Oncorhynchus kisutch) is an anadromous salmonid species that was historically distributed throughout the North Pacific Ocean from central California to Point Hope, AK, through the Aleutian Islands, and from the Anadyr River, Russia, south to Hokkaido, Japan. Historically, this species probably inhabited most coastal streams in Washington, Oregon, and northern and central California. Some populations, now considered extinct, are believed to have migrated hundreds of miles inland to spawn in tributaries of the upper Columbia River in Washington, and the Snake River in Idaho.

In contrast to the life history patterns of other anadromous salmonids, coho salmon on the west coast of North America generally exhibit a relatively simple 3-year life cycle. Adults typically begin their freshwater spawning migration in the late summer and fall, spawn by mid-winter, and then die. Run and spawn timing of adult coho salmon vary between and within coastal and Columbia River Basin populations. Depending on river temperatures, eggs incubate in "redds" (gravel nests excavated by spawning females) for 1.5 to 4 months before hatching as alevins" (a larval life stage dependent on food stored in a yolk sac). Following yolk sac absorption, alevins emerge from the gravel as young juveniles, or "fry," and begin actively feeding. Juveniles rear in fresh water for up to 15 months, then migrate to the ocean as "smolts" in the spring. Coho salmon typically spend two growing seasons in the ocean before returning to their natal streams to spawn as 3 year-olds. Some precocious males, called "jacks," return to spawn after only 6 months at sea.

For additional life histories,and habitat requirements, refer to the following publications:

Hasler,T.K.1987. Species Profiles: Life Histories and Environmental Requirements of Coastal Fishes and Invertebrates Pacific Southwest: Coho Salmon.U.S. Dept. Int., Fish Wild. Serv. Biological report 82 (11.70) TR EL-82-4.

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APPENDIX B.
ASSESSMENT FIELD SHEETS

Watershed Overviews

Watershed Condition Prognosis

Habitat Inventory form
- Riffle Run/Pool Diagram
- Canopy Measurement
- Woody Debris

Habitat Assessment Field Data Sheet-Glide/Pool Prevalence

Pool Frequency, Depth and Volume Measures
- V^* Pool Measurements
- V^* Pool Diagram Measurements

Habitat Assessment Field Data Sheet-Riffle/Run Prevalence
- RASI "D" Index

DFG Water Pollution Control Laboratory-Stream Bioassessment Procedures
- DFG In-Stream Bioassessment Procedures
- California Stream Bioassessment Worksheet
- Stream Bioassessment Record
- DFG Chain of Custody Record

BMP Compliance Check List

Watershed Condition Prognosis

Environmental Condition: ____________________

Current State ____________________

Input Variable(s) Influencing ____________________

Contribution from Past Forest Practices Effects: ____________________

____

____

Contribution from Current Practices: ____________________

____

____

Expected Contribution from Future Practices: ____________________

____

____

Contribution from Non-forestry Related Effects: ____________________

____

Interactive Factors: ____________________

____

____

Influence of Extreme Events: ____________________

____

____

Other: ____________________

____

HABITAT INVENTORY FORM

page #___of___

Date __/__/___ Stream Name ____________________ T___ R___ S___

REFERENCE POINT UTM N E

Surveyors________________________

Channel Type______ Reach #______ Time______ Air T°_____ Water T°_____ Flow ______

Habitat Unit Number							
Habitat Unit Type							
Side Channel Type							
Mean Length							
Gradient (%)							
Mean Width							
Mean Depth							
Maximum Depth							
Depth Pool Tail Crest							
Stream Shelter Value (1 to 4)							
% Unit Shelter							
% undercut banks							
% swd (d<12")							
% lwd (d>12")							
% root mass							
% terrestrial veg.							
% aquatic veg.							
% white water							
% boulders							
% bedrock ledges							
Percent Total Canopy >30cm							
Right Bank dominant type*							
% Right Bank vegetated							
Left Bank dominant type*							
% Left Bank vegetated							

* **Bank composition types:** 1. bedrock/rock 2. boulder 3. cobble/gravel 4. bare soil 5. grass 6. brush 7. trees

Unit #	Comment

Monitoring Program Identification

Resource Sensitivity Number: ______________________________

Prescription Objective: ______________________________

____

Long-term Resource Objective: ______________________________

____

Recommended Monitoring Measures

Effectiveness of Prescription:

Who:

Trends in Resource Condition:

Who:

Date: ____________ Crew Members: ____________

Reach Number: ________ ____________

Riffle/Run/Pool Number: ________ ____________

Stream: ________ Scale 1 cell = ________

Canopy Measurements

Stream: ____________________
Date: ____________________
Reach Number: ______________
Habitat Number: ______________

Crew Members: ____________________________

____

SHERICAL DENSIOMETER

Location	Readings	Open/Closed (O/C)
Top + 5m	___ ___ ___ ___	___
Top	___ ___ ___ ___	___
Middle	___ ___ ___ ___	___
Bottom	___ ___ ___ ___	___
Bottom + 5m	___ ___ ___ ___	___

SIGHTING TUBE

Top + 5m ___

___

Top ___

___

___

Middle ___

___

___

Bottom ___

___

Bottom + 5m ___

BASAL AREA (CRUZ - ALL)

	Top	Middle	Bottom
5			
10			
20			
40			
Total			

HILLSIDE SLOPE (Looking Upstream)

Woody Debris

Stream: ______________ Channel Width ________ Page _____ of _____

Date: / / Min Debris Size ________

Reach ______________ Crew Members: ______________________________

____

Volume		Cover		Pool attributes (low Q)				Substrate	
Active Channel		Bankfull Ch		Active Channel				Bankfull	
Diameter	Length	W	L	D max	D ave	D Rif Cr.	Area	Change	Notes:
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HABITAT ASSESSMENT FIELD DATA SHEET
RIFFLE/RUN PREVALENCE

1. BOTTOM SUBSTRATE - PERCENT FINES [fraction of substrate less .25 inch (6.35mm) in diameter]:

Optimal	Sub-Optimal	Marginal	Poor
Less than 10% fines	Between 10 - 20 % fines	Between 20 - 50 % fines.	Greater than 50 percent fines.
16 - 20 _____	11 -15 _____	6 - 10 _____	0 - 5 _____

2. INSTREAM COVER (FISH):

Optimal	Sub-Optimal	Marginal	Poor
Greater than 50% mix of cobble gravel, large woody debris, undercut banks, or other stable fish cover.	30 - 50 % mix of cobble, gravel, or other stable fish cover. Adequate cover.	10 - 30 % mix of cobble, gravel, or other stable fish cover. Cover availability is less than desirable.	Less than 10% cobble, gravel or other stable cover. Lack of cover is obvious.
16 - 20 _____	11 -15 _____	6 - 10 _____	0 - 5 _____

3. EMBEDDEDNESS (RIFFLE):

Optimal	Sub-Optimal	Marginal	Poor
Gravel, cobble and boulder particles are between 0 - 25% surrounded by fine sediment. [particles less than .25 inches (6.35mm)]	Gravel, cobble and boulder particles are between 25 - 50% surrounded by fine sediment.	Gravel, cobble and boulder particles are between 50 - 75% surrounded by fine sediment.	Gravel, cobble and boulder particles are over 75% surrounded by fine sediment, or bottom is composed of sand, clay or bedrock.
16 - 20 _____	11 -15 _____	6 - 10 _____	0 - 5 _____

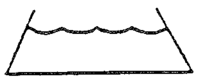
4. VELOCITY/DEPTH:

Optimal	Sub-Optimal	Marginal	Poor
Slow/deep; slow/shallow; fast/deep; and fast/shallow habitats all present.	Only 3 of the 4 habitat categories present (missing riffles or runs score lower than missing pools).	Only 2 of the 4 habitat categories present (missing riffles or runs receive lower scores).	Dominated by 1 velocity/depth category.
16 - 20 _____	11 -15 _____	6 - 10 _____	0 - 5 _____

5. CHANNEL SHAPE (WETTED CHANNEL) - *dominant shape:*

Optimal

Trapezoidal



11 - 15 _____

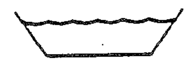
Sub-Optimal/Marginal

Rectangular

6 - 10 _____

Poor

Inverse trapezoidal



0 - 5 _____

6. POOL/RIFFLE RATIO - POOL LENGTH DIVIDED BY RIFFLE LENGTH:

Optimal

Ratio: 1 - 3. Variety of habitat. Pattern of sequence relatively frequent.

12 - 15 _____

Sub-Optimal

Ratio: 4 - 9. Less frequent repeat pattern.

8 - 11 _____

Marginal

Ratio: 10 - 20. Infrequent riffle.

4 - 7 _____

Poor

Ratio: >20. Homogeneous habitat.

0 - 3 _____

7. WIDTH TO DEPTH RATIO (USING WETTED WIDTH):

Optimal

Lower bank width to depth ratio <7 (Channel wetted width divided by depth).

12 - 15 _____

Sub-Optimal

Width to Depth ratio 8- 15.

8 - 11 _____

Marginal

Width to Depth ratio 15 - 25.

4.- 7 _____

Poor

Width to Depth ratio >25.

0 - 3 _____

8. BANK VEGETATION PROTECTION:

Optimal

Over 90% of the streambank surfaces covered by vegetation.

9 - 10 _____

Sub-Optimal

70 - 89% of the streambank surfaces covered by vegetation.

6 - 8 _____

Marginal

50 - 79 % of the streambank surfaces covered by vegetation.

3 - 5 _____

Poor

Less than 50% of the streambank surfaces covered by vegetation.

0 - 2 _____

9. LOWER BANK STABILITY:

Optimal	Sub-Optimal	Marginal	Poor
Lower bank stable. No evidence of erosion or bank failure.	Moderately stable. Infrequent small areas of erosion mostly healed over.	Moderately unstable. Moderate frequency and size of erosional areas.	Unstable. Many eroded areas. "Raw" areas frequent along straight sections and bends.
9 - 10 ____	6 - 8 ____	3 - 5 ____	0 - 2 ____

10. DISRUPTIVE PRESSURES (ON STREAMBANK, IMMEDIATELY ADJACENT TO STREAM):

Optimal	Sub-Optimal	Marginal	Poor
Vegetative disruption minimal or not evident. Almost all potential plant biomass at present stage of development remains.	Disruption evident but not affecting community vigor. Vegetative use is moderate, 60 - 90% of the potential plant biomass remains.	Disruption obvious; some patches of bare soil or closely cropped vegetation present. 30 - 60 % of the potential plant biomass remains.	Disruption of streambank vegetation is very high. Vegetation has been removed to less than 30 % of the potential plant biomass.
9 - 10 ____	6 - 8 ____	3 - 5 ____	0 - 2 ____

11. ZONE OF INFLUENCE - WIDTH OF RIPARIAN VEGETATIVE ZONE - LEAST BUFFERED SIDE:

Optimal	Sub-Optimal	Marginal	Poor
Width of riparian vegetative zone (on each side) is at least 4 times the width of the stream. Human activities have not impacted this zone at all.	Width of riparian zone (each side) is at least 2 times the width of the stream. Human activities have impacted this zone only minimally.	Width of riparian zone (each side) is at least as wide as the stream. Human activities have impacted the riparian zone a great deal.	Little or no riparian vegetation due to man induced activities (parking lots, clearcuts, lawns or crops planted to the edge of stream).
9 - 10 ____	6 - 8 ____	3 - 5 ____	0 - 2 ____

HABITAT ASSESSMENT FIELD DATA SHEET
RIFFLE/RUN PREVALENCE

1. BOTTOM SUBSTRATE - PERCENT FINES [fraction of substrate less .25 inch (6.35mm) in diameter]:

Optimal	Sub-Optimal	Marginal	Poor
Less than 10% fines	Between 10 - 20 % fines	Between 20 - 50 % fines.	Greater than 50 percent fines.
16 - 20 ____	11 -15 ____	6 - 10 ____	0 - 5 ____

2. INSTREAM COVER (FISH):

Optimal	Sub-Optimal	Marginal	Poor
Greater than 50% mix of cobble gravel, large woody debris, undercut banks, or other stable fish cover.	30 - 50 % mix of cobble, gravel, or other stable fish cover. Adequate cover.	10 - 30 % mix of cobble, gravel, or other stable fish cover. Cover availability is less than desirable.	Less than 10% cobble, gravel or other stable cover. Lack of cover is obvious.
16 - 20 ____	11 -15 ____	6 - 10 ____	0 - 5 ____

3. EMBEDDEDNESS (RIFFLE):

Optimal	Sub-Optimal	Marginal	Poor
Gravel, cobble and boulder particles are between 0 - 25% surrounded by fine sediment. [particles less than .25 inches (6.35mm)]	Gravel, cobble and boulder particles are between 25 - 50% surrounded by fine sediment.	Gravel, cobble and boulder particles are between 50 - 75% surrounded by fine sediment.	Gravel, cobble and boulder particles are over 75% surrounded by fine sediment, or bottom is composed of sand, clay or bedrock.
16 - 20 ____	11 -15 ____	6 - 10 ____	0 - 5 ____

4. VELOCITY/DEPTH:

Optimal	Sub-Optimal	Marginal	Poor
Slow/deep; slow/shallow; fast/deep; and fast/shallow habitats all present.	Only 3 of the 4 habitat categories present (missing riffles or runs score lower than missing pools).	Only 2 of the 4 habitat categories present (missing riffles or runs receive lower scores).	Dominated by 1 velocity/depth category.
16 - 20 ____	11 -15 ____	6 - 10 ____	0 - 5 ____

HABITAT ASSESSMENT FIELD DATA SHEET
GLIDE/POOL PREVALENCE

1. POOL SUBSTRATE CHARACTERISTIC:

Optimal	Sub-Optimal	Marginal	Poor
Mixture of substrate materials with gravel and firm sand prevalent; root mats and submerged vegetation common.	Mixture of soft sand, mud, or clay; mud may be dominant; some root mats and submerged vegetation present.	All mud or clay or channelized with sand bottom; little or no submerged vegetation.	Hard-pan clay or bedrock; no root mat or submerged vegetation.
16 - 20 ____	11 -15 ____	6 - 10 ____	0 - 5 ____

2. INSTREAM COVER (FISH):

Optimal	Sub-Optimal	Marginal	Poor
Greater than 50% mix of cobble gravel, large woody debris, undercut banks, or other stable fish cover.	30 - 50 % mix of cobble, gravel, or other stable fish cover. Adequate cover.	10 - 30 % mix of cobble, gravel, or other stable fish cover. Cover availability is less than desirable.	Less than 10% cobble, gravel or other stable cover. Lack of cover is obvious.
16 - 20 ____	11 -15 ____	6 - 10 ____	0 - 5 ____

3. POOL VARIABILITY:

Optimal	Sub-Optimal	Marginal	Poor
Even mix of deep, shallow, large and small pools.	Majority of pools large and deep very few shallow pools.	Shallow pools much more prevalent than deep pools.	Majority of pools small and shallow or pools absent.
16 - 20 ____	11 -15 ____	6 - 10 ____	0 - 5 ____

4. CANOPY COVER (SHADING):

Optimal	Sub-Optimal	Marginal	Poor
A mixture of conditions where some areas of water surface are fully exposed to sunlight, and other areas are receiving various degrees of filtered light.	Covered by sparse canopy; entire water surface receiving filtered light.	Completely covered by dense canopy; water surface completely shaded OR nearly full sunlight reaching water surface. Shading limited to <3 hours per day.	Lack of canopy, full sunlight reaching the water surface.
16 - 20 ____	11 -15 ____	6 - 10 ____	0 - 5 ____

HABITAT ASSESSMENT FIELD DATA SHEET
GLIDE/POOL PREVALENCE

5. CHANNEL SHAPE (WETTED CHANNEL) - *dominant shape:*

Optimal

Trapezoidal

11 - 15 ____

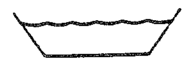
Sub-Optimal/Marginal

Rectangular

6 - 10 ____

Poor

Inverse trapezoidal



0 - 5 ____

6. CHANNEL SINUOSITY:

Optimal

Instream channel length 3 to 4 times the straight line distance.

12 - 15 ____

Sub-Optimal

Instream channel length 2 to 3 times the straight line distance.

8 - 11 ____

Marginal

Instream channel length 1 to 2 times the straight line distance.

4 - 7 ____

Poor

Channel straight; channelized waterway.

0 - 3 ____

7. WIDTH TO DEPTH RATIO (USING WETTED WIDTH):

Optimal

Lower bank width to depth ratio <7 (Channel wetted width divided by depth).

12 - 15 ____

Sub-Optimal

Width to Depth ratio 8- 15.

8 - 11 ____

Marginal

Width to Depth ratio 15 - 25.

4 - 7 ____

Poor

Width to Depth ratio >25.

0 - 3 ____

8. BANK VEGETATION PROTECTION:

Optimal

Over 90% of the streambank surfaces covered by vegetation.

9 - 10 ____

Sub-Optimal

70 - 89% of the streambank surfaces covered by vegetation.

6 - 8 ____

Marginal

50 - 79 % of the streambank surfaces covered by vegetation.

3 - 5 ____

Poor

Less than 50% of the streambank surfaces covered by vegetation.

0 - 2 ____

HABITAT ASSESSMENT FIELD DATA SHEET
GLIDE/POOL PREVALENCE

9. LOWER BANK STABILITY:

Optimal	Sub-Optimal	Marginal	Poor
Lower bank stable. No evidence of erosion or bank failure.	Moderately stable. Infrequent small areas of erosion mostly healed over.	Moderately unstable. Moderate frequency and size of erosional areas.	Unstable. Many eroded areas. "Raw" areas frequent along straight sections and bends.
9 - 10 ____	6 - 8 ____	3 - 5 ____	0 - 2 ____

10. DISRUPTIVE PRESSURES (ON STREAMBANK, IMMEDIATELY ADJACENT TO STREAM):

Optimal	Sub-Optimal	Marginal	Poor
Vegetative disruption minimal or not evident. Almost all potential plant biomass at present stage of development remains.	Disruption evident but not affecting community vigor. Vegetative use is moderate, 60 - 90% of the potential plant biomass remains.	Disruption obvious; some patches of bare soil or closely cropped vegetation present. 30 - 60 % of the potential plant biomass remains.	Disruption of streambank vegetation is very high. Vegetation has been removed to less than 30 % of the potential plant biomass.
9 - 10 ____	6 - 8 ____	3 - 5 ____	0 - 2 ____

11. ZONE OF INFLUENCE - WIDTH OF RIPARIAN VEGETATIVE ZONE - LEAST BUFFERED SIDE:

Optimal	Sub-Optimal	Marginal	Poor
Width of riparian vegetative zone (on each side) is at least 4 times the width of the stream. Human activities have not impacted this zone at all.	Width of riparian zone (each side) is at least 2 times the width of the stream. Human activities have impacted this zone only minimally.	Width of riparian zone (each side) is at least as wide as the stream. Human activities have impacted the riparian zone a great deal.	Little or no riparian vegetation due to man induced activities (parking lots, clearcuts, lawns or crops planted to the edge of stream).
9 - 10 ____	6 - 8 ____	3 - 5 ____	0 - 2 ____

Pool Frequency, Depth and Volume measures

Stream: ________________ Reach Number: ______ Page ____ of ____

Category: ________________ Date: / /

Crew: ____ Elev @ 0 ________

Crew: ____ Elev @ 1000 ______

Comments: ____

< 1 Meter3	1-2 Meter3	2-4 Meter3	4-8 Meter3	>8 Meter3	Max Depth	End Pool	NOTES

V* Pool Measurements

Page ____ of ____

Stream: ____________________

Date: ____________________ Crew Members: ______________________________

Reach Number: __________ ______________________________

Pool Number: __________ Pool Length ________ Pool distance from start reach: _____

Riffle Crest Measurements:

_____

Transect No. __

Distance from head of Pool _____ Transect Intersect @ _____

Dist. from bank															
Water Depth (cm)															
Pool Depth (cm)															

Transect No. __

Distance from head of Pool _____ Transect Intersect @ _____

Dist. from bank															
Water Depth (cm)															
Pool Depth (cm)															

Transect No. __

Distance from head of Pool _____ Transect Intersect @ _____

Dist. from bank															
Water Depth (cm)															
Pool Depth (cm)															

Transect No. __

Distance from head of Pool _____ Transect Intersect @ _____

Dist. from bank															
Water Depth (cm)															
Pool Depth (cm)															

Transect No. __

Distance from head of Pool _____ Transect Intersect @ _____

Dist. from bank															
Water Depth (cm)															
Pool Depth (cm)															

Transect No. __

Distance from head of Pool _____ Transect Intersect @ _____

Dist. from bank															
Water Depth (cm)															
Pool Depth (cm)															

V* Pool Measurements

Date: ____________________ Crew Members: ________________________________

Reach Number: __________ ________________________________

Pool Number: __________ ________________________________

CALIFORNIA STREAM BIOASSESSMENT PROCEDURES

The following procedures are used to conduct the biological assessment portion of the Timber Harvest Program - Pilot Monitoring Study. The biological assessment will be conducted on approximately 20 riffle units in each watershed and five riffle units in a control watershed. Riffle units used for biological assessment should be the same as those used for measuring habitat, temperature and fine sediment.

EQUIPMENT AND SUPPLIES:

D-shaped kick net
White enameled pan
Number 35 sieve
Thermometer
Forceps
Tape measurer (200 ft.)
Random number table
Alcohol-proof pen
Water-proof paper
California Stream Bioassessment Worksheet (CSBW)
WPCL Chain of Custody Form (COC)
Watershed topographic map

*CAUTION: **Each riffle unit used for biological assessment must be approached from downstream and no portion of the riffle walked on until all sampling is complete. All other assessment work must be conducted after macroinvertebrates are collected.***

1. Fill out a CSBW for each riffle unit. At this step enter watershed name, sample identification number, date, time and names of crew members. Locate the site on the watershed topographic map using the sample identification number.

2. Place the measuring tape along the bank of the entire riffle section to be sampled. Each foot mark represents a possible number to be chosen for a sampling transect

3. Selected three transects (foot marks) along the measuring tape using the table of random numbers. Select the first random number by placing a finger on the page with eyes closed. From that number, go down the page looking at the last three digits until three usable numbers are selected. Record the three foot marks on the CSBW.

4. Staring from the downstream transect, collect macroinvertebrates from three locations along the transect using the D-shaped kick-net. Collect macroinvertebrates by placing the kick-net on the substrate and disturbing a one by two foot section of substrate upstream of the kick-net. Pick-up and scrub large rocks by hand under water in front of the net. The three locations are usually at the side margins and the center (thalweg) of the stream. Locations should include leaf-packs and vegetation if present along the transect. Composite the three collections within the kick-net.

5. Place the contents of the kick-net in the #35 sieve. Remove large organic material by hand while carefully inspecting for clinging organisms. Using the forceps, place all remaining material in the ethanol filled jar. When there is considerable debris in the net, the white enameled pan is useful for cleaning the sample. However, rinse material from the pan through the sieve before putting it in the jar.

6. Using the alcohol-proof pen, write the following information on a piece of water-proof paper and place in the jar: sample identification number followed by -01 through -03 (to identify each replicate), watershed name, date and at least one crew members initial.

7. Repeat procedures 4, 5 and 6 for the three transect to produce three replicate samples.

8. Pages 2 through 4 of the CSBW define Habitat Assessment Parameters. Habitat parameters 1 through 4 should be evaluated for that area of the riffle where the transects were established. Habitat parameters 5 through 11 should be evaluated over a larger stream area, primarily in an upstream direction. Record habitat parameter scores on pages 2 through 4 and on the cover page of the CSBW.

9. At the end of each field week, a member of the field crew must submit samples to WPCL in Rancho Cordova. Each shipment of samples will be accompanied with the COC form. The COC form should contain program name (suspect line) watershed name (Incident location line), sampling dates, a crew members name (name of collector line), address and telephone number, list of sample ID numbers and signature of sample deliverer.

10. When the samples are delivered to WPCL a WPCL number will be issued for the COC. Record this number on each individual CSBW as they are released to WPCL personnel. All samples listed on the COC must be accounted for before the WPCL personnel will sign the received portion of the COC.

CALIFORNIA STREAM BIOASSESSMENT WORKSHEET

WATERSHED: ____________________

DATE: ____________

SAMPLE ID: ____________________

TIME: ____________

CREW MEMBERS:

____

____

____

WATER TEMP: ________

RIFFLE LENGTH: ______

TRANSECT 1: ______

TRANSECT 2: ______

TRANSECT 3: ______

HABITAT ASSESSMENT PARAMETERS

1. BOTTOM SUBSTRATE: ______
2. INSTREAM COVER: ______
3. EMBEDDEDNESS: ______
4. VELOCITY/DEPTH: ______
5. CHANNEL SHAPE: ______
6. POOL/RIFFLE RATIO: ______
7. WIDTH/DEPTH RATIO: ______
8. BANK VEGETATION: ______
9. LOWER BANK STABILITY: ____
10. DISRUPTIVE PRESSURES: ____
11. ZONE OF INFLUENCE: ______

COMMENTS: ______________________

____

____

CHAIN OF CUSTODY INFORMATION

WPCL #: ________

QUESTIONS AND CONCERNS SHOULD BE ADDRESS TO:

JIM HARRINGTON
CDFG - WPCL
2005 NIMBUS RD.
RANCHO CORDOVA, CA 95670

PILOT MONITORING PROGRAM
DFG-IN STREAM COMPONENT

STREAM BIOASSESSMENT

DATA FORM SA \PMP_01:\FORMS\MACRO.001 (3 MAY 1994)

STREAM REACH ____________ WATERSHED ____________________ SAMPLE ID ____________

RIFFLE # ____________ DATE ____________ TIME ____________ WPCL # __________

WATER TEMP (°C) __________

RIFFLE LENGTH (M) __________

TRANSECT INTERSECT

#1 (M.CM) ________

#2 (M.CM) ________

#3 (M.CM) ________

CREW MEMBERS

____

____

____

____

HABITAT ASSESSMENT PARAMETERS
(FILL IN AFTER FIELD DATA REVIEW)
(REFER TO HANDOUT FOR DEFINITIONS)

1. BOTTOM SUBSTRATE ___
2. INSTREAM COVER ___
3. EMBEDDEDNESS ___
4. VELOCITY / DEPTH ___
5. CHANNEL SHAPE ___
6. POOL / RIFFLE RATIO ___
7. WIDTH / DEPTH RATIO ___
8. BANK VEGETATION ___
9. LOWER BANK STABILITY ___
10. DISRUPTIVE PRESSURES ___
11. ZONE OF INFLUENCE ___

COMMENTS ____

____

____

____

____

CHAIN OF CUSTODY

	RELEASED BY	RECEIVED BY	DATE
COLLECTOR	____________	____________	________
TRANSPORTER	____________	____________	________
TRANSPORTER	____________	____________	________
TRANSPORTER	____________	____________	________

CALIFORNIA DEPT. OF FISH AND GAME
CHAIN OF CUSTODY

WPCL NO. ______

______________________ Suspect ______________________ County

______________________ Incident Location ______________________ Sampling Date

Samples: (list label of each container and describe contents).

____

____

____

____

____

____

____

____

______________________ Name of Collector (______) Area Code ______________________ Telephone

______________________ Street or P.O. Box ______________________ City ______________________ Zip Code

---

CALIFORNIA DEPT. OF FISH AND GAME
CHAIN OF CUSTODY

Released by	Received by	Date
Collector:		

REMARKS:

BMP COMPLIANCE CHECK

Survey Number_______

I. GENERAL INFORMATION

1. County__________ Section________ Township_______ Range_________
2. Approx. No. of acres treated (logged, planted and or site prepared)_______
3. Ownership (check one) ____Government, ____Industry, _____Private non-ind.
4. If private non-industrial, was technical (professional) forestry assistance provided by (check one): ____DOF Forester, ____Consultant, ____Industry Forester, ____None at all.
5. Dominant site type (before treatment): ___Natural pine, ___Pine Plantation, ____Mixed Pine/Hardwood, ____Bottomland Hardwood, _____Upland Hardwood, ____Field or Pasture.
6. Type of Treatment (check one or more): ___Clearcut, ____Selective cut or shelterwood, ____Seed tree cut, ____Site preparation for natural regeneration,____Site preparation for hand planting, ____Site preparation for machine planting, ____Chemical site preparation.

II. VARIOUS SITE CHARACTERISTICS

1. Terrain: ____Bottomland, ____Flatwoods, ____Upland Clay Hills, ___Sandhill.
2. Principle soil texture: ____Clay, ____Loam, ____Sand.
3. Highest slopes approaching stream bottoms: ____%.
4. Soil type (from soil survey, if available)________________________________.
5. Soil erodibility (K factor): ____High, _____Medium, _____Low.

III. WATER CONDITIONS IN AREA

1. What type of water body (bodies) is on or border the site: ____Perennial stream, _____Intermittent stream, _____Lake/pond (10 acres or greater in size), ____Canal, ____None of the above. Explain: (Name of water body if known):____
   ____
2. How close did the following activities get to the water's edge, if applicable? Site preparation____feet, Clearcut_____feet, Mechanical tree planting____feet.

3. Evidence of damage to stream channel: (may check more than one)
____ Debris left in stream channel from temporary crossing.
____ Slash, other debris randomly left in stream.
____ Erosion and/or failure of stream channel banks.
____ Sediment is being deposited in stream.
____ None
____ Other (specify)____________________

IV. ROADS/SKID TRAILS

		YES	NO
1.	Roads systems on site. If no, then go to #7/	____	____
2.	Does any newly constructed road system (as a result of the operation) occur within 300 ft. of a watercourse?	____	____
3.	Is there sediment from any road system being deposited into the watercourse?	____	____
4.	Are road systems generally located to avoid steep slopes and gullies?	____	____
5.	Are roads locate to avoid streams, and depressional areas as much as possible?	____	____
6.	Are unneeded access roads closed to vehicular use?	____	____
7.	Are any stream crossings on site? If no proceed to #12.	____	____
8.	Are stream crossings adequately stabilized?	____	____
9.	Is harvesting equipment (skidders) randomly crossing streams?	____	____
10.	Is there sediment being deposited into stream from skid trails?	____	____
11.	Are planned stream crossing made at right angles to the watercourse?	____	____
12.	Any culvert or bridge washouts.	____	____
13.	Are any roadside ditches pulled (connected) directly into watercourse?	____	____
14.	Were oil and trash properly disposed of?	____	____

15. Evidence of BMPs applied to roads (check one or more)
____ Waterbars installed
____ Broad-based or rolling dips installed
____ Mulching, seeding, and/or fertilizing
____ Water turnouts or wing ditches
____ Effort made to minimize slopes on road
____ Roads exist, but no BMPs were applied to them
____ No roads on site
____ Other (specify) ____________________

16. Evidence of BMPs applied to skid trails:
____ Seeded
____ Waterbars
____ Slopes minimized
____ Skid trails exist, but no BMPs were applied
____ No skid trails apparent on site

____ Other (specify) ____
____

17. If new roads were constructed, who was responsible for layout and construction? (may be more than one)
____ Government crew
____ Landowner
____ Forest industry crew
____ Private vendor
____ Information not available
____ Not applicable
____ Other (specify) ____
____

18. Were erosion control efforts on road systems generally effective and adequate? ____ Yes ____ No

Evidence is: (check one or more)
____ Water is diverted off roads at intervals which are successfully controlling surface erosion.
____ Water is diverted away from road prior to reaching stream channels.

____ None installed, erosion occurring
____ None installed, no evidence of erosion

19. Were landings and decks properly located, adequately cleaned up, and stabilized? ____ Yes ____ No

V. SITE PREPARATION AND REGENERATION

1. Method of site preparation (check one or more): ____ Bulldozed, ____ Disk/harrow, ____ Shear, ____ Chop, ____ Burn, ____ Bed, ____ Root Rake, ____ Herbicide, ____ Not applicable, Other (specify)________________

		Yes	No	N/A
2.	Was site planted or to be planted by hand?	___	___	___
3.	Was site planted or to be planted by machine?	___	___	___
4.	Planting follows natural land contours? If not, go to #8	___	___	___
5.	Was slash and debris windrowed/piled?	___	___	___
6.	Is there excessive topsoil pushed into windrows/piles?	___	___	___
7.	Do windrows follow natural land contours?	___	___	___
8.	Were any new lateral drainage (field) ditches constructed	___	___	___
9.	Do established lateral field ditches occur on site?	___	___	___
10.	Do firelines exist on the site? If no, go to #14.	___	___	___
11.	Does erosion appear to be associated with firelines?	___	___	___
12.	Any waterbars, other water diversions used on firelines?	___	___	___
13.	Do firelines avoid streamside management zones (SMZ)?	___	___	___
14.	If a perennial stream or lake (10+ acres) is adjacent was a selective cut 35' wide Primary SMZ maintained throughout? (Indicate N/A if no perennial water is present)	___	___	___
15.	If necessary (according to guidelines for perennial			

streams or lakes 10+ acres), does a secondary SMZ appear and does it meet guidelines? (Indicate N/A if no perennial water is present) ___ ___ ___

16. If an intermittent stream, was mechanical site preparation avoided within the required SMZ? (Indicate N/A is no intermittent water is present or if site had not site prepared). ___ ___ ___

17. Type of operator responsible for logging/site preparation work on this site:
____ Private landowner, using own equipment, ____ Government crew,
____ Vendor contracted by forest industry, ____ Forest industry crew,
____ Vendor contracted by private landowner, ____ Other (specify)____

18. Additional comments/summary concerning this site:____________________

19. General grade - Do you feel there was generally good compliance with 208 guidelines on this site? _____ Yes, ____ No. If not, briefly state primary reason for site failure. ______________________________

______________________________ FORESTER ______________________________ LANDOWNER

______________________________ TELEPHONE ______________________________ ADDRESS

______________________________ DATE ______________________________ CITY, STATE, ZIP CODE

BMP Implementation II

At the BMP Effectiveness II level, one observer visits the management area and evaluates in detail the BMP implementation and effectiveness. Roads and skid trails are carefully examined for waterbars, proper drainage, proper bridge and culvert installation, cut-and-fill slope revegetation success, proper location, etc. For example, the effectiveness of waterbars on a skid trail would be evaluated by tracing the path of runoff below the waterbar to determine if the runoff reached the stream and discharged sediment into it. As another example, runoff and eroded soil from a site-prepared area could be traced through the filter strip to determine if runoff and sediment reached the stream. If fresh sediment is found in the stream, the observer would attempt to trace it to its source and determine if it was caused by a specific practice or disturbance in the management area.

APPENDIX C.
RANDOM NUMBER TABLE

Random Number Table

0.49524406	0.67470562	0.09229848	0.29099694	0.07545868	0.61285655	0.12656714
0.28921714	0.00560818	0.77148908	0.37669893	0.79128046	0.57830974	0.63381520
0.56332013	0.73020588	0.37496374	0.17891901	0.05844289	0.34699594	0.27009190
0.70920840	0.88030729	0.99558792	0.82769415	0.44787866	0.19104333	0.03637016
0.85764990	0.46946811	0.57878609	0.76401257	0.20919995	0.19702656	0.90719876
0.25475875	0.46075180	0.06254449	0.68738939	0.33809959	0.66562741	0.53213101
0.27853114	0.15895196	0.01689722	0.84520981	0.50408654	0.24949524	0.73597866
0.09286612	0.77669092	0.04923789	0.43059138	0.75961911	0.61353714	0.38843437
0.36650058	0.63620356	0.81788259	0.41407255	0.95623692	0.31267131	0.85961197
0.29509229	0.62815230	0.27862914	0.87547778	0.42293699	0.80228201	0.40394578
0.65213226	0.63226156	0.01674177	0.30432801	0.28511282	0.81621767	0.52773120
0.39350421	0.30141352	0.96488037	0.46275874	0.02802682	0.52691342	0.16679732
0.25835613	0.94339141	0.50419836	0.93140137	0.33730985	0.05469158	0.46324412
0.66651495	0.92744682	0.40206864	0.53326451	0.89525730	0.77605986	0.28907619
0.79875417	0.20258501	0.48050008	0.62929123	0.89139782	0.32712352	0.13842550
0.06253088	0.12441210	0.00274036	0.98114158	0.17480601	0.33387267	0.77683646
0.07719403	0.20648263	0.49343195	0.87957256	0.51376319	0.88873867	0.52699310
0.90506847	0.57933955	0.17079401	0.73749715	0.08079892	0.15984823	0.21530527
0.63373878	0.40254785	0.87528675	0.95720028	0.52364788	0.88517588	0.22941387
0.65600996	0.07111747	0.58668769	0.24084873	0.37338657	0.01427167	0.22778935
0.26492241	0.62132711	0.73184095	0.16144186	0.25618065	0.79024996	0.20930207
0.67473566	0.59693141	0.90340959	0.59440913	0.00187181	0.77464520	0.56869474
0.93529817	0.91556094	0.19424745	0.17686416	0.60431377	0.26325150	0.89228525
0.38010915	0.54721197	0.00858730	0.96851617	0.33639723	0.36270493	0.62454516
0.09898701	0.75571608	0.84640509	0.31978771	0.96549317	0.00659344	0.35817061
0.58372826	0.81431345	0.82726840	0.61894063	0.11876669	0.40880841	0.43031297
0.68935928	0.35571510	0.70534003	0.83458854	0.03743237	0.94041606	0.26858850
0.42080532	0.69964459	0.45906612	0.31618448	0.69067354	0.32710308	0.87471233
0.44100558	0.42380915	0.49202856	0.70586302	0.13150336	0.17370127	0.45495415
0.82526854	0.87441339	0.46234223	0.98851960	0.20769547	0.12697244	0.91837537
0.04509883	0.82006250	0.20849290	0.05121649	0.56713572	0.39266427	0.68998461
0.82681818	0.13395942	0.10415667	0.80560970	0.01950863	0.92178069	0.47798845
0.18162208	0.49505858	0.90044636	0.14791662	0.76508875	0.04516381	0.69318958
0.56591323	0.09839676	0.26625467	0.99888554	0.55592990	0.63917571	0.98239159
0.24645432	0.14377712	0.52631427	0.99840291	0.74185797	0.57514821	0.70944354
0.20571875	0.08777053	0.34475883	0.88169570	0.04263012	0.53506072	0.18369762
0.51617185	0.52920322	0.18127664	0.40637104	0.26893341	0.09948657	0.52815431
0.99520295	0.58667996	0.67491858	0.16082513	0.43793397	0.03718833	0.10132103
0.58648059	0.82765250	0.59928890	0.48532613	0.13148091	0.04377560	0.82673534
0.93216907	0.87187871	0.75477656	0.13466485	0.05314360	0.22837204	0.16315025
0.92068191	0.71008139	0.74590151	0.43850265	0.83700511	0.92033659	0.85404904
0.40878821	0.12475282	0.87393478	0.39585201	0.79433709	0.22722564	0.08362434
0.62948298	0.66942451	0.33402485	0.32401209	0.13278818	0.07574804	0.16392062

Random Number Table

0.49524406	0.67470562	0.09229848	0.29099694	0.07545868	0.61285655	0.12656714
0.28921714	0.00560818	0.77148908	0.37669893	0.79128046	0.57830974	0.63381520
0.56332013	0.73020588	0.37496374	0.17891901	0.05844289	0.34699594	0.27009190
0.70920840	0.88030729	0.99558792	0.82769415	0.44787866	0.19104333	0.03637016
0.85764990	0.46946811	0.57878609	0.76401257	0.20919995	0.19702656	0.90719876
0.25475875	0.46075180	0.06254449	0.68738939	0.33809959	0.66562741	0.53213101
0.27853114	0.15895196	0.01689722	0.84520981	0.50408654	0.24949524	0.73597866
0.09286612	0.77669092	0.04923789	0.43059138	0.75961911	0.61353714	0.38843437
0.36650058	0.63620356	0.81788259	0.41407255	0.95623692	0.31267131	0.85961197
0.29509229	0.62815230	0.27862914	0.87547778	0.42293699	0.80228201	0.40394578
0.65213226	0.63226156	0.01674177	0.30432801	0.28511282	0.81621767	0.52773120
0.39350421	0.30141352	0.96488037	0.46275874	0.02802682	0.52691342	0.16679732
0.25835613	0.94339141	0.50419836	0.93140137	0.33730985	0.05469158	0.46324412
0.66651495	0.92744682	0.40206864	0.53326451	0.89525730	0.77605986	0.28907619
0.79875417	0.20258501	0.48050008	0.62929123	0.89139782	0.32712352	0.13842550
0.06253088	0.12441210	0.00274036	0.98114158	0.17480601	0.33387267	0.77683646
0.07719403	0.20648263	0.49343195	0.87957256	0.51376319	0.88873867	0.52699310
0.90506847	0.57933955	0.17079401	0.73749715	0.08079892	0.15984823	0.21530527
0.63373878	0.40254785	0.87528675	0.95720028	0.52364788	0.88517588	0.22941387
0.65600996	0.07111747	0.58668769	0.24084873	0.37338657	0.01427167	0.22778935
0.26492241	0.62132711	0.73184095	0.16144186	0.25618065	0.79024996	0.20930207
0.67473566	0.59693141	0.90340959	0.59440913	0.00187181	0.77464520	0.56869474
0.93529817	0.91556094	0.19424745	0.17686416	0.60431377	0.26325150	0.89228525
0.38010915	0.54721197	0.00858730	0.96851617	0.33639723	0.36270493	0.62454516
0.09898701	0.75571608	0.84640509	0.31978771	0.96549317	0.00659344	0.35817061
0.58372826	0.81431345	0.82726840	0.61894063	0.11876669	0.40880841	0.43031297
0.68935928	0.35571510	0.70534003	0.83458854	0.03743237	0.94041606	0.26858850
0.42080532	0.69964459	0.45906612	0.31618448	0.69067354	0.32710308	0.87471233
0.44100558	0.42380915	0.49202856	0.70586302	0.13150336	0.17370127	0.45495415
0.82526854	0.87441339	0.46234223	0.98851960	0.20769547	0.12697244	0.91837537
0.04509883	0.82006250	0.20849290	0.05121649	0.56713572	0.39266427	0.68998461
0.82681818	0.13395942	0.10415667	0.80560970	0.01950863	0.92178069	0.47798845
0.18162208	0.49505858	0.90044636	0.14791662	0.76508875	0.04516381	0.69318958
0.56591323	0.09839676	0.26625467	0.99888554	0.55592990	0.63917571	0.98239159
0.24645432	0.14377712	0.52631427	0.99840291	0.74185797	0.57514821	0.70944354
0.20571875	0.08777053	0.34475883	0.88169570	0.04263012	0.53506072	0.18369762
0.51617185	0.52920322	0.18127664	0.40637104	0.26893341	0.09948657	0.52815431
0.99520295	0.58667996	0.67491858	0.16082513	0.43793397	0.03718833	0.10132103
0.58648059	0.82765250	0.59928890	0.48532613	0.13148091	0.04377560	0.82673534
0.93216907	0.87187871	0.75477656	0.13466485	0.05314360	0.22837204	0.16315025
0.92068191	0.71008139	0.74590151	0.43850265	0.83700511	0.92033659	0.85404904
0.40878821	0.12475282	0.87393478	0.39585201	0.79433709	0.22722564	0.08362434
0.62948298	0.66942451	0.33402485	0.32401209	0.13278818	0.07574804	0.16392062

APPENDIX D.
SOME CHARACTERISTICS OF FOUR MONITORING LEVELS AND VARIOUS TYPES OF MONITORING

Some Characteristics of Four Monitoring Levels (after Dissmeyer, 1994)

Monitoring Level	Quantity and Type of Information Produced	Quality of Information Produced	Levels of Uncertainty and Risk	Typical Uses of Information	Skill Levels Needed for Instream	Control and Study Streams Used	Time to Decision
I	Small to moderate amount of information, mostly empirical observations by experienced professionals; subjective rating of obviously "good" or "bad" conditions; little or no quantitative data	Large intermediate gray area where significant impacts and/or changes are likely to be missed; very imprecise; may be inaccurate	High uncertainty; high risk of making erroneous decisions	Early warning system; obvious Y/N screen for implementation and effectiveness; project complaint; management decisions by individual landowners	One or two trained professionals with a technician	One study stream; upstream/ downstream controls; state ecoregion reference stream	Few hours to a few days
II	Moderate to large amount of information; largely qualitative and/or semiquantitative data; little quantitative data	Gray area is moderate; somewhat more objective, but still largely subjective; much more accurate; moderately precise	Moderate uncertainty; reduced risk of a wrong decision	Complaint involving high-value/public interest stream; implementation, effectiveness, and validation monitoring; revision of voluntary BMPs; cooperative land management decisions	Two trained professionals (hydrology, fisheries, habitat, invertebrates); technicians	2-3 study streams plus controls; plus info on stream order, channel class, ripar-ian and slope vegetation	15-30 days
III	Large to very large amount of information; primarily quantitative data with limited semiquantitative or qualitative data	Gray area is small; most significant impacts and/or changes are detected; much more objective; much improved precision and accuracy	Low uncertainty; allows well-informed, objective defensible decisions with a low risk of error	Same as level II, plus compliance monitoring; revision of mandatory BMPs and regulations; establishing statistical cause/effect association and/or desired future condition	Several profession-als in above disciplines plus statistics and channel geo-morphology; several technicians	3 or more study and control reaches depend-ing on statistical design; use of detailed stream/ ecoregion stratification	2-3 months for initial visits to reaches; 2-3 years for repeated visits for some issues
IV	Very large amount of narrowly focused informa-tion; almost exclusively quantitative data	Gray area is very small; small changes or impacts are detectable; highly objective; very precise and accurate	Very low uncertainty; allows highly objective, defensible, data-based decisions with very low risk of error.	Scientific and legal proof of cause and effect; litigation; revision of man-datory BMPs and statutes	Same as above, but often including researchers	Same as above	2 years or more

Some Characteristics of Various Types of Monitoring (After MacDonald, *et al*, 1991)

Type of Monitoring		Number and Type of Parameters	Relative Frequency of Measurements	Relative Duration of Monitoring	Relative Intensity of Data Analysis	Addresses Whether, to What Degree, and (Sometimes) under What Conditions:
Instream	Baseline	Many instream parameters, including water column parameters; hydrologic, geomorphic, biologic parameters: bed and bank parameters; habitat conditions	Low	Medium to short, preceding trend or project monitoring	Low to moderate	Background stream conditions/ instream parameters are variable
	Trend	Same as above	Low	Long	Low to moderate	Long-term changes are occuring in stream conditions/ parameters
	Project	Variable instream parameters, usually few for any given project	Medium to high	Varies; usually exceeds project duration	Medium to high	A "project" or activity is associated with instream changes
	Validation	Few instream parameters and sometimes hillslope parameters	High	Usually long to medium	High	A model or hypothesis accurately represents observed conditions
	Compliance	Few instream parameters	Variable	Dependent on project	Moderate to high	A project achieves compliance with applicable water quality standards
Hillslope	Implementation	Few to many parameters; no water quality parameters	Variable	Short, during and following project	Low to moderate	Specified/required practices have been carried out during a project
	Effectiveness	Few to many hillslope parameters; few or no water quality parameters	Medium to high	Medium to short, during and following project	Moderate	Specified/required practices have prevented or reduced the generation of discharges

APPENDIX E.
COST ANALYSIS

The following cost analysis assumes that equipment, software, and supplies are acquired separately for each protocol. The costs for equipment and supplies is for equipping that one field crew. Software costs assume a Windows 3.1 PC. Consumable equipment and supplies (recording temperature sensors, flagging, etc) is for conducting the monitoring of one stream reach of six pools, three riffles, and three runs.

	Equipment	Software	Supplies	Hours
V^STAR^				
Field date collection	500	-	5	12
Data entry		150	-	6
Data analysis	-	450	-	12
RASI-D50				
Field data collection	10	-	5	6
Data entry	-	150	-	6
Data analysis	-	-	-	3
TEMPERATURE				
Field data collection	600	-	50	9
Data entry	-	100	-	1
Data analysis	-	-	-	1
HABITAT INVENTORY				
Field data collection	300	-	5	8
Data entry	-	-	-	2
Data analysis	-	-	-	2
MACRO-INVERTEBRATES				
Field data collection	400	-	140	10
Date entry	(lab)	(lab)	(lab)	(lab)
Data analysis	(lab)	(lab)	(lab)	(lab)

(Cost varies for data entry and analysis-our cost during the Pilot Monitoring Program was $1 50 per riffle)

CANOPY				
Field date collection	350	-	5	6
Data entry	-	-	-	3
Data analysis---3				

APPENDIX F. USING THE UTM SYSTEM FOR LOCATING EVALUATION SITES

The Universal Transverse Mercator (UTM) Grid System provides a simple and accurate method for recording the geographic location of sites. Its greatest advantage over the Geographic Coordinate System (latitude/longitude) is its reliability, because its measurements are cited in linear, decimal units, rather than in angular, non-decimal ones. Most people find meters easier to visualize than fractions of degrees, and consequently, are less likely to make mistakes.

The UTM grid location or reference of a point may easily be found if the point can be located on a map with UTM grid tick marks along its edges or with a UTM grid superimposed. USGS quadrangles published since 1959, and many published before then, have these ticks, which are printed in blue. Maps produced by many other federal agencies and by some states also have UTM ticks. If no USGS map with UTM ticks exists for a location, latitude and longitude coordinates, or certain local grid coordinates, may be converted to UTM references by a mathematical formula. However, computer programs are necessary to perform such a task. It is always preferable to initially record locations in UTM terms rather than to use translated values.

The simplicity of the UTM grid method follows from certain assumptions, which do not seriously compromise the accuracy or precision of measurements made on the common types of USGS topographical maps. The primary assumption is that narrow sections of the earth's nearly spherical surface may be drawn on flat maps with little distortion. Larger sections, however, such as the contiguous United States, cannot be drawn on a single flat map without noticeable distortion.

In the UTM system, the earth is divided into 60 zones, running north and south, each 6-degrees wide. Mapping on flat sheets within one of these narrow zones is satisfactory for all but the most critical needs. Each zone is numbered, beginning with zone 1 at the 180th meridian near the International Date Line, with zone numbers increasing to the east. Most of the United States is included in Zones 10 through 19, as shown in Figure 1. On a map, each zone is flattened, and a square grid is superimposed upon it. Any point in the zone may be referred to by citing its zone number, Its distance in meters from the equator ("northing"), and its distance in meters from a north-south reference line ("easting"). These three figures -the zone number, easting. and northing - make up the complete UTM Grid Reference for any point, and distinguish it from any point on earth.

Figure 2 shows a zone, its shape somewhat exaggerated, with its most important features. Note that when drawn on a flat map, its outer edges are curves, since they follow meridian lines on the globe, which are farther apart at the equator than at the poles. Note also that it is the accepted practice to terminate the UTM grid system before it reaches the poles.

The two most important features of the zones are the equator, which runs east and west through its center, and the central meridian,-a north-south line through its center. Easting and northing measurements are based on these two lines. The easting of a point represents its distance, in meters, from the central meridian of the zone in which it lies. The northing of a point represents its distance, in meters, from the equator.

By common agreement, there are no negative numbers for the easting of points west of the central meridian. Instead of assigning a value of 0 meters to the central meridian of each zone, each is assigned an arbitrary value of 500,000 meters. Since at their widest points along the equator, the zones somewhat exceed 600,000 meters, from west to east easting values range from approximately 200,000 meters to approximately 800,000 meters at the equator, with no negative values. The range of possible easting values narrows as the zone narrows toward the poles.

Northings for points north of the equator are measured directly in meters, beginning with a value of zero at the equator and increasing to the north. To avoid negative northing values for points south of the equator, the equator is arbitrarily assigned a value of 10 million meters, and points are measured with decreasing, but positive, northing values heading southward. For clarity, a minus sign usually precedes northing figures for points south of the equator. When actually working with maps, especially at the scales commonly used for locating evaluation sites, the UTM grid system becomes extremely clear and straight forward to use.

Locating sites can be done by various methods. One most straight forward method is given below. Certain elements are common to all five methods, and should be studied carefully:

1. UTM zone numbers appear in the legend in the lower left margin of CGS maps.

2. On these maps, blue tick marks around the margins set off intervals of a thousand, 5 thousand, or 10 thousand meters, depending on the map scale. To check this, use the metric scale printed at the center of the lower map margin. The easting and northing values of these ticks are printed on maps in an abbreviated form that shows values in thousand-meter units such as 77 or 23. These abbreviations are clarified near the northwest and southeast corners of the maps, where at least one tick value will be written out in full, to the nearest whole meter, for each map edge. For example, an easting abbreviated $^{5}23$ would be printed in full as 523000mE, meaning 23,000 meters east of the central meridian. Similarly, an easting abbreviated as $^{4}77$ would be printed in full as 477000mE, meaning 23,000 meters west of the central meridian for the zone in which the map is located. Remember that the central meridian always has an arbitrarily defined easting value of 500,000 meters.

3. Lines connecting UTM grid ticks of equal value are seldom parallel with lines of latitude and longitude, or with the edges of quadrangle maps. This is a result of the map projections used and the fact that longitude lines converge toward the poles. whereas UTM grid lines do not converge. The effect becomes more evident as the distance from the central meridian in each zone increases. None of this noticeably affects the accuracy of measurement at common map scales,

4 When drawing lines between UTM grid tick marks, make the finest line possible. Use a very sharp, hard pencil or very fine pointed pen to draw connecting lines. Lines drawn with dull or soft pencils,or with left markers, are too wide for precise measurement Number-3 office pencils, and number 3H or 4H drafting pencils, H kept sharp, do a good job.

5. USGS has announced that new and newly revised quadrangle maps will have printed UTM gridlines, making it unnecessary to draw them by hand. It will take several years to reprint all of the quadrangles, but as they are issued, the lobor needed to measure UTM references will be reduced significantly.

6. The UTM coordinate counter (see Figure 3) is used in the method given below. It has measuring scales to match the common USGS map series around its edges and each corner of the counter corresponds to a different map scale,

Be sure to choose the correct scale for the desired measurement to be made. The organization of each measuring scale is the same. Values near free corners are always lower than values toward the center of each edge.

In all cases, the basic unit of measure is the meter. For clarity, the smallest ruled divisions of each scale vary in size. In general practice, and with adequate care, the level of precision approaches the limits of visual resolution for any map, as shown in the following chart

Map Scale	Quadrangle Series	Smallest Unit Marked On Coordinate Counter	Measurement to nearest
1:24,000	7.5 minute	20 meters	10 meters
1:62,000	15 minute	50 meters	25 meters
1:125,000		100 meters	50 meters
1:250,000		200 meters	100 meters

7. One of the most frequent errors in writing UTM references is to reverse the easting and northing figures, with digits dropped or zeroes improperly added to make up for the different number of digits required for each. The correct formulation is easy to remember.

a) Eastings are distances east (6 digits)
b) Northings are distances north (7 digits)
c) The order for writing UTM reference is Z-E-N, zone-easting-northing.

8. Cheap straightedges, especially the common school and office rulers made of wood with brass edges, are notorious for drawing crooked lines. Even small deviations have a drastic effect on the accuracy of measurements.

To check the trueness of any straightedge, draw a long line with it using a very sharp pencil. Turn the straightedge end for end, and draw another line connecting the ends of the first line. If the second line does not fall precisely along the first line for Its entire length, then the straightedge is not straight.

The best source for reliable straightedges is an art or drafting supply store. College bookstores at schools where engineering, architecture, or drafting are taught are also good sources. The dealer should not object to you testing the edge.

This method involves drawing part of the UTM grid on the map and measuring from the grid lines to the point. It is the basic method, and its logic underlies the other methods. The following equipment is required:

- a flat work surface on which to spread out the map in full, drafting table helpful but not required;
- a straightedge long enough to reach completely across the map, generally about 36"to 48"
- a very sharp pencil; and
- a UTM coordinate counter (see Figure 3)

For each point to be measured, follow these steps, which will be easier to understand with map and tools at hand:

1.Draw a line from the top of the map to the bottom, connecting the nearest equal-valued pair of UTM ticks to its west,, that is, with the highest easting value west of the point.

2.Draw a line form the left side to the right side of the map, connecting the nearest equal-valued pair of grid ticks to Its south, that is, with the highest northing value south of the point. This will intersect the previous line somewhere to the southwest of the point.

3.Remember that the UTM grid lines are generally not parallel to the map edges.

4.Record the zone number.

5.Record the printed portions of the easting and northing values appropriate to the UTM ticks through which the lines have been drawn. Not all ticks are labeled. It may be necessary to count from a nearby tick. Remember that easting values increase going east, and that northing values increase going north. Check the distance between UTM ticks with the map scale before counting.

6.Locate the scale an the coordinate courtier (Figure 3) matching the the scale of the map. Align the counter on the map so that:

a)the side of the scale that reads from right to left lies along the east-west line, and

b)the side of the scale that reads from left to right passes through the point being measured.

7.Read the coordinate counter scales, right-to-left for the easting and upward for the northing. Record the values.

8.Check the readings for plausibility. Are all figures in the correct decimal places; does the easting have six digits and the nothern seven?

9.Check the figures for accuracy by remeasuring at least once.

10.Be sure that the correct order is observed: zone, easting, northing.

APPENDIX G. DEFINITIONS

ALLOCHTHONOUS:
Derived from outside a system, such as leaves of terrestrial plants that fall into a stream or river.

ANADROMOUS:
Moving from the sea to fresh water environment for reproduction.

AQUATIC COMMUNITY:
An association of interacting biota in an aquatic ecosystem.

ASSEMBLAGE:
A subset of the biota in an ecosystem (e.g., fish assemblage, macroinvertebrate assemblage).

AUFWUCHS:
Complex assemblage of animals and plants living on the surface of a submerged mineral or organic substrate.

AUTOCHTHONOUS:
Derived from within a system, such as organic matter in a stream resulting from photosynthesis by aquatic plants.

BEST MANAGEMENT PRACTICES (BMPs):
Methods, measures, or practices to prevent or reduce water pollution, including, but not limited to structural and nonstructural controls and operation and maintenance procedures. BMPs may be applied before, during, or after pollution-producing activities to reduce or eliminate the introduction of pollution into water bodies.

BIOASSAY:
A toxicity test that uses selected organisms to determine the acute or chronic effects of a chemical pollutant or whole effluent.

BIOCRITERIA:
See biological criteria.

BIOLOGICAL ASSESSMENT:
An evaluation of the biological condition of a waterbody that uses biological surveys and other direct measurements of resident biota in surface waters.

BIOLOGICAL CRITERIA:
Numeric values or narrative expressions that describe the reference biological integrity of aquatic assemblages inhabiting waters that have been given a designated aquatic life use.

BIOLOGICAL INTEGRITY:
A balanced, integrated, adaptive community of organisms having species composition, diversity, and functional organization comparable to that of natural habitat of the region (Karr and Dudley, 1981)

BIOLOGICAL MONITORING:
The use of a biological entity as a detector and its response as a measure to determine environmental conditions. Toxicity test and biological surveys are common biomonitoring methods.

BIOLOGICAL (OR BIOCHEMICAL) OXYGEN DEMAND(BOD):
Amount of oxygen that can be taken up by nonliving organic matter as it decomposes by aerobic biochemical action,

BIOLOGICAL STANDARD:
A legally established State rule that includes a designated biological use (goal)and biological criteria.

COBBLE:
Substrate particles 64-256 mm in diameter (also referred to as rubble).

DESIGNATED USES:
Specified in water quality standards for each waterbody or segment,.whether or not they are being attained. For example, salmonid spawning, primary contact recreation, shellfish harvest.

DIVERSITY INDEX:
Numerical value derived from the number of individuals (abundance) and the number of taxa present (richness).

ECOREGION:
A relatively homogeneous area defined by similarity of vegetation, land form, soil, geology, hydrology, and land use. Ecoregions help define designated use classifications of specific waterbodies.

EMBEDDEDNESS:
The degree to which boulders, rubble, or gravel are surrounded by fine sediment.

FUNCTIONAL GROUPS:
Groups of organisms that obtain energy in similar ways.

GLIDE:
Slow, relatively shallow stream section with little or no surface turbulence.

GRAVEL:
Substrate particles between 2 and 64 mm in diameter.

IMPACT:
A change in the chemical, physical or biological quality or condition of a waterbody that is caused by external forces.

IMPAIRMENT:
A detrimental effect on the biological integrity of a waterbody caused by an impact that prevents attainment of the designated use.

METRIC:
A descriptive measure; as used in this document, a biological unit of measurement (i.e. number of taxa, percent Ephemeroptera (an order of macroinvertebrates), number of juvenile salmonids,etc.)

NONPOINT SOURCE POLLUTION:
Pollution from sources that cannot be defined as discrete points, such as run from areas of timber harvest, agriculture and grazing.

POOL:
Portion of a stream with reduced current velocity, often with deeper water than surrounding areas and with a smooth surface.

REDD:
Nest made in stream gravel, consisting of a depression dug by a fish for egg deposition and associated gravel mounds.

RIFFLE:
An area of the stream with relatively fast currents and cobble/gravel substrate.

RUN:
Swiftly flowing stream reach with little surface agitation.

SUBSTRATE:
The composition of the stream or river bottom ranging from rocks to mud.

TOXICOLOGICAL INDICATORS:
The effects of chemicals on laboratory organisms.