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WATER QUALITY EFFECTS AND NONPOINT SOURCE CONTROL FOR FORESTRY: AN ANNOTATED BIBLIOGRAPHY

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1. INTRODUCTION AND PURPOSE

The purpose of this document is to provide technical background information relevant to forestry-related nonpoint pollution. The impetus for developing this document came in January 1993, when the U.S. Environmental Protection Agency (EPA) released a guidance specifying management measures for sources of nonpoint pollution in coastal waters as required under section 6217 of the Coastal Zone Act Reauthorization Amendments of 1990 (CZARA). The guidance provides the States and Territories with information on the types of management measures that should be included in State and Territorial coastal nonpoint source control programs. The guidance focuses on five major categories of nonpoint sources that impair or threaten coastal waters nationally: (1) agricultural runoff; (2) urban runoff; (3) silvicultural (forestry) runoff; (4) marinas and recreational boating; and (5) channelization and channel modification, dams, and streambank and shoreline erosion.

Chapter 3 of the guidance—"Management Measures for Forestry"—contains 10 management measures designed for various phases of forestry operations relevant to the control of sources of silvicultural nonpoint pollution. They are: (1) preharvest planning; (2) streamside management areas; (3) road construction/ reconstruction; (4) road management; (5) timber harvesting; (6) site preparation and forest regeneration; (7) fire management; (8) revegetation of disturbed areas; (9) forest chemicals management; and (10) wetland forest management. Under each of these management measures, the guidance presents information on: the specific activities and locations for which the measure is suitable; the rationale for the management measure's selection; the management measure's purpose; information on the effectiveness, either alone or in combination with other practices; and information on costs of the practices.

The CZARA guidance document contains limited background information on each of the management measures, however, comprehensive background information from various geographic regions on each of the management measures is not included. Impacts from the forestry activities related to each management measure are well documented, especially when compared to data that show undisturbed forested watersheds provide excellent protection to water and soil resources. The impacts from forestry-related activities, such as road construction, timber harvest, mechanical and chemical site preparation, etc. include changes in the chemical, biological, and physical properties of water resources.

This document builds on the information presented in the guidance by providing a single source of background information to interested parties, in the way of an annotated bibliography, on the impacts of forestry-related activities and the costs and/or effectiveness of best management practices (BMPs) used to mitigate the impacts. This document contains information on over 900 research reports, journal articles, federal publications, etc. Approximately 50 percent have been annotated. The references that are included but not annotated may also be useful in assembling a library of pertinent information on forestry nonpoint source pollution. This annotated bibliography is not intended to be a comprehensive or critical review of all literature, but a review of a relevant subset of available information. The following criteria were used in the selection of papers for annotation: (1) paper content; (2) the relevance to current forestry practices; and (3) the date of publication. The content of the paper was the primary factor used in the determination of whether or not to annotate a paper. Papers with significant amounts of data, with sound conclusions, and that were based on current technologies were annotated. In cases where the age of the paper was the only critical factor, especially when the paper provides a historical perspective, it was also annotated. The references are presented in specific sections based on subject matter.

This document contains the following sections:

- Program and policy studies and reviews
- Instream studies
- Road construction and use

- Timber harvesting
- Site preparation and regeneration
- Forestry chemicals
- Streamside management areas and riparian areas
- Wetlands
- Modeling
- Water quality monitoring

The outline for this document was intended to follow the management measures presented in the guidance as much as possible. The section on program and policy studies and reviews contains documents produced by federal, state, or local regulatory agencies on regulations or laws which may impact the implementation of forestry BMPs or other related activities. Information on most state BMP manuals are presented in this section. The instream studies section is presented in four subsections: chemical (nutrients, pesticides, dissolved oxygen, etc.), biological (aquatic habitat, aquatic life), physical (temperature, suspended solids, sediment, woody debris, etc.), and watershed level studies of cumulative effects. Studies directed at determining the water quality effects of forestry activities are included in this section.

The sections on forestry-related BMPs and protection of natural resources (road construction and use, timber harvesting, site preparation and regeneration, forestry chemicals, streamside management areas and riparian areas, and wetlands) have information presented in the following subsections: (1) impacts on water quality and aquatic habitat, (2) BMP specifications, and (3) costs and effectiveness of BMPs. The section on modeling has two subsections: modeling water quality impacts of forestry operations and modeling water quality effects of management practice implementation. The water quality monitoring section includes subsections on methods and procedures and data analysis and study design.

Because of the large amount of research conducted on the water quality impacts of forestry activities, especially the major activities such as road construction, harvest, and site preparation, these sections of this document contain the majority of papers. However, some repetition of documents exists in the bibliography across the different subject areas. For example, many documents contain significant data and conclusions regarding both road construction and timber harvest impacts on water quality. In many instances, no one topic dominates the data collection and discussion within the paper. In these situations, the bibliography contains the same record (not always annotated) in both sections. This procedure was deemed necessary to ensure that bibliography users do not miss useful references because of its placement in the document.

The bibliography will be available from EPA as a published hardcopy or from the EPA Nonpoint Source Bulletin Board as a retrievable file. The bibliography was developed using a bibliographic software package, however the electronic file from this development will have limited distribution.

To use this document, determine the subject of interest (timber harvest, models, water quality, BMPs, costs, etc.). The references within each section are listed alphabetically, with all the annotated references preceding the non-annotated. The annotation presents the basic objectives of the paper, major results and conclusions, and also contains a brief summary of the information presented.

2. PROGRAM AND POLICY STUDIES AND REVIEWS

American Forest Council. 1991. *Effective use of communications in implementing a highly successful best management practices compliance program, case study West Virginia.* American Forest Council Report. 9 pages.

This paper describes the success of a voluntary best management practices compliance program used by West Virginia prior to the enactment of the Forest Practices Act (FPA) of 1992. The paper describes the methods used to monitor compliance and compares the success of the program with the success of regulatory programs.

Bethea, J.M. 1985. Perspectives on nonpoint source pollution control: Silviculture. In: *Perspectives on Nonpoint Source Pollution: Proceedings of a National Conference.* Kansas City, Missouri, May 19-22, 1985. U.S. Environmental Protection Agency.

Introductory paper on the nature of silviculture disturbances and regulatory/nonregulatory approaches to the management of such disturbances. Suggestions on how to succeed in reducing silvicultural nonpoint source pollution through a nonregulatory approach are given.

Bilby, R.E., and L.J. Wasserman. 1989. The development of the Washington State riparian management regulations. In: *Forestry on the Frontier, Proceedings of the 1989 Society of American Foresters National Convention.* Spokane, Washington. pp. 148-154.

A description of a series of negotiations in Washington State on the development of the Timber, Fish, and Wildlife Agreement is presented in a historical perspective. Regulatory guidelines relating to all aspects of forest practices are provided. Tree population density and other physical parameters were studied to produce site-specific riparian management alternatives for both eastern and western Washington. The amount of woody debris flowing through streams provided the framework for much of the regulations.

Coats, R.N., and T.O. Miller. 1981. Cumulative silvicultural impacts on watersheds: A hydrologic and regulatory dilemma. *Environmental Management.* 5(2):147-160.

The cumulative effects of multiple logging operations on single watersheds are presented. Both California and federal laws require that these effects be considered when approving forest plans, but in actuality plans are approved on an individual basis. Ways to approach the problem and encourage the formation of a geological reference system to be used in planning are included.

Collman, S.J. 1989. Integrated pest management: A Seattle street tree case study. In: *Forestry on the Frontier, Proceedings of the 1989 Society of American Foresters National Convention.* Spokane, Washington. pp. 416-420.

This is a case study of the application of integrated pest management (IPM) to an urban forestry problem. An infestation of oystershell scale (Lepidosaphes ulmi) was reportedly causing the decline of ash cultivars along Seattle's streets. Examination of the declining trees found that 59.7% had only light or no scale infestation. Many healthy trees had heavy infestations. Data on aspects of the life history of the scales during the infestation demonstrated that literature information on hatching times was incorrect, which would have had an effect on the timing of insecticide applications. The author concludes that there was a 70% chance that the declining in some trees was due to less-than- optimum site conditions rather than the scale insects. A thorough examination of the problem should precede any textbook treatment application.

Cubbage, F.W. 1987. Costs of forest water quality protection. In: *Forestry and Water Quality: A Policy Workshop for State Foresters.* Oklahoma City, Oklahoma, July 6-9, 1987.

This paper presents a review of the costs of

forestry NPS controls, including agency administrative costs, direct costs to landowners or timber operators (e.g., plan preparation), and indirect costs on timber supplies. Forest practice costs are reviewed for California, Massachusetts, Nevada, Alaska, Idaho, Oregon, and Washington. The various approaches used by these states and their effect on implementation cost are analyzed as well. The approach used by forestry and other agencies for implementing the voluntary or required practice rules greatly affects the various costs of program implementation, as well as who bears the costs. Criteria used to select the means of controlling NPS pollution must include BMP effectiveness, political and social acceptability, and economic efficiency.

Cubbage, F.W., and C.E. DeForest. 1991. BMPs and harvesting regulations in the South. In: *Forestry and the Environment ...Engineering Solutions*. New Orleans, Louisiana, June 4-6, 1991. American Society of Agricultural Engineers.

This paper provides an overview of best management practices that apply to forestry practices, including road construction, timber harvest, stream crossing, streamside management zones, and maintenance and retiring of structures. This paper presents basic information about the types of BMPs that may be used. The paper introduces regulatory trends in the states of Florida, North Carolina, West Virginia, and Maryland, as well as regulatory trends in forested wetlands.

Cubbage, F.W., M.A. Elfner, and T.G. Harris, Jr. 1991. Economic values of forested wetlands. In: *Southern Forest Economics Workers Meeting*. Washington, DC, February 20-22, 1991. 14 pages.

The economic value of forested wetlands was calculated through market analysis and a cost-benefit analysis to determine whether a policy of protecting wetlands from destruction is warranted. This unbiased approach to the wetland issue bridges the gap between conservationists and timber harvesters by assigning monetary values to the market evaluation of wetland forest products. Despite these calculations, the author concludes that overall wetland protection will be determined by political, not economic, criteria.

Cubbage, F.W., L.K. Kirkman, L.R. Boring, T.G. Harris, and C.E. DeForest. 1990. Federal legislation and wetlands protection in Georgia: Legal foundations, classification schemes, and industry implications. *Forest Ecology and Management*. 33/34:271-286.

This paper provides a detailed review of the development and current status of U.S. laws governing operations in forested wetlands. The potential impacts of these laws on southern forestry are also presented.

Cubbage, F.W., and W.C. Siegel. 1988. State and local regulation of private forestry in the east. *Northern Journal of Applied Forestry*. 5(2):103-108.

State and local regulation of private forestry in the eastern United States is increasing. A number of statewide laws regulate the practice of forestry in some fashion. Many local governments in the northeastern states and a few in the South have enacted or considered ordinances governing logging operations, primarily to prevent property damage or to preserve amenity values. The trend toward disjointed local regulation may prompt renewed calls from the forestry sector for uniform state forest practice laws.

Cubbage, F.W., W.C. Siegel, and P.M. Lickwar. 1989. State water quality laws and programs to control nonpoint source pollution from forest lands in the south. In: *Water: Laws and Management Conference*. Tampa, Florida, September 17-22, 1989. American Water Resources Association. pp. 8A-29 to 8A-37.

This paper briefly reviews federal laws to maintain water quality and specifically reviews state water quality statutes and programs that affect forestry in the South. State programs for controlling nonpoint source pollution are summarized. The authors conclude that state water quality legislation in the South that affects

forestry is not restrictive and most southern states rely on voluntary implementation. Most state water quality laws could be implemented more forcibly.

Cubbage, F.W., W.C. Siegel, and T.K. Haines. 1987. Water quality laws affecting forestry in the eastern United States. In: *Symposium on Monitoring, Modeling, and Mediating Water Quality*. American Water Resources Association. pp. 597-609.

The impact of silvicultural practices on water quality and the history of water quality legislation affecting forestry are briefly addressed. Current regulatory and nonregulatory means of controlling nonpoint sources of pollution and their relationship to forestry practices are addressed. The current status (1987) of the various approaches and future prospects are addressed.

Cunningham, R.S. 1989. Resolving forest plan and project appeals in the eastern region of the Forest Service. In: *Forestry on the Frontier, Proceedings of the 1989 Society of American Foresters National Convention*. Spokane, Washington. pp. 277-280.

The process of open discussions and negotiations with the public and special interest groups over Forest Service (FS) Land and Resource Management Plans (LRMP) is presented. The FS has found that following proper legal processes and being technically correct are not enough to ensure success in solving forest management disputes. Negotiations and discussions allow a better understanding by all parties involved.

Dissmeyer, G.E., and E. Frandsen. 1988. The economics of silvicultural best management practices. In: *Nonpoint Source Pollution: 1988 - Policy, Economics, Management, and Appropriate Technology*. Milwaukee, Wisconsin, November 6-11, 1988. V. Novotony (ed.). American Water Resources Association, Bethesda, Maryland. pp. 77-86.

Matrices were developed to estimate the economic benefits of implementing nonpoint BMPs. Through three examples, this study illustrates incremental outputs and values of induced goods and services to investments in soil and water resource management on forestland and rangeland.

Dissmeyer, G.E., and R. Miller. 1991. *A status report on the implementation of the silvicultural nonpoint source program in the southern states*. 12 pages.

The results of a survey of Forest Service Southern Region states are presented. The survey questionnaire was developed to assess the status of silvicultural nonpoint source programs in the South. This paper documents the State Foresters' involvement and accomplishments and their planned actions in the coming years. The 13 states included in the survey consisted of 5 nonregulatory programs, 4 nonregulatory programs with state authority to make them regulatory, and 4 nonregulatory programs with existing state regulatory programs for non-compliers. The survey questionnaire and the nature of the responses are included.

Essig, D.A. 1991. *Implementation of silvicultural nonpoint source programs in the United States (Report of survey results)*. National Association of State Foresters. 17 pages.

The results of a survey questionnaire developed to provide a nationwide picture of the status of silvicultural nonpoint source programs are presented in this paper. All 19 questions posed to the State Foresters, their individual responses, and a summary of regional responses are presented. The questionnaire contained questions concerning the level of participation by the state forestry office in developing nonpoint source assessments, the presence or absence of a forestry BMPs program, the publications states provide to foresters to reduce water quality impacts, and training or workshops conducted.

Florida Department of Agriculture and Consumer Services, Division of Forestry. 1989. *Results of the 1989 silvicultural 208 compliance survey*. 8 pages.

The results of a biennial survey by the Florida

Department of Environmental Regulation are described. The BMP compliance of sites recently involved in silvicultural operations is evaluated. These BMPs were to remain nonregulatory if compliance had been attained.

Florida Department of Agriculture and Consumer Services, Florida Division of Forestry. 1992. *Results of the 1991 Silvicultural 208 Compliance Survey*. 10 pages.
The primary purpose of the biennial survey was to determine statewide compliance with silvicultural BMPs. Of the 150 surveyed sites, which were chosen in locations with the greatest potential for water quality impacts, 141 were found to be in compliance with silvicultural BMPs.

Floyd, D.W., and M.A. MacLeod. 1993. Regulation and perceived compliance: Nonpoint pollution reduction programs in four states. *Journal of Forestry*. 91(5):41-47.

This article reviews the types of state NPS programs created after passage of the Clean Water Act. State programs are categorized into four groups, and a state program is reviewed as an example of each group: primarily voluntary (Ohio), quasiregulatory (West Virginia), primarily regulatory (Maryland), and those with a comprehensive forest practices law (Massachusetts). The reasons that states may choose one type or another are mentioned. The expected success of voluntary programs is discussed from the point of view of predictive behavior theory. The authors conducted a survey of Society of American Foresters members to test hypotheses regarding the relationship between type of program and degree of compliance, knowledge of BMPs, and attitude toward forestry NPS pollution. They found that as program stringency increases, perceived compliance does also. No strong relationship was found either between program type and BMP knowledge or between program type and attitude toward forestry NPS pollution. The authors conclude that successful forestry NPS pollution reduction plans should combine regulatory and educational elements.

Fowler, J.M., E.O. Heady, and D.A. Christensen. 1983. *Interface of forest and agriculture in nonpoint pollution control*. Center for Agricultural and Rural Development, Iowa State University, Ames, Iowa. CARD Report 117. 131 pages.

The major purpose of the paper was to analyze the contribution of forestry practices to environmental problems so that policy options encompassing both the agricultural and forestry sectors can be formulated. The specific objectives of this study were: (1) to develop relationships between the dominant site characteristics of forested areas and the rate of suspended sediment generated; (2) to integrate results from site-specific local forest research into a comprehensive national model; and (3) to analyze selected environmental and resource policies that are consistent with national, river basin, or producing area objectives. Separate chapters address the role of site characteristics and undisturbed rates of sedimentation, fire, mass erosion, environmental effects of timber harvesting, and mathematical models for achieving forest production and protecting environmental quality that interact with the agricultural sector via the river basin network. Models focused on minimum cost and minimum sediment production, and combinations of these goals, are presented.

Greene, C.S. 1988. Water quality, timber and herbicides. In: *Proceedings of the 9th Annual Forest Vegetation Management Conference*. Redding, California, November 3-5, 1987. pp. 17-33.

This article discusses the evolution of regulations and related enforcement law developed by the California Regional Water Quality Control Board, North Coast Region for the protection of regional waters from the aerial application of herbicides. The sources of State and Regional Board authority, the protocol for initiating proposed spray projects, the development of water monitoring programs, spill contingency plans and water user notification procedures and the adoption of BMPs for the aerial application of herbicides are described. Incompatibilities

between failure to comply with regulations and enforcement law were resolved by recent amendments to and interpretations of the law. The paper emphasizes that laws and their enforcement are separate but related processes, and that feedback from persons involved in the two processes leads to changes in both the laws and their enforcement.

Gregory, R., E. Niemi, and R. Mendelsohn. 1989. A model for evaluating the impacts of forest management regulations. *Journal of Environmental Management*. 29:129-144.

This paper addresses the need of forest-management agencies to anticipate the impacts of regulations governing forest practices and outlines a model for evaluating the economic impacts of proposed changes in the forest environment. The approach described is based on two premises. First, the primary effect of changes of forest management rules is on the environment and therefore linkages between the rule changes, environmental impacts, and then economic values must be developed. Second, both market and nonmarket effects must be evaluated.

Greis, J.G. 1980. Silviculture water quality management program for Florida. In: *Proceedings of the Society of American Foresters*. pp. 158-159.

The Florida Department of Environmental Regulation and a committee of forest professionals teamed up to produce best management practice guidelines for silvicultural activities. The article addresses the demographic framework of Florida's specific needs and conveys the main points of water quality management. This short document contains no data but provides a good summary of the BMP development process.

Hawks, L.J., F.W. Cubbage, H.L. Haney, Jr., R.M. Shaffer, and D.H. Newman. 1993. Forest water quality protection: A comparison of regulatory and voluntary programs. *Journal of Forestry*. 91(5):48-54.

This study compares Maryland's primarily regulatory approach to forestry pollution control with the voluntary approach used in Virginia. Three indirect measures were used to assess and compare the two programs: the method each state uses to meet its pollution control goals, program implementation costs borne by each state, and ease of compliance and execution costs borne by landowners. The authors found each state's approach equally effective at obtaining BMP compliance. However, Virginia's voluntary approach was found to be easier to implement and to be an easier system for foresters and landowners (to obtain information, for instance), whereas Maryland's complex, multilayered regulatory approach is difficult to coordinate and implement and therefore more costly. On a harvest volume basis, Maryland spent $1.70 to $3.20 per thousand board feet (MBF) in 1990, while Virginia's cost was $0.50 to $0.58 per MBF. However, Virginia's harvest was almost 5 times greater than Maryland's, possibly reducing the cost per harvested volume.

Henly, R.K., and P.V. Ellefson. 1987. State-administered forestry programs: Current status and prospects for expansion. *Renewable Resources Journal*. 5(4):19.

This paper provides the results of a national survey of the lead state forestry agencies to determine the types of programs emphasized and what programs need emphasis in the future. This paper presents several tables of regional results from a thorough questionnaire, with a high response from the forestry agencies.

Hickman, C.A., and C.E. Martus. (undated). *Local regulation of private forestry in the eastern United States*. USDA Forest Service, Southern Forest Experiment Station.

The purpose of this study is to determine the nature and extent of state and local forestry regulation, and to evaluate how these laws and ordinances are likely to influence future timber supplies and conditions of availability. The study identifies and describes the local forestry regulatory ordinances that have been adopted in the eastern United States; documents the extent to which such ordinances have been enacted;

highlights important subregional differences in the nature and extent of local forestry regulation; and discusses probable trends in local forestry regulation.

Ice, G.G., R.L. Beschta, R.S. Craig, and J.R. Sedell. 1988. *Riparian rules for Oregon forests*, In: USDA Forest Service. General Technical Report PSW-110. pp. 533-536.

This paper chronicles the development and implementation in 1987 of Forest Practice Rules specifically designed to improve protection of riparian habitat for fish and wildlife.

Jones & Stokes Associates, Inc. 1973. *A method for regulating timber harvest and road construction activity for water quality protection in northern California, Volume II: Review and problem and annotated bibliography*. California State Water Resources Control Board.

The second volume of a two-part document reviews the problems associated with timber harvesting, road construction, and similar land-disturbing practices in northern coastal California. Volume II provides a good general discussion of the problems of erosion associated with forest activities and is intended primarily as background material for understanding the concepts and proposals discussed in Volume I.

Jones & Stokes Associates, Inc. 1973. *A method for regulating timber harvest and road construction activity for water quality protection in northern California, Volume I: Procedures and methods*. California State Water Resources Control Board.

The first volume of a two-part document examines the legal and administrative aspects of water and land resource management in northern coastal California and suggests a system for evaluating the risk to stream ecosystems from forest activities, and for making management decisions based on that evaluation.

Kemper, R.E., and L.S. Davis. 1976. Costs of environmental constraints on timber harvesting and regeneration. *Journal of Forestry*. 74(1):754-761.

This paper presents a methodology for measuring the cost of aesthetic and environmental constraints on timber harvesting and regeneration. The methodology was empirically quantified for two western national forests. The authors concluded from these case studies that the costs of increasing environmental care are substantial enough to warrant detailed quantification and consideration in public timber policy deliberation.

Kolenbrander, L.G. 1984. Special management areas processes and strategies. In: *Proceedings of the Special Management Areas Conference*. Denver, Colorado, April 24-25, 1984. The Nature Conservancy, San Francisco, California. 141 pages.

The purpose of the Special Management Areas Conference was to provide agency resource specialists, resource planners, area managers, and public interest groups with a comprehensive introduction to the purposes, planning, designation, and management of Special Management Areas (SMAs). Speakers at the conference presented information on the value and uses of SMAs and how they fit into a multiple-use land management framework, data bases useful for resource inventories, the planning process for designating SMAs, and the problems and opportunities involved in managing SMAs. Case studies were reviewed. These papers present an overview of the developing concept of SMAs and their role in resource management.

Lickwar, P.M., F.W. Cubbage, and C.A. Hickman. 1990. Current southern state programs for control of forestry nonpoint source pollution. *Southern Journal of Applied Forestry*. 14(2):64-69.

A survey was conducted in the southern states in 1987 to determine what silviculture nonpoint pollution control programs were being implemented. The author determined that virtually all state NPS programs in the South were nonregulatory and that they relied on educational programs to emphasize the value of BMPs. Although the states believed that BMPs would

continue to be the primary method for controlling silviculture NPS pollution, few believe that greater regulation of forestry activities was needed. Overall, this document provides a summary of what is being done about controlling NPS pollution from forestry in the South.

Lotspeich, F.B. 1971. *Environmental guidelines for road construction in Alaska*. Environmental Protection Agency, Alaska Water Laboratory College. Report No. 1610 GOI.

This report compiles and describes the BMPs required to ensure environmental protection during road construction under cold climate conditions. General topics are route selection, engineering design, construction activities, maintenance, and problems of the true arctic. Numerous figures illustrate BMPs. An appendix includes the National Environmental Policy Act (NEPA) of 1969, Executive Order 11514 (Protection and Enhancement of Environmental Quality), and a series of instructional memorandums by the U.S. Department of Transportation dealing with highway construction in response to EO 11514.

Lynch, J.A., and E.S. Corbett. 1990. Evaluation of best management practices for controlling nonpoint pollution from silvicultural operations. *Water Resources Bulletin*. 26(1):41-52.

Fifteen years of streamflow and water quality data were evaluated to determine the effectiveness of BMPs in controlling nonpoint source pollution from a 110-acre commercial clearcut located in the Ridge and Valley Province of central Pennsylvania. In general, the BMPs analyzed effectively reduced water quality impacts associated with timber harvest. Although some increases in water quality constituents were observed, most were well below the drinking water standards although they may violate EPAs antidegradation policy. The authors suggest that buffer strips of unharvested timber provided the most protection to the streams and that improved performance may be possible through annual inspections and increasing the width of buffer strips if necessary. The information presented in this report demonstrates the potential for reductions in nonpoint source pollution possible with various BMPs.

Martus, C.E., H.L. Haney, and W.C. Siegel. 1993. Preliminary impact of local government forestry-related ordinances affecting harvesting in the eastern United States. In: *Proceedings of Southern Forest Economics Workers' Annual Workshop*. Research Triangle Park, North Carolina. , North Carolina.

A survey of 748 loggers and consultants in three northeastern and three southern states. In the Northeast, the importance of regulation is limited by low levels of forest activity and small forested acreage. But in the South, large timber acreage and active markets magnified the importance of local regulation. Loggers and consultants reported examples of costly requirements, but most local laws were not viewed as burdensome. The results show that local forestry laws currently impose less of a burden than their absolute number would suggest.

Orsborn, J.F., and J.W. Anderson. 1986. Stream improvements and fish responses: A bio-engineering approach. *Water Resources Bulletin*. 22:381-388.

This paper discusses the problems and benefits associated with stream improvements and fish response using an integrated, bioengineering approach. Various conceptual models are discussed to describe system complexities and factors that constrain project evaluation. Conclusions regarding the reasons for project success are followed by recommendations for concerted and diversified efforts to improve success in stream stewardship.

Perry, J.A., R.C. Ward, and J.C. Loftis. 1984. Survey of state water quality monitoring programs. *Environmental Management*. 8(1):21-26.

The results of a survey of all state water quality monitoring programs are presented. Twenty questions were asked in the general areas of fixed-station monitoring, special studies, and

biological monitoring. The article presents the survey data and makes recommendations on ways to improve monitoring.

Roby, K., J. Rector, and M. Furniss. 1991. *PSW region of the Forest Service about to launch BMP evaluation process*. USDA Forest Service, Pacific Southwest Region. White paper. 2 pages.

This short article provides a general description of best management practices (BMP). It describes the history, objectives, primary components, and evaluation of BMPs. On-site and in-channel evaluations of BMPs are also addressed.

Salazar, D.J., and F.W. Cubbage. 1990. Regulating private forestry in the West and South. *Journal of Forestry*. 88(1):14.

The authors review two approaches to forest practice regulation: (1)comprehensive regulation by state forestry agencies and (2) fragmented regulation administered by state and local environmental protection and land use agencies. The approach used by a state depends primarily on whether states share forest practice regulatory authority with local governments. Comprehensive regulation is typical in western states, while the fragmented approach is more typical in northeastern states. Southern states have relied primarily on education and voluntary forest practice implementation. The article reviews the regulatory policies of Georgia, Oregon, and California. The regulatory policies of state versus local governments primarily reflect economic concerns such as forest resources value or property value. The use of forest practice regulation to protect water quality is also related to its economic value as measured by fisheries, recreation, and other factors. The authors examine the process of and factors involved in developing forest practice regulatory policy in the West and South.

Salo, E.O., and T.W. Cundy (eds.). 1987. *Streamside management forestry and fishery interactions*. College of Forest Resources, University of Washington. 471 pages.

The results of a symposium held to synthesize technical information on forestry and fisheries interactions and to discuss regulatory changes governing forest management practices are presented. Contents include: Variables Related to Fish Habitat (e.g., sediment, woody debris, temperature); Forest Management of the Streamside Zone; Case Studies - Effects of Timber Harvest on Fishery Resources; and Panel Discussions. The presented papers focus for the most part on the Pacific Northwest. The panel discussions concern economics and social considerations, streamside management zone BMPs, and policy perspectives. This collection of papers provides complete discussion of the interdependence of forestry and fisheries resources.

Schultz, B. 1992. *Montana forestry best management practices implementation monitoring: The 1992 forestry BMP audits final report*. Montana Department of State Lands, Forestry Division, Missoula, Montana. 32 pages.

This report summarizes the findings of Montana's 1992 forestry BMP audits. The audits evaluate whether BMPs are being applied and whether they are effectively limiting NPS pollution. Three audit teams evaluated up to 58 practices on 46 sites for a total of 2,029 practices rated for BMP application. Eight-seven percent of the practices rated on all sites met BMP requirements. Nine high-risk BMPs, the most important for protecting watersheds, were evaluated separately, and 72% of these met application requirements. Most sites-40 of 46-had at least one minor departure from BMP application; 20 of 46 sites had at least one major departure. On 21 of 46 sites, audit teams noted that a change in stream crossing would have prevented or reduced sediment discharge. The wider SMZs were, the fewer were the impacts in the SMZ from harvest practices. The greatest departure from BMPs, as well as the most impacts, was associated with road drainage. Application and effectiveness of BMPs were highest on state lands, followed by federal and industrial sites and nonindustrial private sites. The study recommends that the audits be continued; education programs be

continued; site owners and logging contractors attend the audits; landowners and contractors develop remedies for the problems noted; and the audit process be instituted for other land uses, including mining, livestock grazing, agriculture, and subdivision development.

Sidle, R.C., and A.N. Sharpley. 1991. Cumulative effects of land management on soil and water resources: An Overview. *Journal of Environmental Quality*. 20(1):1-3.

An overview of the cumulative effects of land management is provided, as well as an introduction to the papers presented at a special symposium held during the American Society of Agronomy meetings in 1989. An overview of the research is presented and future research needs are discussed.

Solomon, R.M., and P.E. Avers. 1987. *A water quality monitoring framework to satisfy legal requirements*. American Water Resources Association. Technical Publication Series TPS 87-2. pp. 231-242.

The paper discusses the development of water quality monitoring requirements as they relate to the Forest Service. A monitoring framework that will meet legal requirements is suggested. The framework includes three types of monitoring: (1) implementation, or determining whether monitoring plans were implemented as designed; (2) effectiveness, or determining whether the prescribed practices meet their objectives; and (3) validation, or investigating whether coefficients, models, and standards are valid to meet policy, laws, and regulations. Examples of each type of monitoring are given, and the usefulness of monitoring as a feedback mechanism for management decision-making is discussed.

USDA Forest Service. 1992. *Informational Report: Background Report for Development of the Forest Service Management Strategy for Pacific Salmon and Steelhead Habitat*. USDA Forest Service, Pacific Salmon Work Group and Field Team, Washington, DC.

The purpose of this report is to provide background information for the development for management of Pacific salmon and steelhead stocks, and to increase awareness about the issues within the Forest Service and with outside groups as well. The document discusses the organizational framework that includes three components: a Washington Office Policy Group which provides overall direction, and a Washington Office Work Group and an inter-regional Field Team that will cooperatively develop the strategy. The strategy was targeted for completion in 1993.

USEPA. 1980. *An approach to water resources evaluation of non- point silvicultural sources (a procedural handbook)*. U.S. Environmental Protection Agency, Athens GA.

This useful handbook provides an analysis methodology that can be used to describe and evaluate changes in water resources resulting from nonpoint silvicultural activities. It covers only the pollutant generation and transport processes and does not consider the economic, social, and political aspects of pollution control. The document contains significant amounts of data to aid with the selection of BMPs.

USEPA. 1988. *Effectiveness of agricultural and silvicultural nonpoint source controls: Final report*. U.S. Environmental Protection Agency, Region 10, Seattle, Washington.

This document presents an analysis of specific monitoring methods and monitoring programs for nonpoint source controls associated with silvicultural and agricultural practices. From the analysis, information is provided to aid in determining base guidelines for monitoring the effectiveness of NPS control programs.

USEPA. 1987. *Surface water monitoring: A framework for change*. U.S. Environmental Protection Agency, Office of Water, OPPE, Washington, DC.

This report presents the findings and recommendations of a major EPA study on surface water monitoring activities conducted by the Agency. The results are based on more than

150 structured interviews with key state and federal managers, and numerous less formal discussions with EPA and state scientific and technical staff. The report presents the findings on where surface water monitoring is today, why the present state/EPA program is not adequate to meet emerging needs, and where and how changes should be made.

USEPA. 1991. *Watershed monitoring and reporting for section 319 national monitoring program projects*. U.S. Environmental Protection Agency.

Section 319 of the Clean Water Act requires that EPA develop both a national framework and monitoring guidelines for the National Monitoring Program. Key aspects of the national framework have been developed and are summarized in this document. This document also provides monitoring and reporting guidelines.

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Alaska Department of Natural Resources. 1992. *Draft forest resources and practices regulations*.

Arkansas Forestry Commission. *Best management practices guidelines for silviculture*.

Arkansas Forestry Commission. *Final report, continuing nonpoint source control (Forestry)*. 17 pages.

Bauer, S.B. 1985. Evaluation of nonpoint source impacts on water quality from forest practices in Idaho: Relation to water quality standards. In: *Perspectives on Nonpoint Source Pollution: Proceedings of a National Conference*. Kansas City, Missouri, May 19-22, 1985. U.S. Environmental Protection Agency. pp. 455-458.

Beasley, J.L., and W.C. Harper. 1985. U.S. Department of Agriculture's perspective on silvicultural nonpoint source water quality. In: *Perspectives on Nonpoint Source Pollution: Proceedings of a National Conference*. Kansas City, Missouri, May 19-22, 1985. U.S. Environmental Protection Agency. pp. 321-324.

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Cubbage, F.W., T.M. Skinner, and C.D. Risbrudt. *An economic evaluation of the Georgia rural forestry assistance program*. University of Georgia, College of Agriculture Experiment Stations, Research Bulletin 322. 59 pages.

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3. INSTREAM STUDIES

CHEMICAL

Baker, M.B., Jr. 1990. *Hydrologic and water quality effects of fire*. USDA Forest Service, Rocky Mountain Forest and Range Experiment Station. General Technical Report RM-191. pp. 31-42.

This paper provides a review of studies conducted to determine the effects of prescribed burning on forest and rangelands of the Southwest. It provides a qualitative analysis on the types of water quality effects observed after prescribed burning; no substantial quantitative results are presented. The paper includes citations for nearly 70 articles related to water quality effects from prescribed burning.

Bormann, F.H., G.E. Likens, T.G. Siccama, R.S. Pierce, and J.S. Eaton. 1974. The export of nutrients and recovery of stable condition following deforestation at Hubbard Brook. *Ecological Monographs*. 44(3):255-277.

The effects of deforestation on the export of organic and inorganic particulate matter, erodibility, and the importance of dissolved substances in exported materials are presented in this paper. At the Hubbard Brook Experimental Forest, a forested watershed was clearcut and left in place. For the next 3 years, vegetative regeneration was controlled via the use of herbicides. Large increases (15 times) in particulate matter export were observed in the clearcut watershed, although little difference was observed the first 2 years and a dramatic difference was observed during the third year. In addition, the average ratio of export of dissolved substances to particulate matter was 2.3 for undisturbed and >8.0 during the first two years for clearcut. This paper provides significant amounts of data comparing deforested and undisturbed forested watersheds over several years. The temporal changes in water quality due to changes in vegetative cover provides significant evidence of the impacts of deforestation on water quality.

Bormann, F.H., G.E. Likens, D.W. Fisher, and R.S. Pierce. 1968. Nutrient loss accelerated by clear cutting of a forest ecosystem. *Science*. 159:882-884.

The effect of forest clearcut on nutrient loss was examined. The nutrient concentration in runoff water was compared to concentrations observed in an undisturbed forested watershed. Data from the study indicated significantly higher nutrient losses from the clearcut watershed. The results of this study suggest the following about nutrient depletion due to clearcut: reduced transpiration and increased runoff lead to greater export; reducing root surfaces reduces uptake and storage, removal of nutrients in forest products, and increased mineralization of exposed soils. This paper provides good data for comparison to other similar studies conducted within the Hubbard Brook Experimental Forest.

Brozka, R.J., G.L. Rolfe, and L.E. Arnold. 1981. Water quality from two small forested watersheds in southern Illinois. *Water Resources Bulletin*. 17(3):443-447.

This paper presents partial results of a larger research effort to determine the water quality benefits of various watershed management alternatives. Two intermittent streams on oak-hickory watersheds were tested for Na^+, K^+, Ca^{++}, Mg^{++}, P, and NO_3^-. Water quality in the watersheds was found to be high and was attributed to their forested cover. Tables of precipitation and nutrient concentrations in the streams are provided.

Chang, M., J.D. McCullough, and A.B. Granillo. 1983. Effects of land use and topography on some water quality variables in forested east Texas. *Water Resources Bulletin*. 19(2):191-196.

The spatial variation of five water quality variables was analyzed using composite water samples collected periodically from eight small watershed in forested East Texas during 1977-

1980. Based on 31 observations the average yields of nitrate-nitrite nitrogen, total kjeldahl nitrogen, total phosphorus, chloride, and total suspended sediment were 1.43, 21.96, 3.09, 50.11, and 90.39 kg/ha/yr, respectively. The article closes with three conclusions: (1) water flowing from forested watershed is normally freer from suspended solids than that from pasture watersheds; (2) Drainage density, watershed shape factor, compaction coefficient, stream frequency, and watershed mean slope were most useful in predicting water quality conditions; and (3) none of the observations of Cl, NO_3-NO_2 or TSS exceeded the proposed quality standards of EPA and the State of Texas. Concentrations of PO_4 were in excess of standards.

Childers, D.L., and J.G. Gosselink. 1990. Assessment of cumulative impacts to water quality in a forested wetland landscape. *Journal of Environmental Quality*. 19:455-464.

This article presents a historical analysis of water quality in the Tensas Basin, Louisiana, as part of a cumulative impact analysis of the landscape. Historical records of suspended sediment, N, P, and turbidity from three streams in the basin demonstrated that the watershed's water quality is characteristic where the original forest cover has been cleared. Aquatic primary productivity in the Basin appears to be nitrogen limited. A goal-oriented management plan for the watershed was developed based on the study results. Management practices to counteract the cumulative effects of conversion to agricultural land include runoff control, protecting forested corridors along streams, and creating new buffer zones.

Feller, M.C. 1989. Effects of forest herbicide applications on streamwater chemistry in southwestern British Columbia. *Water Resources Bulletin*. 25(3):607-616.

The herbicide glyphosate was applied to portions of two watersheds in southwestern British Columbia to kill vegetation that was competing with *Pseudotsuga menziesii* (Douglas fir) plantations. This application had little significant effect on streamwater chemistry (K^+, Na^{2+}, Mg^{2+}, Ca^{2+}, Cl^-, NO_3^-, NH_4^+, PO_4^{3-}, SO_4^-, and SiO_2 concentrations, electrical conductivity, and pH) when vegetation cover in a watershed was reduced by 4%, but had significant effects, which lasted for at least 5 years, when cover was reduced by 43%. The greatest percentage increases were observed for NO_3^-, which increased from typical pretreatment levels of <0.5 mg/l to a maximum of 4.6 mg/l during the first posttreatment water year. Nitrate levels, usually the most impacted by forestry activities, stayed below those recommended for drinking water (44 mg/l). This study presents the type of long-term data needed to analyze trends in water quality due to chemical applications.

Ffolliot, P.F. 1989. Water quality of streamflow from selected forested watersheds in Arizona. *Hydrology and water resources in Arizona and the Southwest*. 19:1-5.

A study was initiated to collect baseline water quality data for use in Arizona water resources planning and management strategies. A table is presented with mean and standard deviations for 3 years of samples for the following water quality constituents: total soluble salts, calcium, magnesium, sodium, chloride, sulfate, bicarbonate, fluoride, nitrate, and pH. This paper provides no cause-and-effect relationships for differences in pollutant concentrations in the watersheds. The paper provides baseline data but needs effects of different land uses to be more useful.

Foggin, G.T., III, and L.K. Forcier. 1974. *Cation concentrations in small streams draining match forested and clearcut watersheds in western Montana*. Montana State University, Joint Water Resources Research Center, Bozeman, Montana. Res. Report 58. 54 pages.

The impacts of clearcutting practices on the nutrient output of forested ecosystems and the effect on stream water quality are examined in this study. Fifteen clearcut basins in western Montana were selected and their morphometric characteristics determined. Water samples from these watersheds were analyzed for nutrients and other water quality parameters. It was determined

that the clearcut basin produced higher dissolved nutrient loads, as well as increased flow.

Fredriksen, R.L. 1971. Comparative chemical water quality-Natural and disturbed streams following logging and slash burning. In: *Proceedings of a Symposium: Forest Land Uses and Stream Environment*. Oregon State University, October 19-21, 1970. J.T. Krygier and J.D. Hall (eds.). Corvallis, OR. pp. 125-137.

The loss of nutrients from an old growth Douglas fir forest was measured in streams following timber harvest and slash burning. Nutrient cation losses increased 1.6 to 3.0 times the loss of the undisturbed watershed. The surge of nutrients following slash burning contained ammonia and manganese concentrations greater than federal water quality standards for 12 days after burning. The authors conclude that nitrogen losses can be minimized by avoiding slash burning when possible. This paper presents many figures and tables with the data from the study.

Fredriksen, R.L., D.G. Moore, and L.A. Norris. 1973. The impact of timber harvest, fertilization, and herbicide treatment on streamwater quality in western Oregon and Washington. In: *Forest Soils and Forest Land Management, Proceedings of the Fourth North American Forest Soils Conference*. B. Bernier and C.H. Winget (eds.). pp. 283-313.

This paper describes the impacts of forest management practices on stream water quality in the Douglas fir region. The conceptual base for understanding the processes of soil erosion and stream sedimentation and the outflow of native nutrients, fertilizers, and herbicides in streams is presented in this study. Research findings from studies in Cascade and Coast Range watersheds illustrate these concepts. The methodology commonly used in watershed studies is explained, and water quality effects of forestry activities are reviewed in detail. This is an excellent review of water quality effects, with data presented from numerous studies conducted in the region. The authors present five conclusions based on the review. Sedimentation of forest streams after timber harvest increases with increasing angle of slope, and forest roads that cross steeply inclined streams rather than roads on ridge tops. Clearcut forests and roads in steep country require more recovery time. Sedimentation can be decreased by careful planning. Nutrients are lost after clearcutting, but loss decreases rapidly with revegetation. Nitrogen concentrations in streams does not increase beyond accepted drinking water standards. The biological effects of forest fertilization on N transformations and movements in forest soils should be investigated. Long-term consequences of repeated forest fertilization on water quality must be determined. The drift or direct application of spray materials to surface waters is the principal route of herbicide entry into streams.

Gibbs, K.E., T.M. Mingo, and D.L. Courtemanch. 1984. Persistence of carbaryl (Sevin-4-oil) in woodland ponds and its effects on pond macroinvertebrates following forest spraying. *Canadian Entomologist*. 116:203-213.

The water quality impact of an aerial spraying of the insecticide carbaryl is presented. Carbaryl (Sevin-4-oil) was applied to woodland ponds in northern Maine at the rate of 840 g A.I./ha. Maximum residue levels found were 254 ug/l in the water and 53,793 ug/kg (dry wt) in the sediment. Residues of the carbaryl were detectable in the water samples for 14 months and in the sediment for 16 months after spraying. The study presents significant amounts of data on the levels of the carbaryl residues and on the number of aquatic organisms present prior to and after spraying. The amphipods *Hyallela azteca* and *Crangonyx richmondensis* were reduced to near zero levels after the applications and failed to recolonize ponds for 30 months after treatment. The concentrations observed in this study may be somewhat higher than typical because the sprayed ponds had no vegetative buffer to intercept any of the spray.

Golden, M.S., C.L. Tuttle, J.S. Kush, and J.M. Bradley. 1984. *Forestry activities and water quality in Alabama: Effects, recommended practices, and an erosion-classified system.* Auburn University, Agricultural Experiment Station. Bulletin 555.

The report was prepared primarily as a source of information on the relationship between forestry practices and water quality, with orientation toward forestry practices prevalent in Alabama. Information on stream pollutants such as sediment, nutrients, pesticides, organic material, waste and litter, and temperature is provided. The review includes over 160 directly cited documents on these subjects. Also included in the report are recommendations of principles and practices designed to minimize the water quality impacts from Alabama forestry practices.

Gottfried, G.J., and L.F. DeBano. 1990. *Streamflow and water quality responses to preharvest prescribed burning in an undisturbed ponderosa pine watershed.* USDA Forest Service, Rocky Mountain Forest and Range Experiment Station. General Technical Report RM-191. pp. 222-228.

The impacts of prescribed burning on streamflow and water quality were evaluated following a prescribed burn. Prefire and postfire levels of nitrate-nitrogen, ammonium-nitrogen, phosphates, calcium, magnesium, sodium, and potassium were used as indicators of stream water quality. No significant changes in streamflow were observed after the burn; significant, but small, changes in nutrient levels were observed. Because only 43% of the watershed was burned, the water quality and stream flow values do not represent total loads of nutrients from the watershed or the total water yield. Also, data were presented only for water samples collected for 1 year after burning.

Granillo, A.B., M. Chang, and E.B. Rashin. 1985. Correlation between suspended sediment and other water quality parameters in small streams of forested east Texas. *The Texas Journal of Science.* 37(2/3):227-234.

A study is described in which sediment load and its relationship with four other water quality parameters were examined in streams of eight mostly forested watersheds. Total suspended sediment (TSS) appears to be a reasonable indicator of stream water quality in the study area, as seen by the high correlations between TSS and Kjeldahl nitrogen, total phosphorus, and chloride.

Harr, R.D., and R.L. Fredriksen. 1988. Water quality after logging small watersheds within the Bull Run Watershed, Oregon. *Water Resources Bulletin.* 24(5):1103-1111.

The water quality impacts from clearcut practices and slash burning are presented. Logging significantly increased nitrate- nitrogen levels for up to 7 years after harvest; smaller increases were observed after slash burning. Suspended sediment also had a small increase attributed to construction of a permanent road that crossed streams. Annual stream temperatures increased 2-3 °C after logging but returned to pretreatment levels after 3 years. This watershed study presents significant data on the effects of forest harvest and slash burning on water quality.

Helvey, J.D., J.N. Kochenderfer, and P.J. Edwards. 1989. Effects of forest fertilization on selected ion concentrations in central Appalachian streams. In: *Seventh Central Hardwood Forest Conference.* Carbondale, Illinois, March 5-8. USDA Forest Service. General Technical Report NC-132. pp. 278-282.

Two small forest watersheds in West Virginia were fertilized with nitrogen and phosphorus to determine effects on streamflow chemistry. Fertilizer application rates were 336 kg/ha N as ammonium nitrate and 224 kg/ha P_2O_5 as triple superphosphate. Concentrations of nitrate-N increased on both watersheds 5 months after fertilization. Maximum monthly concentrations were 8.5 and 7.3 mg/l (background levels were a maximum 1-2 mg/l). Elevated levels of nitrate-N were observed for 3 years following treatment. Phosphate-phosphorus concentrations did not change appreciably.

Keeney, D.R. 1973. The nitrogen cycle in sediment-water systems. *Journal of Environmental Quality*. 2(1):15-28.

This paper reviews literature on the fate of nitrogen in waters and sediments. Emphasis is placed on the importance of N to aquatic productivity, the pathways leading to N gains or losses in aquatic ecosystems, and the availability of N in sediments to the overlying waters. The effects of sediment properties, lake morphology, and environmental factors (pH, temperature, DO, oxidation-reduction potential) on the pathways and rates of N turnover are considered. An extensive bibliography is provided.

Kochenderfer, J.N., and G.M. Aubertin. 1975. Effects of management practices on water quality and quantity: Fernow Experimental Forest, West Virginia. In: *Municipal Watershed Management Symposium Proceedings*. USDA Forest Service, Northeastern Forest Experiment Station. General Technical Report NE-13. pp. 14-24.

The data from 22 years of research into the influence of forestry practices on the quantity and timing of streamflow and on water quality parameters such as turbidity, temperature, specific conductance, pH, alkalinity, and nutrient concentrations are reviewed in this paper. Water quality degradation was observed from clearcut experimental watersheds, whereas minor changes in water quality were observed when forestry practices were well planned and conducted. The authors conclude that at the time of this paper, forests could not be managed for timber products and water yield and that water quality degradation could easily be avoided by using erosion control management practices. Data from the research are presented, although no statistical analysis of the data is provided.

Martin, C.W. 1979. Precipitation and streamwater chemistry in an undisturbed forested watershed in New Hampshire. *Ecology*. 60(1): 36-42.

A study was initiated to determine the precipitation and streamwater chemistry of forested watersheds at various stages of succession, including a forested watershed heavily logged 55 years ago, a watershed commercially clearcut in 1970, and a watershed clearfelled in 1967 and sprayed with herbicide for 3 years. The previously reported hypothesis that nutrient concentrations would be higher in streams draining mature forested areas due to lower net accumulation in these stands compared to younger stands was tested. The authors found a net loss of nitrate from all watersheds. However, a net accumulation of ammonium that was sufficient to give a net increase in total N in all watersheds was found.

Meyer, J.L., and C.M. Tate. 1983. The effects of watershed disturbance on dissolved organic carbon dynamics of a stream. *Ecology*. 64(1):33-44.

Two second-order streams in the Coweeta Hydrologic Laboratory, North Carolina, were studied for annual dissolved organic carbon (DOC) export. One of the watersheds was completely clearcut 2 years prior to the beginning of the study, while the other was left undisturbed. The document provides excellent analytical data for DOC transport during baseflow and storm periods. Lower DOC export from the clearcut watershed was concluded to be the result of lower inputs in subsurface water as well as in stream generation.

Mikalsen, K.T. 1986. Preliminary results of Georgia nonpoint source impact assessment study: Commercial forestry. In *Research on the Effects of Forest Harvesting, Drainage, Mechanical Site Preparation, and Prescribed Fire on Water Quality*.

Commercial forestry activities adjacent to five streams throughout physiographic regions in Georgia resulted in varying degrees of water quality impact. Beneficial use was denied in one stream, impaired in two streams, and not substantially affected in two streams. The major impairment observed in the streams was an increase in sediment deposition, which altered or destroyed aquatic habitats. It was concluded that the implementation of BMPs must be continued

and sampling must also be continued to ensure that high water quality standards are maintained.

Neary, D.G., P.B. Bush, J.E. Douglass, and R.L. Todd. 1985. Picloram movement in an Appalachian hardwood forest watershed. *Journal of Environmental Quality*. 14(4):585-591.

The herbicide picloram was applied at a rate of 5.0 kg/ha to 4 ha of a 28-ha watershed in western North Carolina. The herbicide was broadcast manually as a pellet formulation in May, with the intention of removing a poor-quality mixed oak overstory and rhododendron-laurel understory prior to planting white pine. Picloram residues in soil samples peaked in concentration in the upper 0.07 m at 11.58 mg/kg, had a half life of about 4 weeks, and declined to near detection limits 28 weeks after application. Residues were detected in soil solution 1.2 m into the soil. Only sporadic, low-level residues were detected in stream flow during a 70-week period. Use of picloram did not affect the quality of stream flow from the watershed for domestic or agricultural purposes.

Pionke, H.B., and G. Chesters. 1973. Pesticide-sediment-water interactions. *Journal of Environmental Quality*. 2(1):29-45.

This article reviews the impact of pesticide-sediment-water interactions on the distribution and persistence of pesticides in receiving lakes. The authors discuss pesticide persistence, transport through the atmosphere, ground water and surface runoff, and the effects of pH, lake stratification, characteristics and content of sediment organic matter and clay, and salinity. The authors conclude with a discussion and review of the factors affecting pesticide persistence in aquatic systems. An appendix of common and chemical names of insecticides, pesticides, and herbicides is provided, as is an extensive bibliography.

Ponce, S.L. 1974. The biochemical oxygen demand of finely divided logging debris in stream water. *Water Resources Research*. 10(5): 983-988.

The impact of Douglas fir needles and twigs, western hemlock needles, and red alder leaves on dissolved oxygen and thus on the quality of mountain stream water was examined. The leaf material exposed to fluctuating temperature exerted a 5 day BOD of 4.0, 2.4 and 4.2 times greater than the standard temperature BOD for Douglas fir needles, western hemlock needles,and red alder leaves, respectively. Oxygen depletion was more likely to cause aquatic disruptions than were leachate effects.

Silsbee, D.G., and G.L. Larson. 1983. A comparison of streams in logged and unlogged areas of Great Smoky Mountains National Park (Tennessee). *Hydrobiologia*. 102(2):99-111.

This study compared stream quality in a never-logged watershed and a primitively-logged (50 years ago) watershed in the Great Smokey Mountains National Park. Water quality, stream channel characteristics, and macroinvertebrates were evaluated. The water from the unlogged stream was higher in nitrate, sulfate, phosphate, and calcium than that of the logged stream. This paper provides information on the long-term water quality impacts associated with logging.

Swank, W.T., L.F. DeBano, and D. Nelson. 1989. Effects of timber management practices on soil and water. In: *The Scientific Basis for Silvicultural and Management Decisions in the National Forest System*. R.M. Burns (ed.). USDA Forest Service. General Technical Report WO-55. pp. 79-106.

This paper presents a detailed review of the effects of various forest management practices on soil and water characteristics. The major topics reviewed include forest management practices, general effects on soil and water, and effects on different forest types. The section on general effects on soil and water includes review of water quantity, water quality, erosion, nutrient loss/change, fire, and herbicides. The different forest types, including western inland conifers, pacific coast conifers, northeastern conifers, eastern hardwoods, and southern conifers, are reviewed for water yield, streamflow timing,

erosion and sedimentation, water quality and temperature, and soil and soil nutrients. This review cites over 100 references.

Tiedemann, A.R., T.M. Quigley, and T.D. Anderson. 1988. Effects of timber harvest on stream chemistry and dissolved nutrient losses in northeast Oregon. *Forest Science*. 34(2):344-358.

An upper slope conifer forest in eastern Oregon and Washington was studied. Three harvested watersheds (41% clearcut and 17% selection harvest) were compared to a control watershed. Nitrate-N concentrations in stream flow increased in response to both clearcutting treatments. The maximum level observed (0.52 mg/l) was, however, far below maximum allowable levels for drinking water standards (10 mg/l). Small but significant increases in cation concentrations were observed with both clearcutting treatments. Comparisons of chemical characteristics and constituents among the four watersheds under study revealed enormous variability. However, this study supported other studies from the Pacific Northwest that indicated that forest harvest activities have no adverse impact on water quality for drinking purposes. The dissolved nutrient concentrations and variations are provided and discussed in detail.

Blackmon, B.G. (ed). 1985. *Forestry and water quality: A mid- south symposium*. Little Rock, Arkansas, May 8-9, 1985. Arkansas Cooperative Extension Service, University of Arkansas.

Burdick, G.E., H.J. Dean, and E.J. Harris. 1960. The effect of Sevin upon the aquatic environment. *New York Fish and Game Journal*. 7:14-25.

Cole, D.W., W.J.B. Crane, and C.C. Grier. 1973. The effect of forest management practices on water chemistry in a second growth Douglas fir ecosystem. In: *Forest Soils and Forest Land Management, Proceedings of the Fourth North American Forest Soils Conference*. Laval University, Quebec. pp. 195-207.

Cornish, P.M., and D. Binns. 1987. Streamwater quality following logging and wildfire in a dry sclerophyll forest in southeastern Australia. *Forest Ecology and Management*. 22:1-28.

Davis, E.A., and P.A. Ingebo. 1970. Fenuron contamination of stream water from a chaparral watershed in Arizona. In *Research Progress Report of the Western Society of Weed Science*. pp. 22- 23.

Douglass, J.E., and W.T. Swank. 1975. Effects of management practices on water quality and quantity: Coweeta Hydrologic Laboratory, North Carolina. In: *Municipal Watershed Management Symposium Proceedings*. USDA Forest Service, Northeastern Forest Experiment Station. General Technical Report NE-13. pp. 1-13.

Duffy, P.D., J.D. Schreiber, D.C. McClurkin, and L.L. McDowell. 1978. Aqueous- and sediment-phase phosphorus yields from five southern pine watersheds. *Journal of Environmental Quality*. 7(1):45-50.

Feller, M.C., and J.P. Kimmins. 1979. Chemical characteristics of small streams near Haney in southwestern British Columbia. *Water Resources Research*. 15(2):247-258.

Froehlich, H.A. 1976. Inorganic pollution from forests and rangelands. In: *Non-point sources of water pollution*. Oregon State University Water Resources Research Institute. pp. 9-16.

Johnson, P.L., and W.T. Swank. 1973. Studies of cation budgets in the Southern Appalachians on four experimental watersheds with contrasting vegetation. *Ecology*. 54:70-80.

Kerr, P.C., D.L. Brockway, D.F. Paris, and S.E. Craven. 1973. Carbon cycling in sediment water systems. *Journal of Environmental Quality*. 2(1):46-51.

Lawson, E.R., T.L. Rogerson, and L.H. Hileman. 1985. Water quality of stormflows from hardwood forested catchments in the Boston mountains. In: *Fifth Central Hardwood Forest Conference*. Urbana, Illinois, April 15-17, 1985. pp. 215-221.

Likens, G.E., F.H. Bormann, and N.M. Johnson. 1969. Nitrification: Importance to nutrient losses from a cutover forested ecosystem. *Science*. 163:1205-1206.

NCASI. 1980. *Research and field investigation of the impact of southern forestry management practices on receiving water quality and utility*. National Council of the Paper Industry for Air and Stream Improvement. Technical Bulletin No. 337.

Neary, D.G., and J.L. Michael. 1989. Effect of sulfometuron methyl on ground water and stream quality in coastal plain forest watersheds. *Water Resources Bulletin*. 25(3):617-623.

Norris, L.A. 1976. Forests and rangelands as sources of chemical pollutants. In: *Non-Point Sources of Water Pollution*. Oregon State University, Water Resources Research Center. pp. 17-36.

Nutter, W.L. 1982. Water quality and yield from the intensively managed forest. In: *Proceedings of the Society of American Foresters*. pp. 89-93.

Red, J.T., and W.L. Nutter. 1986. Wastewater renovation in a slash pine plantation subjected to prescribed burning. *Journal of Environmental Quality*. 15(4):351-356.

Riekerk, H. 1989. Forest fertilizer and runoff-water quality. In: *Proceedings - Soil and Crop Science Society of Florida*. Vol. 48, pp. 99-102.

Sain, P., J.B. Robinson, W.N. Stammers, N.K. Kaushik, and H.R. Whiteley. 1977. A laboratory study on the role of stream sediment in nitrogen loss from water. *Journal of Environmental Quality*. 6(3):274-278.

Schreiber, J.D., P.D. Duffy, and D.C. McClurkin. 1976. Dissolved nutrient losses in storm runoff from five southern pine watersheds. *Journal of Environmental Quality*. 5(2):201-205.

Tiedemann, A.R., J.D. Helvey, and T.D. Anderson. 1978. Stream chemistry and watershed nutrient economy following wildfire and fertilization in eastern Washington. *Journal of Environmental Quality*. 7(4):580-588.

Triska, F.J., J.R. Sedell, K.C. Cromack, S.V. Gregory, and F.M. McCorison. 1984. Nitrogen budget for a small coniferous forest stream. *Ecological Monographs*. 54(1):119-140.

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Berman, C.H., and T.P. Quinn. 1991. Behavioral thermoregulation and homing by spring chinook salmon, *Oncorhynchus tshawytscha* (Walbaum), in the Yakima River. *Journal of Fish Biology*. 39(3): 301-312.

This study investigated the possible link between elevated thermal regimes and spring chinook salmon habitat selection and migration. Nineteen salmon were radiotagged and monitored for internal body temperature and movement for 4 months. The fish maintained an average internal temperature of 2.5 °C below ambient temperature prior to spawning and were most commonly located in islands, pools, and rock outcroppings along stream banks. Their behavior appeared to be modified to optimize temperature regimes and energy conservation. From these results, the authors concluded that cold-water refuges must be available for the salmon to avoid long-term population problems.

Beschta, R.L., R.E. Bilby, G.W. Brown, L.B. Holtby, and T.D. Hofstra. 1987. Stream temperature and aquatic habitat: Fisheries and forestry interactions. In: *Streamside Management: Forestry and Fishery Interactions*. University of Washington. E.O. Salo, and T.W. Cundy, (eds.) Inst. of Forest Res. No. 57. Ch. 6, pp. 191-232.

The objectives of this paper are to characterize stream temperature regimes in forested

ecosystems, to indicate the underlying physical mechanisms of temperature change resulting from the removal of forest canopies over streams, and to identify the various processes by which temperature changes following logging can affect aquatic communities and the production of fish. Over 100 references are cited in this review.

Bilby, R.E., and P.A. Bisson. 1992. Allochthonous versus autochthonous organic matter contributions to the trophic support of fish populations in clear-cut and old-growth forested streams. *Canadian Journal of Fisheries and Aquatic Science*. 49(3):540-551.

Annual organic matter inputs and production of stocked coho salmon, coastal cutthroat, and shorthead sculpin from spring to autumn was monitored for 2 years in two headwater tributaries of the Deschutes River, Washington. One site was bordered by old- growth coniferous forest and the other an area clearcut without buffer strips 7 years before. Although organic inputs were nearly twice as high in the old-growth stream, the clearcut stream experienced greater fish production. The differences in fish production were most prevalent during early summer. The authors hypothesized that fish populations depended on food derived from autotrophic pathways during spring and summer in the presence or absence of forest canopy.

Binns, N.A., and F.M. Eiserman. 1979. Quantification of fluvial trout habitat in Wyoming. *Transactions of the American Fisheries Society*. 108:215-228.

A habitat quality index was developed to predict trout standing crop in Wyoming streams. Measurements of trout habitat were collected from 36 streams that ranged in elevation from 1,146 to 3,042 m. A multiple regression analysis indicated those habitat measurements best related to trout standing crop in the study streams. Nine habitat attributes, including late summer stream flows, annual stream flow variation, water velocity, trout cover, stream width, eroding stream banks, stream substrate, nitrate- nitrogen concentration,and maximum summer stream temperatures, were used in the model.

Bjornn, T.C., and D.W. Reiser. 1991. *Habitat requirements of salmonids in streams*, In: Influences of Forest Land and Rangeland Management on Salmonid Fishes and Their Habitat. Meehan, W.R., (ed.) American Fisheries Society Special Publication 19. Chapter 4. pp. 83-138.

This chapter presents a review of information on the range of habitat conditions for each life stage of salmonids that allow various species to exist. The chapter focusses primarily on salmonids of the Pacific drainages of North America. The following factors which influence migration, spawning, rearing, and incubation are reviewed: temperature, dissolved oxygen, turbidity, barriers, streamflow, space, water depth and velocity, substrate, cover, and stream productivity.

Bugert, R.M., T.C. Bjornn, and W.R. Meehan. 1991. Summer habitat use by young salmonids and their responses to cover and predators in a small southeast Alaska stream. *Transactions of the American Fisheries Society*. 120:474-485.

The effect of some habitat changes associated with logging on habitat selection by juvenile steelhead, coho salmon and Dolly Varden living together in small spawning and nursery stream on Prince Wales Island was examined. The assessments were based on juvenile use in streams with various types of riparian and instream cover with predators present and absent. Habitat use by the 3 species differed primarily in depth of water and position in water column. All three species selected lower positions in the water column in pools without cover than in pools with riparian or instream cover. In addition to the results presented, a general review (over 50 references) of the literature is included.

Chapman, D.W. 1988. Critical review of variables used to define effects of fines in redds of large salmonids. *Transactions of the American Fisheries Society*. 117:1-21.

The author critically reviews the variates used to evaluate effects of fine sediments on survival to alevin emergence in redds of large salmonids in streams. The following variables are discussed: the structure of the salmonid redd and physical variables within it; the relationships between substrate particle sizes, permeability, and survival; and the effect of fines on incubation and emergence success and the utility of survival predictors.

Chapman, D.W. 1962. Effects of logging upon fish resources of the west coast. *Journal of Forestry*. 60(8):533-537.

This article is a basic summary of the major effects of logging on fish resources. The article is not a description of new research but references other literature.

Cordone, A.J., and D.W. Kelley. 1961. The influences of inorganic sediment on the aquatic life of streams. *California Fish and Game*. 47:189-228.

This report contains a general review of studies on the effects of inorganic sediment on the aquatic life of streams. More than 100 references on the following topics are included: direct effect of sediment on fish, influences of sediment on eggs, alevins, bottom organisms, aquatic plants, chemical and physical characteristics, fish habitats and populations, and long-term siltation research.

Edwards, C.J. A review of aquatic impact associated with turbidity. In: *Proceedings of Technical Workshop on Sediments*. Corvallis, Oregon, February 3-7, 1992. U.S. Environmental Protection Agency and USDA Forest Service.

This paper provides a review of the effects of sediment on the trophic structure of aquatic systems. The report is divided into primary, secondary, and high order producers.

Erman, D.C., and N.A. Erman. 1984. The response of stream macroinvertebrates to substrate size and heterogeneity. *Hydrobiologia*. 108(1):75-82.

The effect of substrate size and heterogeneity on macroinvertebrate abundance and species diversity was presented in this paper. Variation in size class proportions and number of size classes had no independent effect on macroinvertebrate abundance or richness. Median particle size, stream current, and detritus accounted for most of the significant variation in macroinvertebrates colonizing the experimental substrates. Surfaces with high heterogeneity were colonized by more individuals (not taxa) than surfaces with low heterogeneity.

Erman, D.C., J.D. Newbold, and K.B. Roby. 1977. *Evaluation of streamside buffer strips for protecting aquatic organisms*. California Water Resources Center, University of California, Davis, California. 48 pages.

Sixty-two northern California streams were studied to evaluate the impact on invertebrate communities of logging with and without streamside buffer strips. Logging without buffer strips causes a significant change in benthic invertebrates compared to unlogged streams. Populations of Chironomidae, Baetis, and Nemoura increase, but overall invertebrate diversity is reduced in logged streams. Streams with buffer strips at least 30 m wide have invertebrate populations and physical characteristics indistinguishable from those of unlogged streams. Streams with buffer strips less than 30 m wide generally show the same impacts as streams without protective measures. Streams logged without protective measures at least 10 years prior to 1975 still had invertebrate diversities significantly lower than unlogged streams. The indices of taxonomic diversity and ecological distance were used. Numerous data

tables and a full discussion of methods are provided.

Fausch, K.D., C.L. Hawkes, and M.G. Parsons. 1988. *Models that predict standing crop of stream fish from habitat variables: 1950-1985.* USDA Forest Service, Pacific NW Research Station. General Technical Report PNW-213. 52 pages.

The document presents a comprehensive review of a diverse array of models that predict standing crop of stream fish from measurable characteristics of the environment. The purpose of the review was to organize the models diversity by the types of habitat (independent) variables found significant, the mathematical structure, the size of the data sets used to develop the models, and how well the models fit these data. The authors have highlighted investigations they felt used sound approaches to model development, testing, and interpretation so that others might follow that lead.

Fight, R.D., L.D. Garrett, and D.L. Weyermann (eds.). 1990. *SAMM: A prototype southeast Alaska multiresource model.* USDA Forest Service, Pacific Northwest Research Station. General Technical Report PNW-GTR-255. 109 pages.

An environmental assessment method was used by an interdisciplinary team of forest specialists to gain an understanding of resource interactions and tradeoffs resulting from forest management activities in southeast Alaska. A forest multiresource projection model (Southeast Alaska Multiresource Model (SAMM)) was developed in the process. The model was proclaimed to be capable of characterizing and displaying interactions of four major resources over a 150-year rotation: timber, wildlife, hydrology, and fisheries. At the time the document was published, full use of the model for quantitative analysis was not available; only qualitative planning assessment were recommended.

Folmar, L.C., H.O. Sanders, and A.M. Julin. 1979. Toxicity of the herbicide glyphosate and several of its formulations to fish and aquatic invertebrates. *Archives of Environmental Contamination and Toxicology*. 8:269-278.

Studies were conducted of the herbicide's toxicity to aquatic invertebrates (scuds, midge larvae, mayfly nymphs, and daphnids) and fish (Rainbow trout, fathead minnows, channel catfish, and bluegills). Acute toxicities for Roundup ranged from 2.3 mg/L to 43 mg/L. Technical glyphosate was considerably less toxic than Roundup. Roundup was more toxic to rainbow trout and bluegills at higher temperatures and at pH 7.5 than pH 6.5. Eyed eggs were the least sensitive life stage, but toxicity increased markedly as the fish entered the sac fry and early swim-up stages. Application of Roundup at recommended rates along ditchbank areas of irrigation canals should not adversely affect resident populations of fish or invertebrates. However, spring applications in lentic situation, where dissolved oxygen levels are low or temperatures are elevated, could be hazardous to young-of-the-year fishes. Toxicity tables listing the LC50 or EC50 concentrations used and confidence limits are provided.

Fraley, J., T. Weaver, and J. Vashro. 1989. Cumulative effects of human activities on bull trout (*Salvelinus confluentus*) in the Upper Flathead Drainage, Montana. In: *Proceedings of the Symposium on Headwaters Hydrology*. American Water Resources Association, Bethesda, Maryland. pp. 111-120.

The potential cumulative effects of land management practices, such as timber harvest and road building in the Flathead Lake watershed, on the population of the bull trout are summarized. The authors provide evidence from other monitoring studies that suggests that the deposition of fine sediments from streamside disturbances and forest road construction activities have adversely affected and could continue to adversely affect the bull trout. Based on information summarized in this paper, the authors called for amendments of current management

standards, including riparian guidelines and increased implementation of best management practices to reduce sediment delivery.

Frear, S.T. 1982. Ecological benefits of large organic debris in streams. In: *Forestry Research West*. USDA Forest Service, pp. 7-10.

This informational article reveals the benefits of large organic debris in forest streams. The document lacks data but describes qualitative benefits of proper forest stream management. The author concludes by providing guidelines for forest managers to help minimize the impact of human activities on stream environments associated with silviculture.

Gibbs, K.E., T.M. Mingo, and D.L. Courtemanch. 1984. Persistence of carbaryl (Sevin-4-oil) in woodland ponds and its effects on pond macroinvertebrates following forest spraying. *Canadian Entomologist*. 116:203-213.

The water quality impact of an aerial spraying of the insecticide carbaryl is presented. Carbaryl (Sevin-4-oil) was applied to woodland ponds in northern Maine at the rate of 840 g A.I./ha. Maximum residue levels found were 254 ug/l in the water and 53,793 ug/kg (dry wt) in the sediment. Residues of the carbaryl were detectable in the water samples for 14 months and in the sediment for 16 months after spraying. The study presents significant amounts of data on the levels of the carbaryl residues and on the number of aquatic organisms present prior to and after spraying. The amphipods *Hyallela azteca* and *Crangonyx richmondensis* were reduced to near zero levels after the applications and failed to recolonize ponds for 30 months after treatment. The concentrations observed in this study may be somewhat higher than typical because the sprayed ponds had no vegetative buffer to intercept any of the spray.

Graham, A.A. 1990. Siltation of stone-surface periphyton in rivers by clay-sized particles from low concentrations in suspension. *Hydrobiologia*. 199(2):107-115.

This paper presents the results of a study investigating siltation of periphyton in the Waitaki River in New Zealand, a river with chronic loading of clay-sized mineral particles in suspension at low concentrations. At concentrations between 1 and 10 g/m^3 of suspended mineral silt during normal flow, silt accumulation in epilithic periphyton accounted for about 50% of its dry weight. This caused a reduction in the mean organic content of periphyton to 22%, compared to 52% in a reference stream were concentrations were less than 1 g/m^3 during non-freshet flow. Possible implications of the reduction in periphyton food value was also discussed.

Grant, J.W., J. Englert, and B.F. Bietz. 1986. Application of a method for assessing the impact of watershed practices: Effects of logging on salmonid standing crops. *North American Journal of Fisheries Management*. 6:24-31.

Total salmonid biomass is used as an indicator of stream habitat quality for salmonids and to assess the impacts of logging disturbances, including stream crossings, clearcuts, and bank modification, on the salmonid populations of 10 streams in New Brunswick and Nova Scotia. Salmonid biomass decreased significantly downstream of two stream crossings, probably due to increased siltation, while seven clearcuts and one bank modification along the other eight streams had no significant effect on salmonid biomass. Removal of the canopy cover was associated with increases in the fork length or weight at age, or both, of juvenile Atlantic salmon but had no consistent effect on the size at age of brook trout. The authors discuss the negative (increased sediment load) and positive (increased productivity) consequences of canopy cover removal, and emphasize that site-specific circumstances should be taken into account when determining how to manage streams.

Gray, L.J., and J.V. Ward. 1982. Effects of sediment releases from a reservoir on stream macroinvertebrates. *Hydrobiologia*. 96(2):177-184.

The effects of sediment release from the Guernsey reservoir on macroinvertebrates of the North Platte River, Wyoming, were examined. Suspended solids concentrations during the sediment release increased from < 20 mg/L to > 300 mg/L. Because the fine particles remained in suspension, mean particle size was not changed. Densities of chironomids decreased over 90% during sediment release but returned to pre-sediment release levels within 3 weeks. Changes in benthic populations were highly correlated with increases in suspended solids. The authors noted that the direction of changes in macroinvertebrate populations was predictable from previous studies of the effect of sediment on invertebrates, particularly chironomids.

Gurtz, M.E., and J.B. Wallace. 1984. Substrate- mediated response of stream invertebrates to disturbance. *Ecology*. 65(5):1556- 1569.

The response of aquatic invertebrates to clearcutting was examined in a second order stream in the southern Appalachian mountains. For 21 months after clearcut, invertebrates were sampled in the following substrates: rock face, cobble riffles, pebble riffles, and sand. In the clearcut watershed, more taxa increased in rock substrate, followed by cobble riffles, pebble riffles, and sand. The most significant reductions in taxa was observed in sand substrate. The authors noted, based on differences among function groups of insects, that biological stability was closely linked with physical stability.

Hansmann, E.W., and H.K. Phinney. 1973. Effects of logging on periphyton in coastal streams of Oregon. *Ecology*. 54:194-199.

Prelogging and postlogging oxygen levels, temperature, and sedimentation loads were analyzed in a study of small watersheds in Oregon. Clearcut logging was applied to one watershed of 71 hectares, while a second watershed was patch-cut leaving a buffer-strip of vegetation along the stream channel. A third watershed remained as a control. The study showed that a close relationship exists between watershed practices and floral characteristics of the drainage system and that stream characteristics can maintain themselves if adequate protection is given to stream vegetation.

Harr, R.D., and R.A. Nichols. 1993. Stabilizing forest roads to help restore fish habitats: A northwest Washington example. *Fisheries*. 18(4):18-22.

Due to increased landslide risk and sediment delivery from 30 to 40-year old forest roads in the Canyon Creek watershed, the roads were decommissioned by stabalizing fills, removing stream crossings, recontouring slopes, and reestablishing drainage patterns. The failure rate of the roads prior to recommissioning was 110 times higher than undisturbed forest and 6 times higher than logged forest. The average cost of decommissioning the roads was $3,500 per km where considerable earthmoving was necessary. Lower costs were associated with lesser earthmoving jobs; the highest costs resulted when fills at stream crossings or landings had to be removed. In contrast to unused roads not treated, decommissioned roads and landings were largely undamaged by rain on snow runoff that produced a 50-year flood in November 1989 and sustained little damage during rain on snow runoff in November 1990 that severely damaged main haul roads in northwest Washington. The authors concluded that reducing the landslide and failure rate of roads used in forestry operations would greatly improve conditions for salmonids.

Hartman, G.F., and T.G. Brown. 1987. Use of small, temporary, floodplain tributaries by juvenile salmonids in a West Coast rain-forest drainage basin. *Canadian Journal of Fisheries and Aquatic Sciences*. 44:262-270.

The use of small floodplain tributaries by juvenile

salmonids is examined in this paper. Information was gathered on the movement of trout within the floodplain habitat or their distribution within it. The results of this study indicate that adult and juvenile salmonids use many of the small drainages in the Carnation Creek basin and therefore human activities, such as logging, may adversely impact the habitat. The authors recommend the following planning and management steps: mark small tributaries during periods of high flow, locate roads to avoid redirecting ground water seepage, locate landing sites away from small tributaries, plan yarding activities so that yard scars and debris do not block entrances to small tributaries, conduct active logging during dry periods when possible, and plan the application of pesticides to avoid small tributaries and swampy areas.

Hartman, G., J.C. Scrivener, L.B. Holtby, and L. Powell. 1987. Some effects of different streamside treatments on physical conditions and fish population processes in Carnation Creek, a coastal rain forest stream in British Columbia. In: *Streamside Management: Forestry and Fishery Interactions*. E.O. Salo and T.W. Cundy (eds). University of Washington, College of Forest Resources, Seattle, Washington. pp. 330-372.

Carnation Creek has been studied continuously since 1971. During this time 41% of the watershed was logged. Three different streamside treatments conducted in the alluvial floodplain portion were evaluated: (1) an intensive treatment of clearcutting, felling of streambank alder, and yarding of felled trees and merchantable timber; (2) a careful treatment of clearcutting to the margin of the stream and felling of streambank alder, with no in-channel activity; and (3) a leave strip treatment in which a variable width strip of vegetation was left along the stream. Stream temperature increased due to logging. The decrease in volume and stability of large debris was accompanied by streambank erosion and straightening of the channel. This in turn caused a change in gravel quality in the lower sections of the stream. Coho and chum salmon egg-to-fry survival was lower following the first major storm following logging. Trout smolt numbers decreased, but coho smolts increased by 76% between 1976 and 1983. Afterward they decreased to prelogging levels.

Hausle, D.A., and D.W. Coble. 1976. Influence of sand in redds on survival and emergence of brook trout (*Salvelinus fontinalis*). *Transactions of the American Fisheries Society*. 105:57-63.

This study investigates the effect of sand in spawning gravel on emergence of brook trout from redds to estimate the survival rate from egg deposition to emergence for brook trout in Lawrence Creek, Wisconsin. Brook trout alevins were put in sand-gravel mixtures of known composition in a fiberglass trough, and subsequently the emerging fry were recovered. The study showed that sand inhibited emergence.

Hawkins, C.P., M.L. Murphy, and N.H. Anderson. 1982. Effects of canopy, substrate composition, and gradient on the structure of macroinvertebrate communities in Cascade Range streams of Oregon. *Ecology*. 63:1840-1856.

The relationship between stream community structure and abundance and the density and type of riparian vegetation present is examined. Six streams in the western Cascade Mountains were studied between 1978 and 1979, and it was determined that neither the canopy nor the substrate strongly influenced the number of taxa. This paper presents limited data addressing the complexity of streamside forests and focuses almost exclusively on community structure. Numerous tables on community structure for the Western Cascades are provided.

Heifetz, J., M.L. Murphy, and K.V. Koski. 1986. Effects of logging on winter habitat of juvenile salmonids in Alaskan streams. *North American Journal of Fisheries Management.* 6:52- 58.

This study was conducted in southeastern Alaska to determine the effects of logging on winter habitat of juvenile salmonids. The types of streams studied were located in the following areas: undisturbed old-growth forest, clearcut with riparian buffer strips, and clearcut logged along at least one bank. The authors found that most fish species resided in pools, and riffles and glides were avoided. The types of pools utilized varied widely during the study. Also, the amount of woody debris, which caused over 70% of the pools, was significantly greater in occupied pools. Several tables of data quantifying salmonid numbers for each stream type and pool type are included.

Hilmon, J.B., and J.E. Douglass. 1968. Potential impact of forest fertilization on range, wildlife, and watershed management. In: *Forest Fertilization: Practice and Theory.* Tennessee Valley Authority. pp. 197-202.

This is a review of the potential impacts of fertilization on forage, wildlife, and water resources. Results of studies carried out in Florida, Georgia, and North Carolina are presented. Plots received different rates of fertilization, and the nutrient quality of forage for livestock was measured. A similar study was carried out on plots managed for both timber and forage production. The authors briefly discuss the effects of fertilization on the nutrient value of wildlife forage, and, in greater detail, the water quality and yield effects of fertilization.

Hiltibran, R.C. 1967. Effects of some herbicides on fertilized fish eggs and fry. *Transactions of the American Fisheries Society.* 96:414-416.

The toxicity of amitrole, dalapon, endothall, dichlobenil, dimethylamine salt of 2,4-D, isooctyl ester of 2,4-DP, propionic acid, and potassium salt of silvex at various concentrations was examined in a laboratory study. At the concentrations used, no reduction in the survival period of any of the fry was observed. Other herbicides did reduce the survival period at some of the concentrations used. Endothall, because of its low toxicity to fish, low toxicity to eggs or fry, and rates of aquatic use, appears to be one of the safest herbicides to use during the spawning season. Fry were more susceptible to the toxicity of herbicides than were fertilized eggs. Granular formations of some herbicides proved to be less toxic than liquid formulations.

House, R., V. Crispen, and R. Monthey. 1989. *Evaluation of stream rehabilitation projects - Salem district (1981-1988).* Technical Note OR-6:6600. USDI, Bureau of Land Management, Portland OR. 50 pages.

This document presents information on the effectiveness of stream rehabilitation structures in the Alsea and Nestucca River drainages, Oregon. Over 800 structures were evaluated in this study. Cost data for the structures is also included. In general, large increases in aquatic populations were observed after installation of the structures. The following structure types were evaluated: dams, deflectors, diversions, cover, scour, riprap, gravel, and others. Many tables are presented with information of changes in habitat attributable to the rehabilitation projects, adult and juvenile fish populations, and estimated benefits and costs.

Howard, R.J., and J.A. Allen. 1989. Streamside habitats in southern forested wetlands: Their role and implications for management. In: *Proceedings of the Symposium: Forested Wetlands of the Southern United States.* Orlando, FL, July 12-14, 1988. USDA Forest Service. GTR SE-50. pp. 97-106.

This paper summarizes recent literature concerning the value of streamside forested wetlands of the Southern United States as fish and wildlife habitat. The role of wetlands in providing fish spawning and nursery habitat

during inundation, protecting water quality, and supplying cover and food to channel-dwelling fish is described. Habitat edge and vegetation composition and structural complexity for wildlife are examined, as well as the effects of soil moisture and proximity of permanent surface water on wildlife species distribution. Lastly, management practices and recommended widths for forested streamside buffer zones are also presented.

Johnson, S.W., J. Heifetz, and K.V. Koski. 1986. Effects of logging on the abundance and seasonal distribution of juvenile steelhead in some southeastern Alaska streams. ***North American Journal of Fisheries Management.*** **6:532-537.**

This study was conducted in southeastern Alaska to determine the effects of logging on the seasonal abundance of juvenile steelhead. The paper presents results from 18 streams surveyed during the study. The streams studied were located in the following areas: undisturbed old-growth forest, clearcut with riparian buffer strips, and clearcut logged along at least one bank. Results indicated seasonal differences in fry abundance and size by stream type. In summer, the fry were larger in the clearcut streams due to greater overall production attributed to higher water temperatures and increased solar radiation. However, in winter, parr density increased in the undisturbed and buffered stream types. This was assumed to result from migration of parr to preferred winter habitat of pools and abundant cover. The authors concluded that the benefits observed during clearcut were negated by the lack of winter rearing habitat.

Lantz, R.L. 1971. Influence of water temperature on fish survival, growth, and behavior. In: ***Proceedings of a Symposium: Forest Land Uses and Stream Environment.*** **Oregon State Univ., October 19-21, 1971. J.T Krygier and J.D. Hall (eds.). OSU, Corvallis, OR. pp. 182-193.**

This paper presents a review of the effect of water temperature on fish and the influence that streamside vegetation has on controlling temperature fluctuations. The authors conclude that an important land management tool is leaving buffer strips along streams in forested areas. This paper provides a general review of the literature on stream water temperature control, as well as the resulting improvement in fish survival and reproduction resulting from leaving buffer strips when harvesting.

Li, H.W., C.B. Schreck, C.E. Bond, and E. Rexstad. 1987. ***Factors influencing changes in fish assemblages of pacific northwest streams,*** **In: Community and Evolutionary Ecology of North American Stream Fishes. Matthews, W.J., and D.C. Heins, (eds.) Chapter 24: 193-202.**

The practices affecting the change in fish populations in the pacific northwest are reviewed in this chapter. Dams and, forestry, grazing, and bank stabilization practices have changed the morphology of watersheds and diminished the role of woody debris and riparian vegetation as regulators of physical change and stream metabolism. Topics reviewed include faunal characteristics in relationship to spatial scale, Impacts of fishing, impacts of dams, and impacts on riparian habitats.

Lloyd, D.S. 1987. Turbidity as a water quality standard for salmonid habitats in Alaska. ***North American Journal of Fisheries Management.*** **7(1):34-45.**

A review of studies on the effects of turbidity on salmonid habitat was used to determine if turbidity could be used as a water quality standard. Based on information from the review, water quality standards allowing increases of 25 or 5 nephelometric turbidity units above ambient turbidity in clear cold-water habitats provides moderate and relatively high protection, respectively, for salmonid fish resources in Alaska. Stricter standards may be required for extremely clear waters, but stringent standards are not required for naturally turbid waters. Over 90

references are cited in this review.

Lloyd, D.S., J.P. Koenings, and J.D. LaPerriere. 1987. Effects of turbidity in fresh waters of Alaska. *North American Journal of Fisheries Management*. 7(1):18-33.

Findings from previous investigations are reviewed to describe the effects of turbidity on coldwater systems in Alaska and to describe relationships between suspended sediment concentration and resulting turbidity. A model was developed that describes the decrease in primary production in shallow interior Alaskan streams caused by sediment-induced turbidity. The turbidity measurements correlated less consistently with measures of suspended sediment concentrations, but provided an adequate estimator for use as a water quality standard to protect aquatic habitats.

Mayack, D.T., P.B. Bush, D.G. Neary, and J.E. Douglass. 1982. Impact of hexazinone on invertebrates after application to forested watersheds. *Archives of Environmental Contamination and Toxicology*. 11:209-217.

The herbicide hexazinone was applied to a forested watershed in the Piedmont region of Georgia. Aquatic macrophytes and terrestrial invertebrates were monitored and sampled for residue levels of the chemical. Residue levels in terrestrial invertebrates were a maximum of two orders of magnitude greater than comparable levels (0.01 to 0.18 ppm) found in forest floor material. Hexazinone and its metabolites were generally not detected (<0.1 ppm) in aquatic invertebrates and macrophytes. No community changes, alteration in species, or population densities were recorded as a result of this application. No data on forestry activities and impacts are included.

McCabe, G.D., and W.J. O'Brien. 1983. The effects of suspended silt on feeding and reproduction of Daphnia pulex. *The American Midland Naturalist*. 110(2):324-337.

This paper presents the effect of suspended silt on the feeding and reproduction of Daphnia pulex and the impact of suspended silt and clay on freshwater zooplankton community structure. Both filtering and assimilation rates were severely depressed at low concentrations of silt and clay. The population growth rate of zooplankton was also diminished by suspended silts and clays. Between two lakes with differing turbidity levels, the relative abundance of zooplankton was different, with the more turbid lake having a higher relative abundance of large zooplankton species. The authors concluded that higher concentrations of fines may result in changes in aquatic population structure.

McIntyre, J.D. Responses of intermountain salmonids to sediment in streams. In: *Proceedings of Technical Workshop on Sediments*. Corvallis, Oregon, February 3-7, 1992. U.S. Environmental Protection Agency and USDA Forest Service.

This paper presents a short review of the literature on the effects of sediment on salmonids. Better methods are needed for developing appropriate indices of stream disturbance and to determine how much sediment disturbs stream productivity, not whether it does.

Meehan, W.R., and T.C. Bjornn. 1991. *Salmonid distributions and life histories*, In: Influences of Forest Land and Rangeland Management on Salmonid Fishes and Their Habitat. Meehan, W.R., (ed.) American Fisheries Society Special Publication 19. Chapter 3. pp. 47-82.

The distribution and life histories of salmonids in North America are presented in this chapter. General distribution and life history patterns are discussed for salmonids in general. Specific distribution and life history pattern information in presented for the following salmonids: pink salmon, chum salmon, sockeye salmon or kokanee, coho salmon, chinook salmon, rainbow trout or steelhead, cutthroat trout, brown trout, atlantic salmon, arctic char, Dolly Varden, bull

trout, brook trout, and lake trout.

Meehan, W.R., W.A. Farr, D.M. Bishop, and J.H. Patric. 1969. *Some effects of clearcutting on salmon habitat of two southwest Alaska streams*. USDA Forest Service, Pacific Northwest Forest and Range Experiment Station. Research Paper PNW-82.

This report presents significant amounts of data from research and describes the main conclusions regarding the effect of clearcutting on streamflow, suspended sediment, water temperature, and log debris on salmon habitat. Temperature measurements show that on clear summer days, shade-producing streamside vegetation plays a definite role in cooling or maintaining coolness of the study streams. No significant difference was found between the two areas under clear-shaded and cloudy weather conditions. This report also contains the references from a detailed literature review.

Murphy, M.L., and J.D. Hall. 1981. Varied effects of clear-cut logging on predators and their habitat in small streams of the Cascade Mountains, Oregon. *Canadian Journal of Fisheries and Aquatic Sciences*. 38:137-145.

The differences in predator numbers in a stream draining a logged and forested area are presented in this paper. Stream inventories of the predators including fishes, salamanders, and certain invertebrates were conducted. Varied results were obtained. Newly logged areas exposed to sunlight had greater biomass of predators than did old growth forest areas. However, second-growth logged areas reshaded by deciduous forest canopy had lower biomass than the old growth forest. This journal article provides a detailed discussion of the predator-prey interactions that may be occurring in the old growth and logged forests and also provides significant data and results.

Murphy, M.L., C.P. Hawkins, and N.H. Anderson. Effects of canopy modification and accumulated sediment on stream communities. *Transactions of the American Fisheries Society*. 110:469-478.

Small streams differing in sediment composition were compared in logged and forested reaches to determine the effects of accumulated fine sediment on stream communities under different trophic conditions. Trophic levels (treatments) included recently clear-cut areas without forest canopies, second-growth forest with deciduous canopy, and old-growth coniferous forest. One stream with predominantly coarse sediment and one with fine sediment were compared for each treatment. In general, streams traversing open clearcuts had greater rates of microbial respiration and greater densities or biomass of aufwuchs, benthos, drift, salamanders, and trout than did the shaded, forested sites regardless of sediment composition. The article concludes that for these small Cascade Range streams, changes in trophic status and increased primary productivity resulting from shade removal may mask or override the effects of sedimentation.

Murphy, M.L., J. Heifetz, S.W. Johnson, K.V. Koski, and J.F. Thedinga. 1986. Effects of clear-cut logging with and without buffer strips on juvenile salmonids in Alaskan streams. *Canadian Journal of Fisheries and Aquatic Sciences*. 43(8):1521-1533.

To assess short-term effects of logging on juvenile *Oncorhynchus kisutch*, *Salvelins malma*, *Salmo gairdneri*, and *Salmo clarki* in southeastern Alaska, the fish density and habitat in summer and winter were compared in 18 streams in old-growth forest and in clearcuts with and without buffer strips. The study concludes that clearcutting may increase fry abundance in summer in some streams by increasing primary production, but may reduce abundance of parr in winter if debris is removed. Use of buffer strips maintains or increases debris, protects habitat, allows increased primary production, and can increase abundance of fry or parr. The report also contains references to more than 50 other papers.

Murphy, M.L., K.V. Koski, J. Heifetz, S.W. Johnson, D. Kirchhofer, and J.F. Thedinga. 1984. Role of large organic debris as winter habitat for juvenile salmonids in Alaska streams. In: *Western Proceedings of the 64th Annual Conference of the Western Association of Fish and Wildlife Agencies*. Victoria, British Columbia, July 16-19, 1984. pp. 251-262.

To assess short-term effects of logging on juvenile *Oncorhynchus kisutch*, *Salvelins malma*, *Salmo gairdneri*, and *Salmo clarki* in southeastern Alaska, the fish density and habitat in summer and winter were compared in 18 streams in old-growth forest and in clearcuts with and without buffer strips. Buffered reaches did not consistently differ from old-growth reaches; clearcut reaches had more periphyton, lower channel stability, and less canopy, pool volume, large woody debris, and undercut banks than old-growth reaches. Fry abundance was related to the amount of large woody debris. Clearcutting may increase fry abundance in summer in some streams by increasing primary production, but may reduce abundance of parr in winter if debris is removed. Use of buffer strips maintains or increases debris, protects habitat, allows increased primary production, and can increase abundance of fry and parr. This paper presents partial results of a larger study; the companion paper is Thedinga, Murphy, Heifetz, Koski, and Johnson, 1989. This report presents significant amounts of data and conclusions and contains references to more than 50 other papers.

Narver, D.W. 1971. Effects of logging debris on fish production. In: *Proceedings of the Symposium: Forest Land Uses and Stream Environment*. , 19-21 October, 1970. J.T. Krygier and J.D. Hall (eds.). Oregon State University, Corvallis, Oregon. pp. 100-111.

Stream salmonids (eight species of Pacific salmon, trout, and char) are discussed in relation to their environmental requirements and the possible impact of logging debris on their production. The emphasis is on small streams because of their great importance as nursery and spawning areas for certain species and because they may be more susceptible to damage than larger streams or rivers. Extensive use is made of pertinent literature. The author concludes that accumulations of logging debris in small streams can have serious effects on the production of salmonid fishes.

Newcombe, C.P., and D.D. MacDonald. 1991. Effects of suspended sediments on aquatic ecosystems. *North American Journal of Fisheries Management*. 11(1):72-82.

This paper provides a review of the factors that contribute to effects of suspended sediment on fish and aquatic life. The information presented in this review is intended to provide guidance on data that should be collected to develop a verified model of the environmental effects of suspended sediment. Topics reviewed include: effects on salmonid fishes, aquatic invertebrates, and periphyton and models of suspended sediment effects. Over 50 references are cited in this paper.

Nuttall, P.M. 1972. The effects of sand deposition upon the macroinvertebrate fauna of the River Camel, Cornwall. *Freshwater Biology*. 2:181-186.

A monitoring effort was initiated in western England to determine the effects of sand deposition on macroinvertebrates in the stream. The authors found that a lower incidence of plant and animal species was observed after large sand deposits. The decrease in numbers was found to result from the unstable nature of the sand deposits rather than the turbidity or abrasion caused by the sand.

Phillippi, M.A., and G.B. Coltharp. 1990. Post-treatment effects of forest fertilization on the predominant benthic community of a headwater stream in eastern Kentucky. *Transactions of the Kentucky Academy of Science*. 51(1/2):18-25.

Biological sampling was conducted from 1978 to

1981. Higher concentrations of nitrate-N were present in the affected stream compared to two unaffected streams. Standing-crop biomass of invertebrates and the number of individuals were not significantly different between the treated stream and one untreated stream. The number of taxa and the species diversity were significantly higher in the unaffected stream in the unfertilized watershed. The authors conclude that the benthic fauna is unaffected by the forest fertilization. Graphs of species abundance and number of individuals of different taxa accompany the text.

Platts, W.S. 1979. Relationships among stream order, fish populations, and aquatic geomorphology in an Idaho river drainage. *Fisheries*. 4(2):5-9.

This study evaluates the relationship of stream order on fishery status. Correlations are made between stream order and number of fish species, summer water space for fish, fish population increases and approximate stream size. Little information was presented which related this information with watershed or riparian management.

Platts, W.S., and W.F. Megahan. 1975. Time trends in riverbed sediment composition in salmon and steelhead spawning areas: South Fork Salmon River, Idaho. In: *Transactions of the 40th North American Wildlife and Natural Resources Conference*. Wildlife Management Institute, Washington, DC. pp. 229-239.

The number of returning adult summer chinook salmon and steelhead trout entering the South Fork Salmon River steadily declined for the 17 years prior to the report's publication. This report discusses the history of land use and habitat rehabilitation efforts in the river watershed, siting possible reasons for increased sedimentation that could affect salmon habitat. The report specifically describes temporal trends in riverbed material size composition in the four major spawning areas of the main river channel. Considerable variation in riverbed sediment size composition was found at varying locations in the river. Fine and coarse sands in excess of 10-15% led to unsuccessful salmon spawning. Changes in forest practices, particularly a moratorium on logging and road construction in the upper drainage, led to a change in sediment composition, from 45-80% fines to 12-26% fines, and an increase in suitability for spawning.

Platts, W.S., and R.L. Nelson. 1989. Stream canopy and its relationship to salmonid biomass in the intermountain West. *North American Journal of Fisheries Management*. 9:446-457.

Several riparian habitat components, including canopy density, light intensity, unobstructed sun arc, and average potential daily thermal input in grazed and ungrazed portions of representative streams in the northern Rocky Mountains and the Great Basin of the western United States, were measured. The objectives were to assess prevailing stream canopy conditions and to determine to what extent these habitat components were correlated with salmonid biomass. Unobstructed sun arc was significantly correlated with thermal input and was the best overall predictor of salmonid biomass per unit volume. Thermal input was a better predictor of salmonid biomass per unit volume in the Great Basin than in the Rocky Mountains. Mean estimates of fish biomass per unit volume were better related to stream canopy attributes than to biomass estimates based on stream surface area.

Reeves, G.H., F.H. Everest, and T.E. Nickelson. 1989. *Identification of physical habitats limiting the production of coho salmon in western Oregon and Washington*. USDA Forest Service, Pacific Northwest Research Station. General Technical Report PNW-GTR-245. 18 pages.

This document was designed to help fishery managers identify factors limiting the production of coho salmon in streams of coastal and interior Oregon and Washington. The guide is designed to identify potential physical limitations to fish production that may be moderated or removed by

habitat rehabilitation or enhancement programs. The guide is most accurate for streams up to large fourth-order and small fifth- order streams.

Richards, C. Ecological effects of fine sediments in stream ecosystems. In: *Proceedings of Technical Workshop on Sediments*. Corvallis, Oregon, February 3-7, 1992. U.S. Environmental Protection Agency and USDA Forest Service.

A review of the ecological effects of fine sediment in stream ecosystems is presented. Topics include suspended sediment, sediment deposition, and secondary effects of sediment. Also included are several general approaches that have been taken to develop sediment criteria.

Rutherford, D.A., A.A. Echelle, and O.E. Maughan. 1987. *Changes in the fauna of the Little River drainage, southeastern Oklahoma, 1948-1955 to 1981-1982: A test of the hypothesis of environmental degradation*, In: Community and Evolutionary Ecology of North American Stream Fishes. Matthews, W.J., and D.C. Heins, (eds.) Chapter 22:178-183.

This chapter presents an analysis of the differences in fish fauna between two intervals of time separated by 25 years. In those 25 years, the drainage area was altered by clearcut logging. No evidence was found to suggest extinctions or invasions of new species. However, the frequency of occurrence of individual species and indices of community similarity suggest that the faunal structure is different than in 1949-1955. The authors concluded that the change was the result of the timber harvesting activities which occurred in the watershed.

Scannell, P.W. Effects of increased sedimentation on fresh waters of interior Alaska. In: *Proceedings of Technical Workshop on Sediments*. Corvallis, Oregon, February 3-7, 1992. U.S. Environmental Protection Agency and USDA Forest Service.

This paper presents a summary of a research effort in Alaska to determine the effects of sediments on water quality, stream habitat, and fisheries. The focus of this paper is on the effects of increased sedimentation on aquatic invertebrates, stream periphyton, and site-feeding fish. Aquatic invertebrate density was strongly correlated with both turbidity and total suspended solids in the stream. Increased sediment loads reduced primary productivity but did not preclude it until settleable solids became measurable. Arctic graylings were excluded from segments of streams with low water quality and direct and indirect mortality resulting from sediment was observed.

Schlosser, I.J. 1982. Trophic structure, reproductive success, and growth rate of fishes in a natural and modified headwater stream. *Canadian Journal of Fisheries and Aquatic Sciences*. 39(7):968-978.

The impact of removing riparian vegetation, channel straightening, and fluctuations in flow regime on trophic structure, reproductive success, and growth rate of fishes was assessed in east-central Illinois. The authors found that channel morphology, in conjunction with flow regime, appears to be especially important in determining habitat stability and a broad range of fish community attributes. Also, alteration of riparian vegetation increased instability in the fish community by shifting the nature and seasonal dynamics of the organic energy base.

Scrivener, J.C., and B.C. Anderson. 1984. Logging impacts and some mechanisms that determine the size of spring and summer populations of coho salmon fry in Carnation Creek, B.C. *Canadian Journal of Fisheries and Aquatic Sciences*. 41:1097-1105.

The effects of forestry practices on salmonid resources in British Columbia are analyzed in this paper. The Coho fry movement, distribution, and growth for spring and summer were recorded over a 2-year period prior to and following logging. Interestingly, growth rates tended to be high following streamside logging. It was found

that a complex number of factors affect the physical parameters of Coho fry and that they are not necessarily dependent exclusively on silvicultural activity.

Scrivener, J.C., and M.J. Brownlee. 1989. Effects of forest harvesting on spawning gravel and incubation survival of chum (*Oncorhynchus keta*) and coho salmon (*O. kisutch*) in Carnation Creek, British Columbia. *Canadian Journal of Fisheries and Aquatic Sciences*. 46(3):681-696.

The objective of this study was to assess the effects of current forestry harvesting practices on spawning gravel composition, intergravel dissolved oxygen, and permeability, and the influence of these features on the survival and size of emerging fry. Following logging, fines in the stream bed of Carnation Creek increased from 4.6 to 5.7%, although suspended sediment concentration did not increase. Also following logging, the survival to emergence declined from 29.1 to 16.4% for coho salmon and from 22.2 to 11.5% for chum salmon. Annual changes in substrate composition and peak flows explained 60 and 73% of the variability in survival to emergence for chum and coho salmon, respectively. Changes in streambed fines appeared to depend on the timing of logging operations and large freshets.

Sedell, J.R., P.A. Bisson, F.J. Swanson, and S.V. Gregory. 1988. *What we know about large trees that fall into streams and rivers*, In: From the forest to the sea: A story of fallen trees. USDA Forest Service, Pacific Northwest Forest and Range Experiment Station. General Technical Report PNW-229. pp. 47-81.

The physical and biological characteristics of forested streams in the Northeast are discussed at length. The history of logging activities, riparian management, and ecosystem structure are compared; the effects of removed and downed timber on habitat are emphasized. Physical variables and stream debris frequency were studied for their effects on fish species and habitat development. The data indicate that complete removal of timber from any stream has an adverse impact on fish-dependent food chains and sediment capture. Overall, this article addresses stream debris dynamics and the effects on indigenous species. The document contains numerous figures and tables.

Sigler, J.W., T.C. Bjorn, and F.H. Everest. 1984. Effects of chronic turbidity on density and growth of steelheads and coho salmon. *Transactions of the American Fisheries Society*. 113(2): 142-150.

The effects of chronic turbidity on young steelhead and coho salmon were evaluated in laboratory experiments in straight and oval channels. Fish exposed to continuous clay turbidities had lower weight gain and growth than fish living in clear water, and more of them emigrated from channels during the experiments. The authors conclude that fish in natural waters subjected to turbidity soon after emergence will emigrate, which could reduce production in those tributaries if the emigrants do not secure suitable habitat in downstream areas.

Thedinga, J.F., M.L. Murphy, J. Heifetz, K.V. Koski, and S.W. Johnson. 1989. Effects of logging on size and age composition of juvenile coho salmon and density of pre-smolts in southeast Alaska streams. *Canadian Journal of Fisheries and Aquatic Science*. 46:1383-1391.

Short-term effects of logging on age composition and size of juvenile coho salmon (*Onchrhynchus kisutch*) were studied in 18 streams in southeast Alaska in 1982 and 1983. Studies were in old-growth forests where stream reaches had been clearcut with or without buffer strips. The number of fry in summer and winter was proportionately higher in clearcut and buffered reaches than in undisturbed reaches. A higher percentage of large (≥75 mm) fry remained in buffered reaches than in clearcut and undisturbed reaches. Therefore, the density of fry that were potentially large enough to become smolts the next spring was greater in buffered reaches. The

larger fry in the buffered and clearcut reaches compared with undisturbed reaches were probably the result of earlier fry emergence resulting from increased water temperature. This paper presents partial results of a larger study. The companion paper is Murphy, Heifetz, Johnson, Koski and Thedinga, 1986.

Tripp, D.B., and V.A. Poulin. 1986. *The effects of logging and mass wasting on salmonid spawning habitat in stream on the Queen Charlotte Islands*. British Columbia Ministry of Forests and Lands, Research Branch. 29 pages.

Three separate investigations were carried out in this study to assess the effects of logging and mass wasting on salmonid spawning habitats, including: (1) a synoptic survey of the gravel composition in logged and unlogged streams affected by varying degrees of mass wasting; (2) a survey of the amount of gravel scour occurring in 12 logged streams subjected to various degrees of mass wasting; and (3) an egg incubation study designed to examine coho fry emergence success in upwelling-type incubation boxes containing different concentrations of sand and gravel. Declines in coho egg-to-fry survival due to logging and/or mass wasting were estimated at 15-20%, with logging accounting for most of the decline in gravel quality. This paper presents significant results from a comprehensive study of forestry- related habitat degradation.

Tschaplinski, P.J., and G.F. Hartman. 1983. Winter distribution of juvenile coho salmon (*Oncorhynchus kisutch*) before and after logging in Carnation Creek, British Columbia, and some implications for overwinter survival. *Canadian Journal of Fisheries and Aquatic Sciences*. 40:452-461.

Carnation Creek on the west coast of Vancouver Island was studied for the movement of coho fry prior to and after logging activities. In the areas of streambank damage, the coho fry moved to more sheltered settings during the winter season. Management practices, such as leaving streambank vegetation, were confirmed to prevent the influx of undesirable silvicultural materials from entering the spawning areas of salmon and cutthroat trout. Tables and figures presented demonstrate that logging the SMZ neither reduces the number of coho wintering in Carnation Creek nor reduces the number leaving in the spring.

USDA Forest Service. 1992. *Informational Report: Background Report for Development of the Forest Service Management Strategy for Pacific Salmon and Steelhead Habitat*. USDA Forest Service, Pacific Salmon Work Group and Field Team, Washington, DC.

The purpose of this report is to provide background information for the development for management of Pacific salmon and steelhead stocks, and to increase awareness about the issues within the Forest Service and with outside groups as well. The document discusses the organizational framework that includes three components: a Washington Office Policy Group which provides overall direction, and a Washington Office Work Group and an inter-regional Field Team that will cooperatively develop the strategy. The strategy was targeted for completion in 1993.

Vohs, P.A., I.J. Moore, and J.S. Ramsey. 1993. *A critical review of the effects of turbidity on aquatic organisms in large rivers*. U.S. Fish and Wildlife Service, Environmental Management Technical Center, Special report 93-S002. 139 pages.

A comprehensive critical review of the biological effects of suspended sediments (including turbidity, washload, and filterable solids) was prepared by the United States Fish and Wildlife Service. This critical review covers 121 references.

Waters, T.F. 1961. Standing crop and drift of stream bottom organisms. *Ecology*. 42:532-537.

The study was performed to investigate the standing crop and drift rate of bottom fauna as

affected by varying levels of productive capacity. The distribution of mean rates of drift among the five streams corresponded closely to the ranking of the streams on the basis of expected productivity. The study states that it would appear that the drifting of stream invertebrate animals is a process very intimately associated with production and may be essential for the orderly conduct of stream communities.

Webster, J.R. 1983. The role of benthic macroinvertebrates in detritus dynamics of streams: A computer simulation. *Ecological Monographs*. 53(4):383-404.

Detritus dynamics in a second-order stream in the southern Appalachian Mountains were simulated with a computer model, based on data from a number of stream studies. The model was used to evaluate the role of macroinvertebrates in the stream. Macroinvertebrates accounted for only a small portion of the respiration of detritus. Their major contribution was a conversion of benthic detritus into transported detritus. On an annual budget, macroinvertebrates decrease the efficiency of detritus processing because they increase transport loss, while on a long-term basis they prevent accumulation of large amounts of detritus in the stream. In this way they provide an important link between low-order and higher-order streams. The paper fully discusses the model used for this simulation and analyzes the results with respect to field data.

Yee, C.S., and T.D. Roelofs. 1980. *Planning forest roads to protect salmonid habitat*. USDA Forest Service, Pacific Northwest Forest and Range Experiment Station. General Technical Report PNW-109. 260 pages.

This document presents information on alleviating the environmental impacts, particularly on anadromous fish and their habitats, associated with forest road construction. The document provides design, construction, and maintenance guidelines for roads to minimize impacts. Sections on sedimentation, road-stabilizing additives, and fish migration are included.

Berg, L., and T.G. Northcote. 1985. Changes in territorial, gill- flaring, and feeding behavior in juvenile coho salmon (*Oncorhunchus kisutch*) following short-term pulses of suspended sediment. *Canadian Journal of Fisheries and Aquatic Sciences*. 42:1410-1417.

Bisson, P.A., and J.A. Sedell. *Salmonid population in streams in clearcut vs. old-growth forests of western Washington*. Weyerhaeuser Company, Tacoma, Washington, 17 pages,.

Brown, G.W. 1974. *Fish habitat*. USDA Forest Service, Pacific Northwest Forest and Range Experiment Station, General Technical Report PNW-24. pp. E1-E15.

Bugert, R.M., and T.C. Bjornn. 1991. Habitat use by steelhead and coho salmon and their responses to predators and cover in laboratory streams. *Transactions of the American Fisheries Society*. 120:486-493.

Burns, J.W. 1972. Some effects of logging and associated road construction on northern California streams. *Transactions of the American Fisheries Society*. 101(1):1-17.

Chutter, F.M. 1969. The effects of silt and sand on the invertebrate fauna of streams and rivers. *Hydrobiologia*. 34:57- 76.

Crouse, M.R., C.A. Callahan, K.W. Malueg, and S.E. Dominguez. 1981. Effects of fine sediments on growth of juvenile coho salmon in laboratory streams. *Transactions of the American Fisheries Society*. 110:281-286.

Crowder, L.B., and W.E. Cooper. 1982. Habitat structural complexity and the interaction between bluegills and their prey. *Ecology*. 63(6):1802-1813.

Everest, F.H., and W.R. Meehan. 1981. Forest management and anadromous fish habitat productivity. In: *Transactions of the 46th North American Wildlife and Natural Resources*

Conference. Wildlife Management Institute, Washington, DC. pp. 521-530.

Gibbons, D.R., and E.O. Salo. 1973. *An annotated bibliography of the effects of logging on fish of the western United States and Canada.* USDA Forest Service, Pacific Northwest Forest and Range Experiment Station, Portland, Oregon. General Technical Report PNW-10. 145 pages.

Gorman, O.T., and J.R. Karr. 1978. Habitat structure and stream fish communities. *Ecology*. 59(3):507-515.

Gregory, S.V., G.A. Lamberti, D.C. Erman, K.V. Koski, M.L. Murphy, and J.R. Sedell. 1987. Influence of forest practices on aquatic production. In: *Streamside Management: Forestry and Fishery Interactions*. University of Washington. E.O. Salo, and T.W. Cundy, (eds.) Institute of Forest Resources No. 57. Chapter 7, pp. 233-255.

Hawkins, C.P., and J.R. Sedell. 1981. Longitudinal and seasonal changes in functional organization of macroinvertebrate communities in four Oregon streams. *Ecology*. 62:387-397.

Heller, D.A., J.R. Maxwell, and M. Parsons. 1983. *Modeling the effects of forest management on salmonid habitat*. USDA Forest Service, Pacific Northwest Region. 63 pages.

Hesser, R., R. Hoopes, C.B. Weirich, J. Selcher, B. Hollender, and R. Snyder. 1975. Chapter 2: The aquatic biota. In: *Clearcutting in Pennsylvania*. Pennsylvania State University, School of Forestry Resources, University Park, Pennsylvania. pp. 9-20.

Hoffman, R.J. 1986. A horizontal intragravel pipe for sampling water quality in salmonid spawning gravel. *North American Journal of Fisheries Management*. 6:445-448.

House, R., and V. Crispen. 1990. *Economic analyses of the value of large woody debris as salmonid habitat in coastal Oregon streams*. Technical Note OR-7:6512. USDI, Bureau of Land Management, Portland OR. 11 pages.

Hurlbert, S.H., M.S. Mulla, and H.R. Willson. 1972. Effects of an organophosphorus insecticide on the phytoplankton, zooplankton, and insect populations of fresh-water ponds. *Ecological Monographs*. 42(3):269-299.

Lawson, P.W. 1993. Cycles in ocean productivity, trends in habitat quality, and the restoration of salmon runs in Oregon. *Fisheries*. 18(8):6-10.

Lee, R., and D.E. Samuel. 1976. Some thermal and biological effects of forest cutting in West Virginia. *Journal of Environmental Quality*. 5(4):362-366.

Meehan, W.R. (ed.). 1991. *Influences of forest and rangeland management on salmonid fishes and their habitat*. American Fisheries Society Special Publication 19. 751 pages.

Miller, D.L., P.M. Leonard, R.M. Hughes, J.R. Karr, P.B. Moyle, L.H. Schrader, B.A. Thompson, R.A. Daniels, K.D. Fausch, G.A. Fitzhugh, J.R. Gammon, D.B. Halliwell, P.L. Angermeier, and D.J. Orth. 1988. Regional applications of an index of biotic integrity for use in water resources management. *Fisheries*. 13(5):12-20.

Moyle, P.B., and J.E. Williams. 1990. Biodiversity loss in the temperate zone: Decline of the native fish fauna of California. *Conservation Biology*. 4(3):275-284.

Newbold, J.D., D.C. Erman, and K.B. Roby. 1980. Effects of logging on macroinvertebrates in streams with and without buffer strips. *Canadian Journal of Fisheries and Aquatic Sciences*. 37: 1076-1085.

Reeves, G.H. Sediment and aquatic organisms in the Pacific Northwest: The need for new

perspectives. In: *Proceedings of Technical Workshop on Sediments*. Corvallis, Oregon, February 3-7, 1992. U.S. Environmental Protection Agency and USDA Forest Service.

Ringler, N.H., and J.D. Hall. 1975. Effects of logging on water temperature and dissolved oxygen in spawning beds. *Transactions of the American Fisheries Society*. 104:111-121.

Ringler, N.H., and J.D. Hall. 1988. Vertical distribution of sediment and organic debris in coho salmon redds in three small Oregon Streams. *Canadian Journal of Fisheries and Aquatic Science*. 45:742-747.

Salo, E.O., and T.W. Cundy (eds.). 1987. *Streamside management forestry and fishery interactions*. College of Forest Resources, University of Washington. 471 pages.

Sheldon, A.L. 1988. Conservation of stream fishes: Patterns of diversity, rarity, and risk. *Conservation Biology*. 2(2):149-156.

Sheridan, W.L., and W.J. McNeil. 1968. Some effects of logging on two salmon streams in Alaska. *Journal of Forestry*. 66:128-133.

Shortreed, K.S., and J.G. Stockner. 1983. Periphyton biomass and species composition in a coastal rainforest stream in B.C.: Effects of environmental changes caused by logging. *Canadian Journal of Fisheries and Aquatic Sciences*. 40:1887-1895.

Stanford, J.A., and J.V. Ward. 1988. The hyporheic habitat of river ecosystems. *Nature*. 335:64-66.

Thut, R.N., and E.P. Haydu. 1971. Effects of forest chemicals on aquatic life. In: *Proceedings of the Symposium: Forest Land Uses and Stream Environment*. Oregon State University, October 19-21, 1970. J.T. Krygier and J.D. Hall (eds.). OSU, Corvallis, Oregon. pp. 159-171.

PHYSICAL

Anderson, H.W. 1971. Relative contributions of sediment from source areas, and transport processes. In: *Proceedings of the Symposium: Forest Land Uses and Stream Environment*. Oregon State University, Corvallis, Oregon, October 19-21, 1970. J.T. Krygier and J.D. Hall, (eds.) pp. 55-63.

This paper reports new findings and summarizes pertinent results from the literature on the contribution and movement of sediment from various timber practices. Multiple methods of sediment introduction are discussed, and their relative impacts on streams are quantified. This is not a case study for one particular watershed or stream, but a summary of the expected effects of timber harvest activities on sediment discharge. Overall, the author provides a general review of limited data for sediment transport processes.

Andrus, C.W., B.A. Long, and H.A. Froehlich. 1988. Woody debris and its contribution to pool formation in a coastal stream 50 years after logging. *Canadian Journal of Fisheries and Aquatic Sciences*. 45:2080-2086.

The objective of this study was to determine how young stands of timber might be managed so that they supply adequate amounts of woody debris to fish-bearing streams. The amount of woody debris is, in part, a product of the surrounding forest. The amount of woody debris in coastal Oregon streams has been altered over the past 80 years as a result of logging, road building, and the conversion of forested land to other uses. In this study, a watershed that had not been logged since a wildfire swept through the area 50 years earlier was sampled for age of debris and pool depth and volume. Debris from the current stand of trees along the stream accounted for only 14% of debris volume in the stream and only 8% of the debris responsible for creating pools. Study results indicate that riparian trees must be left to grow longer than 50 years to ensure that an adequate, long-term supply of woody debris is

available to stream channels. Debris from previous stands plays a crucial role in the interim and should not be removed from stream channels.

Angermeier, P.L., and J.R. Karr. 1984. Relationships between woody debris and fish habitat in a small warmwater stream. *Transactions of the American Fisheries Society*. 113(6):716-726.

This paper presents the results of a study conducted to determine the effect of woody debris removal on habitat, invertebrate availability, and fish distribution in warmwater streams. In general, when woody debris was removed from one side of the channel, fish and benthic invertebrates were more abundant on the side with woody debris. The adaptive significance between fish and woody debris appeared to be related to camouflage more than increased food availability or protection from strong currents. The authors concluded that excessive removal of woody debris from streams, particularly low gradient streams (water depth decreased upon removal of woody debris), would disrupt the structure and function of small streams.

Angino, E.E., and W.J. O'Brien. 1968. *Effects of suspended material on water quality*. International Association of Scientific Hydrology 78:120-128.

This paper summarizes some of the effects of suspended load on water quality, particularly its effect on turbidity, hardness, alkalinity, water color, photosynthetic activity, and organisms. When written, the direct effect of suspended solids on these aspects of water quality was poorly understood. This paper provides a review of the state of knowledge at the time.

Baker, M.B., Jr. 1990. *Hydrologic and water quality effects of fire*. USDA Forest Service, Rocky Mountain Forest and Range Experiment Station. General Technical Report RM-191. pp. 31-42.

This paper provides a review of studies conducted to determine the effects of prescribed burning on forest and rangelands of the Southwest. It provides a qualitative analysis on the types of water quality effects observed after prescribed burning; no substantial quantitative results are presented. The paper includes citations for nearly 70 articles related to water quality effects from prescribed burning.

Beschta, R.L. 1979. Debris removal and its effects on sedimentation in an Oregon Coast Range stream. *Northwest Science*. 53:71-77.

This paper addresses the consequences of removing large organic debris from streams. Results indicated an increase in suspended sediment and turbidity during storms occurring after removal of the debris. The author suggests removal of woody debris to allow for fish passage should be conducted with consideration of sediments stored within the debris and the potential for scour upon debris removal.

Beschta, R.L., R.E. Bilby, G.W. Brown, L.B. Holtby, and T.D. Hofstra. 1987. Stream temperature and aquatic habitat: Fisheries and forestry interactions. In: *Streamside Management: Forestry and Fishery Interactions*. University of Washington. E.O. Salo, and T.W. Cundy, (eds.) Institute of Forest Resources No. 57. Chapter 6, pp. 191-232.

The objectives of this paper are to characterize stream temperature regimes in forested ecosystems, to indicate the underlying physical mechanisms of temperature change resulting from the removal of forest canopies over streams, and to identify the various processes by which temperature changes following logging can affect aquatic communities and the production of fish. Over 100 references are cited in this review.

Beschta, R.L., and R.L. Talyor. 1988. Stream temperature increases and land use in a forested Oregon watershed. *Water Resources Bulletin*. 24(1):19-25.

The long-term changes in stream temperatures in

relation to management activities and natural hydrologic events was studied in the Salmon Creek watershed in western Oregon. Over a 30-year period, average daily maximum and minimum stream temperatures (calculated from the 10 warmest days of each year) have risen 6 °C and 2 °C, respectively although only a small increase in air temperature was observed over the same period. The authors noted a highly significant relationship between a cumulative index of forest harvesting and maximum stream temperatures. Maximum temperatures also increased for several years following peak flow events, which tended to obscure specific cause and effect relationships between timber harvest activities and long-term stream temperature changes.

Bilby, R.E. 1984. Removal of woody debris may affect stream channel stability. *Journal of Forestry*. 82:609-613.

This paper reports on an investigation of the effect of removing large woody debris (LWD) from a small stream after logging, as is mandated by several western states. Large changes in channel structure were observed during the first high flow after cleaning. The location of debris left in the stream and stream sediment were substantially altered. The degree of channel rearrangement was greater than that in a comparable undisturbed stream. The loss in channel stability due to indiscriminate removal of LWD may have adverse effects on fish populations. LWD influencing channel morphology should be left in place during cleaning. Post-logging cleaning guidelines are provided in the form of a dichotomous key, though the author stresses that these guidelines are applicable only to streams similar to Salmon Creek in the Coast Range of Washington, where the study was conducted. The author found that the degree to which the debris is buried, its length and diameter, and whether it is braced by boulders, bedrock outcrops, or other stable pieces of debris determine whether it should be removed or left in place.

Bilby, R.E., and G.E. Likens. 1980. Importance of organic debris dams in the structure and function of stream ecosystems. *Ecology*. 61(5):1107-1113.

Small headwater streams in forested areas are heavily dependent on the input of organic material from the surrounding terrestrial system as an energy source. Debris dams act as retention mechanisms that allow organic matter to be processed in the stream ecosystem rather than transported downstream in coarse particulate form. In this study, all organic debris was removed from a 175-m stretch of a second-order stream in New Hampshire. A dramatic increase in organic carbon export (dissolved = 18%; fine particulate = 632%; coarse particulate = 138%) from the system resulted. Organic debris dams are extremely important components of small stream ecosystems. In first-order streams, the dams contain nearly 75% of the standing stock of organic matter. In second-order streams, this proportion drops to 58%, and in third-order streams it is 20%.

Bilby, R.E., and J.W. Ward. 1991. Characteristics and function of large woody debris in streams draining old-growth, clear-cut, and second-growth forests in southwestern Washington. *Canadian Journal of Fisheries and Aquatic Science*. 48(12):2,499-2,508.

A comparison of large woody debris (LWD) abundance, characteristics, and function in streams bordered by forests of differing ages: old-growth, recent clearcut, and 40 to 60-year second growth was made in this paper. The amount of LWD in 70 stream reaches decreased with increasing stream size for all stand types but was greatest at old-growth sites. Pool size was similar for all stand types in smaller streams, but averages $10m^2$ in streams > 10 m wide at old-growth and $4m^2$ for other stand types. The authors noted that changes in LWD amount, characteristics, and function occurred very rapidly following removal of streamside vegetation.

Bisson, P.A., R.E. Bilby, M.D. Bryant, C.A. Dolloff, G.B. Grette, R.A. House, M.L. Murphy, K.V. Koski, and J.R. Sedell. 1987. Large woody debris in forested streams in the Pacific Northwest: Past, present, and future. In: *Streamside Management: Forestry and Fishery Interactions*. University of Washington. E.O. Salo, and T.W. Cundy, (eds.) Institute of Forest Resources No. 57. Chapter 5, pp. 142-190.

This chapter presents a review of the form, function, and management of woody debris in streams. Three conclusion were made based on the review: 1)large woody debris enhances the quality of fish habitat in all stream sizes; 2) fish population abundance and species composition are altered during logging, stream cleaning, and short-term harvest rotations because of changes to sources and delivery mechanisms; and 3) there is an urgent need for field experiments and long-term studies that focus on protection of large woody debris in streams and recruitment of debris from the surrounding forest.

Brown, G.W. 1969. Predicting temperatures of small streams. *Water Resources Research*. 5:68-75.

Sections of three small streams in western Oregon, typical of streams in the forested regions of the Oregon Cascade and Coast Ranges, were studied to determine whether stream temperature could be accurately predicted. One section was heavily shaded and had a graved bottom, and the other sections were exposed to direct sunlight. One exposed section had a rock bottom and the other had a gravel bottom. The author found that hourly temperatures of small streams can be accurately predicted using an energy balance. On the three study streams, hourly temperature changes of 0-16°F were predicted to within 1°F more than 90% of the time. On unshaded stretches, net radiation is the predominant energy source, while evaporation and convection account for less than 10% of the total energy exchange. Conduction of heat into the stream bottom is an important energy balance component on shallow streams having a bedrock bottom, where up to 25% of the energy absorbed by the stream may be transferred into the bed. Using this technique, foresters can control water temperature through manipulation of streamside vegetation.

Brown, G.W. 1970. Predicting the effect of clearcutting on stream temperature. *Journal of Soil and Water Conservation*. 25:11-13.

This paper presents a methodology for predicting the effects of clearcutting on stream water temperature. The author states that predicting the effects could be done by estimating maximum daily changes, rather than hourly changes which would require experience in micrometeorology and additional equipment. This paper presents a simple model for estimating the daily maximum changes assuming the following: the stream surface is uniformly exposed to direct sunlight, direct solar radiation dominates the net heat gain in small streams, maximum temperature will occur during midday hours on a clear day, and predicted solar input can be used to estimate heat input. Model equations are also presented in this paper. Much of the background to this work was published in Brown 1969 and Brown and Kryger 1970.

Brown, G.W., and J.T. Krygier. 1967. Changing water temperatures in small mountain streams. *Journal of Soil and Water Conservation*. 22:242-244.

Two small streams in Oregon were studied for the effect on water temperature of clearcutting. This is an early study of the effect of logging practices on water temperature, and the water quality and biological consequences of elevated water temperature due to clearcutting are discussed.

Brown, G.W., and J.T. Krygier. 1971. Clear-cut logging and sediment production in the Oregon coast range. *Water Resources Research*. 7(5):1189-1198.

The impact of road construction, two patterns of

clear-cut logging, and controlled slash burning on the suspended sediment yield and concentration from three small watersheds was studied for 11 years. Sediment production was doubled after road construction but before logging in one watershed and was tripled after burning and clearcutting of another watershed. Felling and yarding did not produce statistically significant changes in sediment concentration. Variation in the relation between sediment concentration and water discharge on small undisturbed streams was large. Conclusions about the significance of all but very large changes in sediment concentrations are limited because of annual variation for a given watershed, variation between watersheds, and variation with stage at a given point. Tables present sediment concentrations in the two altered watersheds and one control watershed for the duration of the study.

Brozka, R.J., G.L. Rolfe, and L.E. Arnold. 1981. Water quality from two small forested watersheds in southern Illinois. *Water Resources Bulletin*. 17(3):443-447.

This paper presents partial results of a larger research effort to determine the water quality benefits of various watershed management alternatives. Two intermittent streams on oak-hickory watersheds were tested for Na^+, K^+, Ca^{++}, Mg^{++}, P, and NO_3^-. Water quality in the watersheds was found to be high and was attributed to their forested cover. Tables of precipitation and nutrient concentrations in the streams are provided .

Bryant, M.D. 1980. *Evolution of large, organic debris after timber harvest: Maybeso Creek, 1949 to 1978*. USDA Forest Service, Pacific Northwest Forest and Range Experiment Station. General Technical Report PNW-101. 30 pages.

The role of large debris (tree boles and root wads) in contributing to the morphological changes to Maybeso Creek, Alaska were presented in the paper. The Maybeso Creek valley was logged from 1953 to 1960 and maps showing large accumulations of debris and stream channel features were made in 1949 and updated in 1960. Before logging (1949 maps), sparse accumulations of large debris were scattered throughout the stream. After logging, the debris accumulations increased in number and density. In addition, the natural material was well-controlled and stable, whereas logging debris was floatable and less stable.

Burns, R.G., and J.D. Hewlett. 1983. A decision model to predict sediment yield from forest practices. *Water Resources Bulletin*. 19(1):9-14.

The authors propose a sediment hazard index based on the amount of exposed mineral soil and its proximity to streams as a means to choose among BMPs. Forest managers need to predict sediment yield to perennial streams following forestland operations, but the universal soil loss equation (USLE) is not directly applicable to forest operations because of the heterogeneous soil surface conditions left by harvesting, site preparation, and planting. The model described includes rainfall erosivity, soil erodibility and average land slope, together with the sediment hazard index (W). A paired watershed experiment in the central Georgia Piedmont was used to estimate parameters in the model. The 80-acre experimental basin was clearcut, drum roller chopped twice, and machine planted. The standard error of estimate of sediment yield was computed to be about 50 lb/ac per 4-month sampling period. Use of William's erosivity index (storm flow times peak flow) reduced the standard error to 33 lb/ac. A graph of sediment delivery versus sediment hazard index is provided, and the index can be used to design and evaluate forest operations in advance. The authors note that application of the method presumes the use of streamside management zones and sensible roading standards.

Chatwin, S.C., D.E. Howes, J.W. Schwab, and D.N. Swanston. 1991. *A guide for management of landslide-prone terrain in the Pacific Northwest*. British Columbia Ministry of Forests. Land Management Handbook No. 18. 212 pages.

This guide was prepared for personnel operating in areas with existing or potential land stability problems. The document was developed for use in the Pacific Northwest; however, the principles presented may be applicable to other areas. Four topics are addressed: slope movement processes, recognition of landslide-prone areas, measures to manage unstable terrain during forestry activities (especially road construction and timber harvest), and road deactivation and revegetation on unstable terrain. Detailed definitions and techniques for determining potential instability and methods for preventing landslides from forestry roads are included.

Childers, D.L., and J.G. Gosselink. 1990. Assessment of cumulative impacts to water quality in a forested wetland landscape. *Journal of Environmental Quality*. 19:455-464.

This article presents a historical analysis of water quality in the Tensas Basin, Louisiana, as part of a cumulative impact analysis of the landscape. Historical records of suspended sediment, N, P, and turbidity from three streams in the basin demonstrated that the watershed's water quality is characteristic where the original forest cover has been cleared. Aquatic primary productivity in the Basin appears to be nitrogen-limited. A goal-oriented management plan for the watershed was developed based on the study results. Management practices to counteract the cumulative effects of conversion to agricultural land include runoff control, protecting forested corridors along streams, and creating new buffer zones.

Cordone, A.J., and D.W. Kelley. 1961. The influences of inorganic sediment on the aquatic life of streams. *California Fish and Game*. 47:189-228.

This report contains a general review of studies on the effects of inorganic sediment on the aquatic life of streams. More than 100 references on the following topics are included: direct effect of sediment on fish, influences of sediment on eggs, alevins, bottom organisms, aquatic plants, chemical and physical characteristics, fish habitats and populations, and long-term siltation research.

Dietrich, W.E., T. Dunne, Humphrey N.F., and L.M. Reid. 1982. Construction of sediment budgets for drainage basins. In: *Sediment Budgets and Routing in Forested Drainage Basins*. F.J. Swanson, R.J. Janda, T. Dunne, and D.N. Swanston, (eds.) USDA Forest Service, Pacific Northwest Forest and Range Experiment Station. General Technical Report PNW-141. pp. 5-23.

This paper presents information the authors suggest is essential to make a sediment budget meaningful. Information presented included definition of sediment budget, recognition and quantification of transport processes, identification of linkages among processes and storage elements, definition of recurrence intervals, and quantification of storage elements. Over 50 references are cited in this paper.

Edwards, C.J. A review of aquatic impact associated with turbidity. In: *Proceedings of Technical Workshop on Sediments*. Corvallis, OR, February 3-7, 1992. U.S. Environmental Protection Agency and USDA Forest Service.

This paper provides a review of the effects of sediment on the trophic structure of aquatic systems. The report is divided into primary, secondary, and high order producers.

Erman, D.C., and N.A. Erman. 1984. The response of stream macroinvertebrates to substrate size and heterogeneity. *Hydrobiologia*. 108(1):75-82.

The effect of substrate size and heterogeneity on macroinvertebrate abundance and species diversity was presented in this paper. Variation in size

class proportions and number of size classes had no independent effect on macroinvertebrate abundance or richness. Median particle size, stream current, and detritus accounted for most of the significant variation in macroinvertebrates colonizing the experimental substrates. Surfaces with high heterogeneity were colonized by more individuals (not taxa) than surfaces with low heterogeneity.

Everest, F.H., R.L. Beschta, J.C. Scrivener, K.V. Koski, J.R. Sedell, and C.J. Cedarholm. 1987. Fine sediment and salmonid production: A paradox. In: *Streamside Management: Forestry and Fishery Interactions*. University of Washington. E.O. Salo, and T.W. Cundy, (eds.) Institute of Forest Resources No. 57. Chapter 4, pp. 98-142.

The purpose of this chapter is to examine state-of-the-art knowledge of the effects of sediment on salmonids The topics reviewed include forest management and sediment production, sediment processing by forest streams, forest management and sedimentation, variability of fine sediments in streambeds, effects of sedimentation on salmonids, natural mitigation of the effects of fine sediment in streams, sediment as a factor limiting salmonid populations, cumulative effects of sedimentation and fishing, and streamside management guidelines and sediment. Over 120 references are cited in this review.

Feller, M.C. 1981. Effects of clearcutting and slash burning on stream temperature in southwestern British Columbia. *Water Resources Bulletin*. 17(5):863-866.

Two watersheds were studied for the effect of logging practices on summer and winter water temperatures. One of the watersheds was clearcut and then planted, and the other was clearcut, slash burned, and then planted.Tables of watershed characteristics and duration of temperature effects are included. Both practices were found to increase stream temperature, but slash burning increased the temperature effect beyond that of clearcutting alone. This is attributed to burning the slash that remains at streamside after clearcutting. Clearcutting was found to increase minimum and maximum winter stream temperatures during the second winter following the cutting. Slash burning decreased minimum and maximum winter stream temperatures in the first winter following the burning. The effect on stream temperature of clearcutting and slash burning lasted longer (>7 years) than that of clearcutting alone.

Frear, S.T. 1982. Ecological benefits of large organic debris in streams. In: *Forestry Research West*. USDA Forest Service, pp. 7- 10.

This informational article reveals the benefits of large organic debris in forest streams. The document lacks data but describes qualitative benefits of proper forest stream management. The author concludes by providing guidelines for forest managers to help minimize the impact of human activities on stream environments associated with silviculture.

Grant, G. 1988. *The RAPID technique: A new method for evaluating downstream effects of forest practices on riparian zones*. USDA Forest Service, Pacific Northwest Research Station. General Technical Report PNW-GTR-220. 36 pages.

The riparian aerial photographic inventory of disturbance (RAPID) techniques is a method for using measurements made on aerial photographs of patterns of riparian canopy disturbance to evaluate changes in channel conditions and relating them to their possible upstream causes. This document uses examples from western Oregon to describe an application of the technique to evaluate downstream or cumulative effects of forest practices. Information is provided on background and theory, collecting data, analyzing and interpreting results, and conclusions.

Gray, J.R.A., and J.M. Edington. 1969. Effect of woodland clearance on stream temperature. *Journal of the Fisheries Research Board of Canada*. 26:399-403.

This paper presents the results of a study quantifying the differences in stream temperature after clearance of the adjacent woods. The authors observed significantly greater water temperatures in the cleared areas than in undisturbed areas. The temperatures in the forested stream were also compared to temperatures in stream flowing through an open farm to demonstrate the cooling affect of forests.

Grenney, W.J., and E. Heyse. 1985. Suspended sediment-river flow analysis. *Journal of Environmental Engineering*. 111(6):790-803.

The application of bivariate probability distribution functions to represent the suspended sediment concentration-water discharge data for the San Juan River at Bluff, Utah, is presented. This approach has several advantages over more traditional methods, including preservation of sediment concentration information and convenience for computer implementation. A bivariate log-normal density function was found to be a convenient, accurate method for parameterizing the frequency distribution of sediment concentrations and water discharges for the San Juan River.

Guy, H.P., and G.E. Ferguson. 1970. Stream sediment: An environmental problem. *Journal of Soil and Water Conservation*. 25:217-221.

A general review of problems associated with sediment deposited in streams. The article tabulates sediment sources and their common environmental effects. Two case histories-one of sediment runoff from highway construction and one of residential construction-are reviewed. The authors suggest a number of research areas where data are needed to alleviate the problems of erosion and sedimentation.

Hansen, E.A. 1971. *Sediment in a Michigan trout stream: Its source, movement, and some effects on fish habitat*. USDA Forest Service. Research Paper NC-59. 14 pages.

A study is described in which three monitoring stations were set up on the Pine River to monitor total sediment load and to determine contributing sources to sediment load. Other categories of focus are sediment budget, sediment size, and streambank erosion. There was less sand on the streambed in the downstream section, despite the 560% increase in sand sediment load due to the high transport capacity of a pool and rifle stream. A hypothetical program stabilizing all of the identifiable eroding banks would reduce sediment load by 45% at one of the stations. Because the particle size distribution of streambank sediments was nearly the same as that of sediments already in transport, stabilization of eroding banks would not produce much change in the particle size distribution of the sediment load. If the objective were to lower turbidity during floods, banks containing clays should be stabilized.

Harmon, M.E., J.F. Franklin, F.J. Swanson, P. Sollins, S.V. Gregory, J.D. Lattin, N.H. Anderson, S.P. Cline, N.G. Aumen, J.R. Sedell, G.W. Lienkaemper, K. Cromack, Jr., and K.W. Cummins. 1986. Ecology of coarse woody debris in temperate ecosystems. *Advances in Ecological Research*. 15:133-302.

This paper presents a comprehensive review of the ecological role of coarse woody debris (CWD) in temperate climates. The following topics are reviewed: 1) input of woody debris, including spatial and temporal patterns and rates of input; 2) decomposition of woody debris which encompasses types of decay processes, decay models, decay rates, and factors controlling decomposition; 3) amount and distribution of CWD,including information on estimating biomass, factors controlling biomass, and distribution of CWD; 4) role of CWD, including information on plant and animal habitat, importance of CWD in nutrient cycling, and geomorphic functions; and 5) conclusions which

compare CWD in terrestrial and aquatic ecosystems and presents information on the effects of human activities on CWD. The review references over 500 articles.

Harr, R.D. Overview of sediment research on forestland in the Pacific Northwest. In: *Proceedings of Technical Workshop on Sediments*. Corvallis, Oregon, February 3-7, 1992. U.S. Environmental Protection Agency and USDA Forest Service.

The effect of forest management activities on soil erosion in the Pacific Northwest is summarized in this cursory literature review of past and current research. Topics include small watershed studies, suspended sediment and turbidity, and sediment delivery and transport. Nearly 50 references are cited in this paper.

Heede, B.H. 1990. *Stream dynamics: An overview for land managers*. General Technical Report RM-72. USDA Forest Service, Rocky Mountain Forest and Range Experiment Station. 26 pages.

Concepts of stream dynamics are demonstrated through discussion of processes and process indicators. Theory is included only where helpful to explain concepts. Although only qualitative predictions of stream behavior are presented, these predictions show how management actions will affect the stream and its environment.

Heifetz, J., M.L. Murphy, and K.V. Koski. 1986. Effects of logging on winter habitat of juvenile salmonids in Alaskan streams. *North American Journal of Fisheries Management*. 6:52- 58.

This study was conducted in southeastern Alaska to determine the effects of logging on winter habitat of juvenile salmonids. The types of streams studied were located in the following areas: undisturbed old-growth forest, clearcut with riparian buffer strips, and clearcut logged along at least one bank. The authors found that most fish species resided in pools, and riffles and glides were avoided. The types of pools utilized varied widely during the study. Also, the amount of woody debris, which caused over 70% of the pools, was significantly greater in occupied pools. Several tables of data quantifying salmonid numbers for each stream type and pool type are included.

Hicks, B.J., R.L. Beschta, and R.D. Harr. 1991. Long-term changes in streamflow following logging in western Oregon and associated fisheries implications. *Water Resources Bulletin*. 27(2):217-226.

The long-term effects of logging on low summer streamflow was investigated using data collected from 1953-1988. Three watersheds in western Oregon were clearcut and burned, unlogged, and 25% patch cut and burned. Monitoring occurred for 9- 10 years pre-logging and 21-25 years post-logging and burning. August streamflows, which were the lowest of any month, increased by 159% after clearcutting watershed 1 but the effects lasted for only eight years. August streamflow increased by 59% in watershed three after 25% patch cut and burning. This paper presents important data on the changes in water yield during periods of summer low flow conditions. Some evidence was presented which suggests that conifer species in the riparian zone maintain summer water yields better than hardwoods.

Holtby, L.B. 1988. Effects of logging on stream temperatures in Carnation Creek, B.C. *Canadian Journal of Fisheries and Aquatic Sciences*. 45:502-515.

The objectives of this study were to quantify the effects of clearcut logging on stream temperatures in Carnation Creek and to quantify the effects of the logging-related component of those temperature changes on the coho salmon population. Forty-one percent of the basin of the creek was clearcut, increasing stream temperatures in all months of the year. As a result, coho salmon emerged earlier and increased the length of their summer growing season by up

to 6 weeks. Over-winter survival improved as a result of increased growth by the fall. Warmer spring temperatures were also associated with earlier seaward migration of smolts, probably resulting in decreased smolt-to-adult survivals. For this analysis, the author used a linked series of models to predict the effects of logging on stream temperatures and then the effects of those temperatures on critical coho life history events. A life history model was used to quantify the effects of stream temperature changes related to logging on the population size of adult coho salmon. The author concludes: (1) habitat perturbations can have quantifiable effects on fish populations; (2) habitat alteration can affect more than one life stage simultaneously and in opposite directions; (3) the effects of perturbations at one life stage can persist throughout the remainder of the life cycle; and (4) for anadromous fish species, the effects of habitat perturbations during freshwater rearing can persist into the marine phase.

House, R., V. Crispen, and R. Monthey. 1989. *Evaluation of stream rehabilitation projects - Salem district (1981-1988).* Technical Note OR-6:6600. USDI, Bureau of Land Management, Portland OR. 50 pages.

This document presents information on the effectiveness of stream rehabilitation structures in the Alsea and Nestucca River drainages, Oregon. Over 800 structures were evaluated in this study. Cost data for the structures is also included. In general, large increases in aquatic populations were observed after installation of the structures. The following structure types were evaluated: dams, deflectors, diversions, cover, scour, riprap, gravel, and others. Many tables are presented with information of changes in habitat attributable to the rehabilitation projects, adult and juvenile fish populations, and estimated benefits and costs.

King, J.G. Sediment production and transport in forested watersheds in the northern Rocky Mountains. In: *Proceedings of Technical Workshop on Sediments*. Corvallis, Oregon, February 3-7, 1992. U.S. Environmental Protection Agency and USDA Forest Service.

A review of erosion and sedimentation research from forest activities in the northern Rocky Mountains is presented. Topics include erosion and sedimentation from undisturbed forest watersheds, harvesting and road-building effects, and future prospects for understanding sediment movement processes. Limitations of the current methodologies for estimating sediment movement from watersheds are presented.

Kunkle, S.H., and G.H. Comer. 1971. Estimating suspended sediment concentrations in streams by turbidity measurements. *Journal of Soil and Water Conservation*. 26(1):18-20.

The authors investigate the relationship between turbidity and sediment loading to determine whether it is practical to estimate suspended sediment loading from turbidity measurements. The study was conducted on the Sleepers River in Vermont. Turbidity measurements were found to have value in estimating suspended sediment loadings, but a sediment-turbidity relationship must be developed specific to the watershed of interest due to the numerous variables involved that influence sediment loadings. An equation to estimate suspended sediment concentration from turbidity for the Sleepers River watershed is presented.

Lantz, R.L. 1971. Influence of water temperature on fish survival, growth, and behavior. In: *Proceedings of a Symposium: Forest Land Uses and Stream Environment*. Oregon State University, October 19-21, 1971. J.T Krygier and J.D. Hall (eds.). OSU, Corvallis, Oregon. pp. 182-193.

This paper presents a review of the effect of water temperature on fish and the influence that streamside vegetation has on controlling temperature fluctuations. The authors conclude that an important land management tool is leaving buffer strips along streams in forested areas. This paper provides a general review of the literature on stream water temperature control, as well as

the resulting improvement in fish survival and reproduction resulting from leaving buffer strips when harvesting.

Lloyd, D.S. 1987. Turbidity as a water quality standard for salmonid habitats in Alaska. *North American Journal of Fisheries Management*. 7(1):34-45.

A review of studies on the effects of turbidity on salmonid habitat was used to determine if turbidity could be used as a water quality standard. Based on information from the review, water quality standards allowing increases of 25 or 5 nephelometric turbidity units above ambient turbidity in clear cold-water habitats provides moderate and relatively high protection, respectively, for salmonid fish resources in Alaska. Stricter standards may be required for extremely clear waters, but stringent standards are not required for naturally turbid waters. Over 90 references are cited in this review.

Marion, D.A., and S.J. Ursic. Sediment production in forests of the Coastal Plain, Piedmont, and Interior Highlands. In: *Proceedings of Technical Workshop on Sediments*. Corvallis, Oregon, February 3-7, 1992. U.S. Environmental Protection Agency and USDA Forest Service.

This paper presents a discussion of sediment production from small catchments in various physiographic regions and provides information on the magnitude and duration of the changes associated with silvicultural activities. Higher sediment delivery was reported from Coastal Plain soils than the Piedmont and Interior Highlands because of the high erosion potential of the soils and channelization of flow. The authors also reported on the effects of timber harvest activities on sediment delivery. No long-term increases (greater than 3 years) in sediment production were observed in harvested and burned watersheds. In contrast, persistent increases in sediment production can occur when intensive mechanical site preparation is employed. Harvest activities which minimized ground disturbance and protect channel areas were identified as practices that would not increase on- site sediment production.

Martin, C.W., and J.W. Hornbeck. Erosion, sediment, and turbidity in New England forests. In: *Proceedings of Technical Workshop on Sediments*. Corvallis, Oregon, February 3-7, 1992. U.S. Environmental Protection Agency and USDA Forest Service.

The current knowledge, primarily from research conducted at Hubbard Brook, for protecting forest streams against erosion, sedimentation, and stream turbidity is summarized in this paper. Data on the impacts of forest harvest experiments at Hubbard Brook Experimental Forest are presented, and future research and modeling needs are discussed.

Maser, C., R.F. Tarrant, J.M. Trappe, and J.F. Franklin (tech. eds.). 1988. *From the forest to the sea: A story of fallen trees*. General Technical Report PNW-GTR-229. USDA Forest Service and USDI BLM. 153 pages.

This document presents a synthesis of existing research information on the impact of fallen trees in various stages on ecological diversity and offers some hypotheses and conclusions. The information presented is intended to help resource managers make decisions on the loss of woody debris on habitat diversity and ecological processes. The following chapters are included: coarse woody debris in forests and plantations of coastal Oregon; what is known about large trees that fall to the forest floor and into streams and rivers, estuaries, the sea, and coastal beaches; and options for public lands. Nearly 350 references are cited in this document.

McDade, M.H., F.J. Swanson, W.A. McKee, J.F. Franklin, and J. Van Sickle. 1990. Source distances for coarse woody debris entering small streams in western Oregon and Washington. *Canadian Journal of Forest Research*. 20(3):326-330.

The objective of this study was to determine the source-distance patterns of coarse woody debris in selected streams. The distance from streambank to rooting site was determined for at least 30 fallen trees at each study site on 39 streams in the Cascade and Coast ranges of Oregon and Washington. The distribution of distances from rooting site to bank was similar among streams of different characteristics. From all streams, 11 percent of the total number of debris pieces originated within 1 meter of the channel and over 70 percent originated within 20 meters. Tall stands (old-growth conifers) contributed woody debris from greater distances than shorter (mature) trees.

McIntyre, J.D. Responses of intermountain salmonids to sediment in streams. In: *Proceedings of Technical Workshop on Sediments*. Corvallis, Oregon, February 3-7, 1992. U.S. Environmental Protection Agency and USDA Forest Service.

This paper presents a short review of the literature on the effects of sediment on salmonids. Better methods are needed for developing appropriate indices of stream disturbance and to determine how much sediment disturbs stream productivity, not whether it does.

Meehan, W.R. 1970. *Some effects of shade cover on stream temperature in southeast Alaska*. Research Note PNW-113. USDA Forest Service, Pacific Northwest Forest and Range Experiment Station.

This study was done to determine the role of streamside vegetation under the cool, moist conditions of southeast Alaska. Study objectives were (1) to develop a practical method for measuring the effects of shade on stream temperature and (2) to conduct exploratory studies of the relationship between stream cover and water temperature. The study was conducted in small streams in the northern part of southeast Alaska. Measurements of stream temperature were taken on sunny and completely overcast days and along unshaded and shaded stretches of the streams. Weather information for sampling days and temperature data are tabulated. Temperature measurements demonstrated that streamside vegetation plays a definite role in maintaining cool stream temperatures. The author notes that temperature increases in streams after clearcutting in southeast Alaska do not approach levels lethal to fish. The precise role of streamside vegetation in the aquatic environment needs further research in order for fisheries and land managers to prescribe clearcutting for optimum timber and fisheries production.

Meehan, W.R., W.A. Farr, D.M. Bishop, and J.H. Patric. 1969. *Some effects of clearcutting on salmon habitat of two southwest Alaska streams*. USDA Forest Service, Pacific Northwest Forest and Range Experiment Station. Research Paper PNW-82.

This report presents significant amounts of data from research and describes the main conclusions regarding the effect of clearcutting on streamflow, suspended sediment, water temperature, and log debris on salmon habitat. Temperature measurements show that on clear summer days, shade-producing streamside vegetation plays a definite role in cooling or maintaining coolness of the study streams. No significant difference was found between the two areas under clear-shaded and cloudy weather conditions. This report also contains the references from a detailed literature review.

Minckley, W.L., and J.N. Rinne. 1985. Large woody debris in hot- desert streams: An historical review. *Desert Plants*. 7(3):142- 153.

This paper provides a review of woody debris input into southwestern desert streams. Debris has been denied to present- day desert streams

because of interception by impoundments and decimation of riparian vegetation. Historical changes, functions of large woody debris in the system, and probable future conditions are reviewed.

Murphy, M.L., and K.V. Koski. 1989. Input and depletion of woody debris in Alaska streams and implications for streamside management. *North American Journal of Fisheries Management*. 9(4):427-436.

Natural rates of input and depletion of large woody debris (LWD) in southeast Alaska streams were studied to provide a basis for managing streamside zones to maintain LWD for fish habitat after timber harvest. Input and depletion rates were inversely proportional to LWD diameter and ranged from 1%/year for large LWD in all stream types to 3%/year for small LWD in large, high-energy, bedrock-controlled streams. A model indicated that 90 years after clear-cut logging without a stream-side buffer strip large LWD would be reduced by 70% and recovery to prelogging levels would take more than 250 years. Because nearly all LWD is derived from within 30 m of the stream, the use of a 30-m wide, unlogged buffer strip along both sides of the stream during timber harvest should maintain LWD.

Murphy, M.L., K.V. Koski, J. Heifetz, S.W. Johnson, D. Kirchhofer, and J.F. Thedinga. 1984. Role of large organic debris as winter habitat for juvenile salmonids in Alaska streams. In: *Western Proceedings of the 64th Annual Conference of the Western Association of Fish and Wildlife Agencies*. Victoria, British Columbia, July 16-19, 1984. pp. 251-262.

To assess short-term effects of logging on juvenile Oncorhynchus kisutch, Salvelins malma, Salmo gairdneri, and Salmo clarki in southeastern Alaska, the fish density and habitat in summer and winter were compared in 18 streams in old-growth forest and in clearcuts with and without buffer strips. Buffered reaches did not consistently differ from old-growth reaches; clearcut reaches had more periphyton, lower channel stability, and less canopy, pool volume, large woody debris, and undercut banks than old-growth reaches. Fry abundance was related to the amount of large woody debris. Clearcutting may increase fry abundance in summer in some streams by increasing primary production, but may reduce abundance of parr in winter if debris is removed. Use of buffer strips maintains or increases debris, protects habitat, allows increased primary production, and can increase abundance of fry and parr. This paper presents partial results of a larger study; the companion paper is Thedinga, Murphy, Heifetz, Koski, and Johnson, 1989. This report presents significant amounts of data and conclusions and contains references to more than 50 other papers.

Platts, W.S., and W.F. Megahan. 1975. Time trends in riverbed sediment composition in salmon and steelhead spawning areas: South Fork Salmon River, Idaho. In: *Transactions of the 40th North American Wildlife and Natural Resources Conference*. Wildlife Management Institute, Washington, DC. pp. 229-239.

The number of returning adult summer chinook salmon and steelhead trout entering the South Fork Salmon River steadily declined for the 17 years prior to the report's publication. This report discusses the history of land use and habitat rehabilitation efforts in the river watershed, siting possible reasons for increased sedimentation that could affect salmon habitat. The report specifically describes temporal trends in riverbed material size composition in the four major spawning areas of the main river channel. Considerable variation in riverbed sediment size composition was found at varying locations in the river. Fine and coarse sands in excess of 10-15% led to unsuccessful salmon spawning. Changes in forest practices, particularly a moratorium on logging and road construction in the upper drainage, led to a change in sediment composition, from 45-80% fines to 12-26% fines, and an increase in suitability for spawning.

Reeves, G.H., F.H. Everest, and T.E. Nickelson. 1989. *Identification of physical habitats limiting the production of coho salmon in western Oregon and Washington.* USDA Forest Service, Pacific Northwest Research Station. General Technical Report PNW-GTR-245. 18 pages.

This document was designed to help fishery managers identify factors limiting the production of coho salmon in streams of coastal and interior Oregon and Washington. The guide is designed to identify potential physical limitations to fish production that may be moderated or removed by habitat rehabilitation or enhancement programs. The guide is most accurate for streams up to large fourth-order and small fifth- order streams.

Richards, C. Ecological effects of fine sediments in stream ecosystems. In: *Proceedings of Technical Workshop on Sediments.* Corvallis, Oregon, February 3-7, 1992. U.S. Environmental Protection Agency and USDA Forest Service.

A review of the ecological effects of fine sediment in stream ecosystems is presented. Topics include suspended sediment, sediment deposition, and secondary effects of sediment. Also included are several general approaches that have been taken to develop sediment criteria.

Rishel, G.B., J.A. Lynch, and E.S. Corbett. 1982. Seasonal stream temperature changes following forest harvesting. *Journal of Environmental Quality.* 11(1):112-116.

The objectives of this study were to document changes in water temperature of small headwater streams following a clearcut—herbicide treatment and a commercial clearcut harvest. The study was designed to provide data on the maximum expected change in stream temperature following forest cover removal and to evaluate the effectiveness of a buffer zone on the commercial clearcut site in controlling stream temperature changes. The average monthly maximum temperature change in the clearcut-herbicide treatment stream was 4.4 °C, and the highest recorded temperature in the stream was 32 °C, compared to 22 °C on an adjacent forested watershed. On the clearcut watershed with a buffer strip, only slight changes in stream temperature were observed. The average monthly maximum stream temperature increase was < 1 °C, and the highest temperature recorded was 23 °C.

Robison, E.G., and R.L. Beschta. 1990. Characteristics of coarse woody debris for several coastal streams of southeast Alaska, USA. *Canadian Journal of Fisheries and Aquatic Sciences.* 47(9): 1684-1693.

Coarse woody debris was measured along five undisturbed low- gradient stream reaches. Measurements taken included volume, decay class, and horizontal orientation. Debris is an important component of salmonid fish habitat in the Pacific Northwest and influences habitat for other aquatic organisms. Debris can also deflect stream flows and block fish migration; however, its removal is usually associated with lowered salmonid production. This study was undertaken to evaluate the extent to which debris volume, piece characteristics, and spatial distribution varied with stream size. The authors identified four "influence zones" for stream reaches: Zone 1 includes debris that offers cover at low flow, Zone 2 affects stream flow at high flow, and Zones 3 and 4 provide sources of debris to the streams. The authors conclude that the amount and location of coarse woody debris varies with stream size, and they recommend that debris locations be differentiated by stream influence zone in forest inventories.

Scannell, P.W. Effects of increased sedimentation on fresh waters of interior Alaska. In: *Proceedings of Technical Workshop on Sediments.* Corvallis, Oregon, February 3-7, 1992. U.S. Environmental Protection Agency and USDA Forest Service.

This paper presents a summary of a research effort in Alaska to determine the effects of

sediments on water quality, stream habitat, and fisheries. The focus of this paper is on the effects of increased sedimentation on aquatic invertebrates, stream periphyton, and site-feeding fish. Aquatic invertebrate density was strongly correlated with both turbidity and total suspended solids in the stream. Increased sediment loads reduced primary productivity but did not preclude it until settleable solids became measurable. Arctic graylings were excluded from segments of streams with low water quality and direct and indirect mortality resulting from sediment was observed.

Schlosser, I.J. 1982. Trophic structure, reproductive success, and growth rate of fishes in a natural and modified headwater stream. *Canadian Journal of Fisheries and Aquatic Sciences*. 39(7):968-978.

The impact of removing riparian vegetation, channel straightening, and fluctuations in flow regime on trophic structure, reproductive success, and growth rate of fishes was assessed in east-central Illinois. The authors found that channel morphology, in conjunction with flow regime, appears to be especially important in determining habitat stability and a broad range of fish community attributes. Also, alteration of riparian vegetation increased instability in the fish community by shifting the nature and seasonal dynamics of the organic energy base.

Scrivener, J.C., and M.J. Brownlee. 1989. Effects of forest harvesting on spawning gravel and incubation survival of chum (Oncorhynchus keta) and coho salmon (o. kisutch) in Carnation Creek, British Columbia. *Canadian Journal of Fisheries and Aquatic Sciences*. 46(3):681-696.

The objective of this study was to assess the effects of current forestry harvesting practices on spawning gravel composition, intergravel dissolved oxygen, and permeability, and the influence of these features on the survival and size of emerging fry. Following logging, fines in the stream bed of Carnation Creek increased from 4.6 to 5.7%, although suspended sediment concentration did not increase. Also following logging, the survival to emergence declined from 29.1 to 16.4% for coho salmon and from 22.2 to 11.5% for chum salmon. Annual changes in substrate composition and peak flows explained 60 and 73% of the variability in survival to emergence for chum and coho salmon, respectively. Changes in streambed fines appeared to depend on the timing of logging operations and large freshets.

Sedell, J.R., P.A. Bisson, F.J. Swanson, and S.V. Gregory. 1988. *What we know about large trees that fall into streams and rivers*, In: From the forest to the sea: A story of fallen trees. USDA Forest Service, Pacific Northwest Forest and Range Experiment Station. General Technical Report PNW-229. pp. 47-81.

The physical and biological characteristics of forested streams in the Northeast are discussed at length. The history of logging activities, riparian management, and ecosystem structure are compared; the effects of removed and downed timber on habitat are emphasized. Physical variables and stream debris frequency were studied for their effects on fish species and habitat development. The data indicate that complete removal of timber from any stream has an adverse impact on fish-dependent food chains and sediment capture. Overall, this article addresses stream debris dynamics and the effects on indigenous species. The document contains numerous figures and tables.

Stall, J.B. 1972. Effects of sediment on water quality. *Journal of Environmental Quality*. 1(4):353-360.

This paper documents the role of sediment in water quality and describes the magnitude of erosion and sedimentation, their predictability, the effect of erosion on land economic values and water use, and control programs. General information is provided pertaining to all major land uses.

Swank, W.T., L.F. DeBano, and D. Nelson. 1989. Effects of timber management practices on soil and water. In: *The Scientific Basis for Silvicultural and Management Decisions in the National Forest System*. R.M. Burns (ed.). USDA Forest Service. General Technical Report WO-55. pp. 79-106.

This paper presents a detailed review of the effects of various forest management practices on soil and water characteristics. The major topics reviewed include forest management practices, general effects on soil and water, and effects on different forest types. The section on general effects on soil and water includes review of water quantity, water quality, erosion, nutrient loss/change, fire, and herbicides. The different forest types, including western inland conifers, pacific coast conifers, northeastern conifers, eastern hardwoods, and southern conifers, are reviewed for water yield, streamflow timing, erosion and sedimentation, water quality and temperature, and soil and soil nutrients. This review cites over 100 references.

Swanson, F.J., R.J. Janda, T. Dunne, and D.N. Swanston. 1982. *Sediment budgets and routing in forested drainage basins*. USDA Forest Service, Pacific Northwest Forest and Range Experiment Station. General Technical Report PNW-141. 165 pages.

This document contains results from 14 papers and 5 summaries from discussion groups on sediment budget and routing studies conducted principally in forested drainage basins. Other topics included in the papers include sediment routing studies using computer models, physical models, and field observations. This work emphasizes methods for judging the relative importance of sediment sources within a basin, the many roles of biological factors in sediment transport and storage, and the importance of recognizing changes in sediment storage within basins when interpreting sediment yield.

Swanson, F.J., and G.W. Lienkaemper. 1978. *Physical consequences of large organic debris in Pacific Northwest streams*. USDA Forest Service, Pacific Northwest Forest and Range Experiment Station. General Technical Report PNW-69.

This paper presents a general overview of the physical characteristics, history, and effects of natural organic debris in streams. A case study showing the characteristics of potential management impacts of the movement of stream debris is presented. Evidence of increased frequency of debris torrents after clearcutting and road construction was observed. In two western Oregon watersheds, increases in debris torrents of about 4 and 9 times for clearcut and 40 to 130 times for road rights-of-way relative to the frequency in forested areas were observed.

Swift, L.W., Jr. 1982. Duration of stream temperature increases following forest cutting in the southern Appalachian Mountains. *Water Resources Bulletin*. 18(6):273-275.

The effect of clearcutting riparian areas on water temperature was examined at the Coweeta Hydrologic Laboratory, North Carolina. During the first two summers of the study, stream temperatures at the downstream edge of clearcut was increased by an average of 3.3 °C. The increase declined the next three summers to 1.2 °C. In addition, the daily range of water temperatures (maximum minus minimum) increased for all 5 years after clearcut. The authors also used a method by Brown (1970) to estimate water temperature changes and found that the method significantly overestimated the actual increase.

USDA Forest Service. Undated. *Forest hydrology: Hydrologic effects of vegetative manipulation, Part II*.

This document is concerned with the manipulation of vegetation and the subsequent effects that may be expected from water yield. The techniques, procedures, and guidelines contained in the

document are designed for use by field foresters to assess past, present, and future vegetation manipulation practices on the water and watershed resource. The guidelines are intended to aid in the optimum management of the forest resource while maintaining values placed on it by silvicultural, social, economic, and ecological constraints.

Van Sickle, J., and S.V. Gregory. 1990. Modeling inputs of large woody debris to streams from falling trees. *Canadian Journal of Forest Research*. 20(10):1593-1601.

This paper presents a generalized model for estimating the amount of large woody debris delivered to streams from stands of mixed tree heights and species composition. The estimates of debris input were based on the density (trees/area), tree size distribution, and tree-fall probability of the riparian stand adjacent to the stream. The model was applied to an old-growth coniferous stand in Oregon's Cascade Mountains. Debris pieces in the stream were generally shorter than predicted by the model, probably because of bole breakage during tree fall. The authors discuss the coupling of the model to a stream dynamics model to give land managers a tool to explore the long-term consequences of management alternatives for woody debris inputs to streams and floodplains.

Vohs, P.A., I.J. Moore, and J.S. Ramsey. 1993. *A critical review of the effects of turbidity on aquatic organisms in large rivers*. U.S. Fish and Wildlife Service, Environmental Management Technical Center, Special report 93-S002. 139 pages.

A comprehensive critical review of the biological effects of suspended sediments (including turbidity, washload, and filterable solids) was prepared by the United States Fish and Wildlife Service. This critical review covers 121 references.

Adams, T.N., and K. Sullivan. 1988. *The physics of forest stream heating: A simple model.* Weyerhaeuser Technical Report.

Benda, L. 1990. The influence of debris flows on channels and valley floors in the Oregon coast range, USA. *Earth Surface Processes and Landforms*. 15:457-466.

Berry, J.D. 1975. Modeling the impact of logging debris in streams. In: *Proceedings of the Watershed Management Symposium*. Logan, Utah, August 11-13, 1975. American Society of Civil Engineers, Division of Irrigation and Drainage. pp. 676-680.

Beschta, R.L. 1983. Sediment and organic matter transport in mountain streams of the pacific northwest. In: *Symposium on Erosion and Sedimentation*. Colorado State University, Fort Collins, Colorado. Dr. D.B. Simons Symposium. pp. 169-189.

Bethlahmy, N. 1971. *Maximum peak flows for selected return periods for watersheds west of the continental divide in Idaho and Montana*. USDA Forest Service, Research Paper INT-113.

Bilby, R.E. 1981. Role of organic debris dams in regulating the export of dissolved and particulate matter from a forested watershed. *Ecology*. 62(5):1234-1243.

Blackmon, B.G. (ed). 1985. *Forestry and water quality: A mid- south symposium*. Little Rock, Arkansas, May 8-9, 1985. Arkansas Cooperative Extension Service, University of Arkansas.

Burton, T.M., and G.E. Likens. 1973. The effect of strip-cutting on stream temperatures in the Hubbard Brook Experimental Forest, New Hampshire. *BioScience*. 23:433-435.

Cherry, J., and R.L. Beschta. 1989. Coarse woody debris and channel morphology: A flume study. *Water Resources Bulletin*. 25(5):1031-1036.

Crouse, M.R., C.A. Callahan, K.W. Malueg, and S.E. Dominguez. 1981. Effects of fine sediments on growth of juvenile coho salmon in laboratory streams. *Transactions of the American Fisheries Society*. 110:281-286.

Douglass, J.E., and W.T. Swank. 1975. Effects of management practices on water quality and quantity: Coweeta Hydrologic Laboratory, North Carolina. In: *Municipal Watershed Management Symposium Proceedings*. USDA Forest Service, Northeastern Forest Experiment Station. General Technical Report NE-13. pp. 1-13.

Glymph, L.M., and H.C. Storey. 1967. Sediment-its consequences and control. In: *Agriculture and the quality of our environment*. N.C. Brady (ed.). American Association for the Advancement of Science Pub. 85:205-220.

Gorman, O.T., and J.R. Karr. 1978. Habitat structure and stream fish communities. *Ecology*. 59(3):507-515.

Gregory, S.V., G.A. Lamberti, D.C. Erman, K.V. Koski, M.L. Murphy, and J.R. Sedell. 1987. Influence of forest practices on aquatic production. In: *Streamside Management: Forestry and Fishery Interactions*. University of Washington. E.O. Salo, and T.W. Cundy, (eds.) Institute of Forest Resources No. 57. Chapter 7, pp. 233-255.

Heede, B.H. 1985. Application of geomorphological concepts to evaluate timber harvest influences on a stream channel-A case study. *Annals of Geomorphology, Supplement 55, Fluvial Geomorphology*. H. Bremer (ed.). Gebruder Borntraeger, Berlin. pp. 121-130.

Hewlett, J.D., and J.C. Fortson. 1982. Stream temperature under an inadequate buffer strip in the Southeast Piedmont. *Water Resources Bulletin*. 18(6):983-988.

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Sedell, J.R., G.H. Reeves, F.R. Hauer, J.A. Stanford, and C.P. Hawkins. 1990. Role of refugia in recovery from disturbances: Modern fragmented and disconnected river systems. *Environmental Management*. 14(5):711-724.

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WATERSHED LEVEL STUDIES

Anderson, H.W. 1954. Suspended sediment discharge as related to streamflow, topography, soil, and land use. *Transactions of the American Geophysical Union*. 35:268-281.

Suspended sediment sampling yielded values for average annual suspended sediment from 29 watersheds in western Oregon. These values were related by regression analysis to streamflow (mean annual runoff and peakedness of runoff), topography (slope, area and elevation), soil type, and channel bank characteristics. Sediment discharge was found to be significantly related to mean annual runoff, peakedness of runoff, slope, soil type, and land use. Based on the study, the author developed a map of erosion potential for western Oregon and discusses at some length the factors responsible for differences in suspended sediment discharge between watersheds. Application of the results to land use planning and future predictions of erosion within watersheds is also discussed.

Beschta, R.L., and R.L. Talyor. 1988. Stream temperature increases and land use in a forested Oregon watershed. *Water Resources Bulletin*. 24(1):19-25.

The long-term changes in stream temperatures in relation to management activities and natural hydrologic events was studied in the Salmon Creek watershed in western Oregon. Over a 30-year period, average daily maximum and minimum stream temperatures (calculated from the 10 warmest days of each year) have risen 6 °C and 2 °C, respectively although only a small increase in air temperature was observed over the same period. The authors noted a highly significant relationship between a cumulative index of forest harvesting and maximum stream temperatures. Maximum temperatures also increased for several years following peak flow events, which tended to obscure specific cause and effect relationships between timber harvest activities and long-term stream temperature changes.

Brooks, K.N., H.M. Gregersen, E.R. Berglund, and M. Tayaa. 1982. Economic evaluation of watershed projects-an overview methodology and application. *Water Resources Bulletin*. 18(2):245-250.

An economic tool for use in determining which watershed rehabilitation projects are most

economically viable is presented. The tool was applied to a project in Morocco to control sedimentation and thereby increase downstream reservoir capacity for irrigation. The tool involves four steps: (1) analyzing existing watershed and expected watershed conditions based on changes resulting from the project; (2) developing value estimates for the project inputs and outputs; (3) calculating the project's worth; and (4) testing the sensitivity of the analysis to the assumptions used in its development. A full cost/benefit analysis for the case study project is presented. The authors present this economic tool as an alternative to a much more costly feasibility study.

Childers, D.L., and J.G. Gosselink. 1990. Assessment of cumulative impacts to water quality in a forested wetland landscape. *Journal of Environmental Quality*. 19:455-464.

This article presents a historical analysis of water quality in the Tensas Basin, Louisiana, as part of a cumulative impact analysis of the landscape. Historical records of suspended sediment, N, P, and turbidity from three streams in the basin demonstrated that the watershed's water quality is characteristic where the original forest cover has been cleared. Aquatic primary productivity in the Basin appears to be nitrogen limited. A goal-oriented management plan for the watershed was developed based on the study results. Management practices to counteract the cumulative effects of conversion to agricultural land include runoff control, protecting forested corridors along streams, and creating new buffer zones.

Coats, R.N., and T.O. Miller. 1981. Cumulative silvicultural impacts on watersheds: A hydrologic and regulatory dilemma. *Environmental Management*. 5(2):147-160.

The cumulative effects of multiple logging operations on single watersheds are presented. Both California and federal laws require that these effects be considered when approving forest plans, but in actuality plans are approved on an individual basis. Ways to approach the problem and encourage the formation of a geological reference system to be used in planning are included.

Fraley, J., T. Weaver, and J. Vashro. 1989. Cumulative effects of human activities on bull trout (Salvelinus confluentus) in the Upper Flathead Drainage, Montana. In: *Proceedings of the Symposium on Headwaters Hydrology*. American Water Resources Association, Bethesda, Maryland. pp. 111-120.

The potential cumulative effects of land management practices, such as timber harvest and road building in the Flathead Lake watershed, on the population of the bull trout are summarized. The authors provide evidence from other monitoring studies that suggests that the deposition of fine sediments from streamside disturbances and forest road construction activities have adversely affected and could continue to adversely affect the bull trout. Based on information summarized in this paper, the authors called for amendments of current management standards, including riparian guidelines and increased implementation of best management practices to reduce sediment delivery.

Frear, S.T. 1982. Timber harvesting and water quality in the Bull Run Municipal Watershed. In: *Forestry Research West*. USDA Forest Service, pp. 4-8.

Timber harvesting and its effects on the Bull Run Municipal Watershed are discussed. The watershed contains significant silvicultural activity and also serves as a large source of drinking water for the region. The interaction between the two amenities was studied. The study included three watersheds: one was a control, and two were used for various timber management practices including road construction, timber harvest, and site preparation. The author concludes that timber harvest activities in this watershed do not cause appreciable degradation in water quality.

Hansmann, E.W., and H.K. Phinney. 1973. Effects of logging on periphyton in coastal streams of Oregon. *Ecology*. 54:194-199.

Prelogging and postlogging oxygen levels, temperature, and sedimentation loads were analyzed in a study of small watersheds in Oregon. Clearcut logging was applied to one watershed of 71 hectares, while a second watershed was patch-cut leaving a buffer-strip of vegetation along the stream channel. A third watershed remained as a control. The study showed that a close relationship exists between watershed practices and floral characteristics of the drainage system and that stream characteristics can maintain themselves if adequate protection is given to stream vegetation.

Hilmon, J.B., and J.E. Douglass. 1968. Potential impact of forest fertilization on range, wildlife, and watershed management. In: *Forest Fertilization: Practice and Theory*. Tennessee Valley Authority. pp. 197-202.

This is a review of the potential impacts of fertilization on forage, wildlife, and water resources. Results of studies carried out in Florida, Georgia, and North Carolina are presented. Plots received different rates of fertilization, and the nutrient quality of forage for livestock was measured. A similar study was carried out on plots managed for both timber and forage production. The authors briefly discuss the effects of fertilization on the nutrient value of wildlife forage, and, in greater detail, the water quality and yield effects of fertilization.

Kochenderfer, J.N., and G.M. Aubertin. 1975. Effects of management practices on water quality and quantity: Fernow Experimental Forest, West Virginia. In: *Municipal Watershed Management Symposium Proceedings*. USDA Forest Service, Northeastern Forest Experiment Station. General Technical Report NE-13. pp. 14-24.

The data from 22 years of research into the influence of forestry practices on the quantity and timing of streamflow and on water quality parameters such as turbidity, temperature, specific conductance, pH, alkalinity, and nutrient concentrations are reviewed in this paper. Water quality degradation was observed from clearcut experimental watersheds, whereas minor changes in water quality were observed when forestry practices were well planned and conducted. The authors conclude that at the time of this paper, forests could not be managed for timber products and water yield and that water quality degradation could easily be avoided by using erosion control management practices. Data from the research are presented, although no statistical analysis of the data is provided.

Martin, C.W. 1979. Precipitation and streamwater chemistry in an undisturbed forested watershed in New Hampshire. *Ecology*. 60(1): 36-42.

A study was initiated to determine the precipitation and streamwater chemistry of forested watersheds at various stages of succession, including a forested watershed heavily logged 55 years ago, a watershed commercially clearcut in 1970, and a watershed clearfelled in 1967 and sprayed with herbicide for 3 years. The previously reported hypothesis that nutrient concentrations would be higher in streams draining mature forested areas due to lower net accumulation in these stands compared to younger stands was tested. The authors found a net loss of nitrate from all watersheds. However, a net accumulation of ammonium that was sufficient to give a net increase in total N in all watersheds was found.

Meyer, J.L., and C.M. Tate. 1983. The effects of watershed disturbance on dissolved organic carbon dynamics of a stream. *Ecology*. 64(1):33-44.

Two second-order streams in the Coweeta Hydrologic Laboratory, North Carolina, were studied for annual dissolved organic carbon (DOC) export. One of the watersheds was completely clearcut 2 years prior to the beginning

of the study, while the other was left undisturbed. The document provides excellent analytical data for DOC transport during baseflow and storm periods. Lower DOC export from the clearcut watershed was concluded to be the result of lower inputs in subsurface water as well as in stream generation.

Neary, D.G., and J.B. Currier. 1982. Impact of wildfire and watershed restoration on water quality on South Carolina's Blue Ridge Mountains. *Southern Journal of Applied Forestry*. 6(2):81- 90.

Neary and Currier studied the change in water quality caused by a large wildfire in South Carolina's Blue Ridge Mountains. Five watersheds contained five different conditions, including undisturbed; burned only; burned and fertilized; and burned, fertilized and covered with fire retardant. Concentrations of NO_3-N increased the most (peak of 0.394 mg/l) as a result of fertilizer applications during restoration operations. Nitrate-N, NH_4-N, PO_4-P levels were elevated on the burned and fertilized watersheds mainly during storm events. Sodium, K, Ca, and Mg concentrations were 12-82% above background levels during most of the monitoring period. Suspended solid concentrations showed no relationship to watershed condition. Changes in water quality were of no biological significance to aquatic ecosystems and did not affect use of the watersheds as sources of drinking water. Based on the results of this intensive study, the authors concluded that the wildfire did not adversely affect the water quality for ecosystems or drinking.

Pearce, R. 1987. *Casper Creek: Discovering how watersheds respond to logging*. USDA Forest Service, Pacific Southwest Forest and Range Experiment Station.

This paper discusses the watershed impacts associated with different forestry practices in the Casper Creek watershed in California. Changes in streamflow and sedimentation from road building and timber harvest were documented from two different long-term studies. In the first study, results indicated an 80% increase in sediment after road building and a 275% increase after logging. Most sediment was lost during short periods of high flow in the watersheds. In the second study (not yet completed), the roles of the two watersheds were switched after the watersheds were allowed to stabilize. The authors hope to present the results of the second study soon after the research is completed.

Troendle, C.A., and R.M. King. 1985. The effect of timber harvest on the Fool Creek watershed, 30 years later. *Water Resources Research*. 21(12):1915-1922.

The Fool Creek watershed at the Fraser Experimental Forest, Colorado, was harvested using a pattern of alternating clearcut and forested strips in 1956. After 30 years of postharvest record, subtle impacts on the hydrology of the watershed were detected that had not been significant in the past.

Yount, J.D., and G.J. Niemi. 1990. Recovery of lotic communities and ecosystems from disturbance-A narrative review of case studies. *Environmental Management*. 14(5):547-569.

This paper presents a review of case studies of the recovery of flowing water systems from disturbance. The case study of interest to forestry NPS is the recovery of streams from disturbances to a watershed. The review presents information suggesting that stream recovery would lag behind terrestrial recovery after a disturbance because of the temporal relationship between forest succession and the dynamics of organic debris accumulation. Other case studies are presented on the following: recovery from floods and spates; recovery from drought; recovery from biocide applications, recovery from toxic chemical discharges and spills; recovery from fish management practices; recovery from physical modification of the channel; recovery from experimental manipulations; and recovery from multiple disturbances.

Anderson, H.W., M.D. Hoover, and K.G. Reinhart. 1976. *Forests and water: Effects of forest management on floods, sedimentation, and water supply*. USDA Forest Service. General Technical Report PSW-18. 115 pages.

Anderson, H.W., and J.R. Wallis. 1965. Some interpretations of sediment sources and causes, Pacific Coast basin in Oregon and California. In: *Proceedings of the Federal Inter-Agency Sedimentation Conference*. pp. 22-30.

Baumgartner, D.M. (ed). 1981. *Interior west watershed management: Proceedings of a symposium*. Spokane, Washington, April 8-10, 1980. Washington State University, Cooperative Extension Service. 288 pages.

Bethlahmy, N. 1971. *Maximum peak flows for selected return periods for watersheds west of the continental divide in Idaho and Montana*. USDA Forest Service, Research Paper INT-113.

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Dillon, P.J., and W.B. Kirchner. 1975. The effects of geology and land use on the export of phosphorus from watersheds. *Water Resources*. 9:135-148.

Fisher, S.G., and G.E. Likens. 1973. Energy flow in Bear Brook, New Hampshire: An integrative approach to stream ecosystem metabolism. *Ecological Monographs*. 43(1):421-439.

Gregory, J.D. 1988. Hydrologic impacts of forest water management. In: *The Ecology and Management of Wetlands, Volume 2: Management, Use and Value of Wetlands*. Hook et al. (eds.). Timber Press, Portland, Oregon. pp. 137-147.

Hewlett, J.D., and J.E. Douglass. 1968. *Blending forest uses*. USDA Forest Service, Southeastern Forest Experiment Station. Research Paper SE-37. 16 pages.

Leaf, C.F. 1975. *Watershed management in the central and southern Rocky Mountains: A summary of status of our knowledge by vegetation type*. USDA Forest Service, Rocky Mountain Forest and Range Experiment Station. Research Paper RM-142. 28 pages.

Leaf, C.F. 1975. *Watershed management in the Rocky Mountain subalpine zone: The status of our knowledge*. USDA Forest Service, Rocky Mountain Forest and Range Experiment Station. Research Paper RM-137. 31 pages.

Lotspeich, F.B. 1980. Watersheds as the basic ecosystem: This conceptual framework provides a basis for a natural classification system. *Water Resources Bulletin*. 16:581-586.

Love, L.D., and B.C. Goodell. 1960. Watershed research on the Fraser Experimental Forest. *Journal of Forestry*. 58:272-275.

Lull, H.W., and K.G. Reinhart. 1972. *Forests and floods in the eastern United States*. USDA Forest Service, Northeastern Forest Experiment Station. Research Paper NE-226. 94 pages.

Meehan, W.R. (ed.). 1991. *Influences of forest and rangeland management on salmonid fishes and their habitat*. American Fisheries Society Special Publication 19. 751 pages.

NCASI. 1984. *Forestry management practices and cumulative effects on water quality and utility*. National Council of the Paper Industry for Air and Stream Improvement. Technical Review Bulletin No. 435.

NCASI. 1991. *The New Alsea Watershed study*. National Council of the Paper Industry for Air and Stream Improvement. Technical Bulletin No. 602.

Odum, E.P. 1985. Trends expected in stressed ecosystems. *Bioscience*. 35(7):419-422.

Pierce, R.S. 1967. Evidence of overland flow on forest watersheds. *Forest Hydrology*. W.E. Sopper, and H.W. Lull (eds.). Pergamon Press, NY. p.247-252.

Richter, D.D., C.W. Ralston, and W.R. Harms. 1983. Chemical composition and spatial variation of bulk precipitation at a coastal plain watershed in South Carolina. *Water Resources Research*. 19(1):134-140.

Rygh, J. 1990. *Fisher Creek Watershed improvement project final report*. Payette National Forest. 13 pages.

Salo, E.O., and T.W. Cundy (eds.). 1987. *Streamside management forestry and fishery interactions*. College of Forest Resources, University of Washington. 471 pages.

Settergren, C.D., R.M. Nugent, and G.S. Henderson. 1980. Timber harvest water yields in the Ozarks. In: *Symposium on Watershed Management, vol.II*. pp. 661-669.

Sparks, R.E., P.B. Bayley, S.L. Kohler, and L.L. Osborne. 1990. Disturbance and recovery of large floodplain rivers. *Environmental Management*. 14(5):699-709.

Woodwell, G.M. 1970. Effects of pollution on the structure and physiology of ecosystems. *Science*. 168(3929):429-433.

4. ROAD CONSTRUCTION AND USE

IMPACTS ON WATER QUALITY

Amaranthus, M.P., R.M. Rice, N.R. Barr, and R.R. Ziemer. 1985. Logging and forest roads related to increased debris slides in southwestern Oregon. *Journal of Forestry*. 83(4):229-233.

This article presents data from a study of mass erosion in the Siskiyou National Forest in southwestern Oregon. The effects of forest activities on soil mass movement frequency and volumes and information on the conditions at landslide sights which might aid in the prediction of future slides was identified. The slide frequency during the study period was one slide every 4.3 years per 1000 acres. Erosion from roads was approximately 100 times those on undisturbed areas, while erosion from harvested areas was 7 times that of undisturbed areas. About 75% of slides occurred on slopes steeper than 70%.

Anderson, B., and D.F. Potts. 1987. Suspended sediment and turbidity following road construction and logging in western Montana. *Southern Journal of Applied Forestry*. 23(4):681-690.

Suspended sediment production and turbidity following forest management activities are well documented for areas where soils are highly erodible or where terrain is unstable. Areas with stable sediments may require less stringent forest practice regulations for logging and road construction than areas with unstable soils. This study investigated the relationships between suspended sediment production, turbidity, and discharge in a watershed characterized by stable sediments and the changes in these parameters associated with logging and road construction. Sediment yields increased 7.7-fold in the first year following road construction in a second-order drainage and twofold in the second year following logging. Sediment supply limitations resulted in poor correlations between sediment concentrations and discharge. Turbidity was much better correlated with discharge and serves as a better indicator of sediment concentration.

Askew, G.R., and T.M. Williams. 1984. Sediment concentrations from intensively prepared wetland sites. *Southern Journal of Applied Forestry*. 8(3):152-157.

This study was designed to evaluate the drainage and conversion process used by a major forest industry and to determine which aspect of the conversion process, if any, was a primary source of sediment. Suspended sediment concentrations were measured in water draining from a 5,900-acre Carolina bay undergoing conversion to loblolly pine plantations. Samples were collected during the first stormflow event of each month between January 1981 and December 1982 from subwatersheds involved in some of several phases of conversion. Suspended sediment concentration in water leaving the bay averaged only 16 mg/l for 13 storms. Road erosion and ditch installation produced the highest suspended sediment concentrations. Suspended sediment concentrations decreased substantially with increasing distance from the sediment source. Logging and site preparation activities did not cause an appreciable increase in suspended sediment when equipment did not operate in the drainage ditches. This study indicates that main haul roads and new drainage ditches are the sources of much of the increased suspended sediments found in drainage from managed forests in the lower coastal plain. The authors conclude that the impact of these activities can be minimized by using a drainage system that contains a length of main channel between sediment sources and sensitive areas.

Bauer, S.B. 1985. Evaluation of nonpoint source impacts on water quality from forest practices in Idaho: Relation to water quality standards. In: *Perspectives on Nonpoint Source Pollution: Proceedings of a National Conference*. Kansas City, Missouri, May 19-22, 1985. U.S. Environmental Protection Agency. pp. 455-458.

The results of an interdisciplinary task force appointed to determine the impacts of forest operations on water quality are presented. Twenty-five forestry sites, operated by state, federal, and private ownership, were reviewed. Seven of the sites had major impacts on salmonid habitat due to direct delivery of sediment from skid trails or roads. The remaining sites had impacts prevented by low geologic hazards, streams with no protected uses, or good practices. Other task force findings are also presented in the paper.

Beasley, R.S., E.L. Miller, and S.C. Gough. 1984. Forest road erosion in the Ouachita mountains. In: *Mountain Logging Symposium Proceedings*. West Virginia University, June 5-7, 1984. P.A. Peters and J. Luckok= (eds.), (eds.) pp. 202-213.

The quantity and deposition of sediments eroded from four segments of an established forest road in the Ouachita Mountains of Arkansas were determined for each storm event that occurred between June 1, 1982, and May 31, 1983. Measurements included total discharge volume, discharge rates and peaks, deposited sediment, suspended sediment, and downslope movement of deposited sediments. Of 36 storm events, one storm (13 inches in 24 hours) accounted for about half of the total annual sediment yield. Most of the sediment was deposited a short distance downslope of the road. The results of this study may be very useful to managers of sites similar to those used in the study.

Bilby, R.E. 1985. Contributions of road surface sediment to a western Washington stream. *Forest Science*. 31(4):827-838.

This paper presents the results of a study conducted to determine the extent to which forest road sediments deposit in streambeds. The results showed that sediment deposition occurred only during low flow conditions because the majority of the sediment from the road surface was very fine. In addition, the gradient of the road and the roadside vegetation were thought to reduce the magnitude of larger sediment particles reaching the stream. This study presents information on the mechanisms of sediment runoff from forest roads.

Blackmon, B.G. (ed). 1985. *Forestry and water quality: A mid- south symposium*. Little Rock, Arkansas, May 8-9, 1985. Arkansas Cooperative Extension Service, University of Arkansas.

This document contains papers from a symposium on forestry and water quality. Topics addressed in the symposium include historical perspectives on forestry and water quality, legislative trends, physical and chemical elements of forest hydrology, education programs, and results of original research. Because of the importance of forest road construction in reducing forestry-related water quality problems, a section is also included on the hydrology of forest roads. The symposium proceedings contain nearly 20 individual papers addressing these topics.

Brown, G.W., and J.T. Krygier. 1971. Clear-cut logging and sediment production in the Oregon coast range. *Water Resources Research*. 7(5):1189-1198.

The impact of road construction, two patterns of clear-cut logging, and controlled slash burning on the suspended sediment yield and concentration from three small watersheds was studied for 11 years. Sediment production was doubled after road construction but before logging in one watershed and was tripled after burning and clearcutting of another watershed. Felling and yarding did not produce statistically significant changes in sediment concentration. Variation in the relation between sediment concentration and water discharge on small undisturbed streams was large. Conclusions about the significance of all but very large changes in sediment concentrations

are limited because of annual variation for a given watershed, variation between watersheds, and variation with stage at a given point. Tables present sediment concentrations in the two altered watersheds and one control watershed for the duration of the study.

Burns, J.W. 1972. Some effects of logging and associated road construction on northern California streams. *Transactions of the American Fisheries Society*. 101(1):1-17.

This report describes the results of a study conducted from 1966 to 1969 to determine the degree of streambed sedimentation, water quality degradation, and aquatic habitat alteration associated with forest road construction. The authors found that heavy use of bulldozers on steep slopes during road construction causes excessive sedimentation. Also, if the road construction is conducted at a time when juvenile fish are present, decay of debris in the water may significantly decrease the dissolved oxygen in the water. This paper provides a good review of the effects of road construction on water quality and fish survival and reproduction.

Campbell, A.J., R.C. Sidle, and H.A. Froehlich. 1982. *Prediction of peak flows for culvert design on small watersheds in Oregon*. Oregon State University, Water Resources Research Institute, WRRI-74. 98 pages.

Equations developed from 80 watersheds ranging in size from 0.21 to 10.60 square miles and useful for predicting peak flows on small watersheds in Oregon are presented. Oregon was divided into six physiographic regions for the purposes of the study and equations specific to each region are given. Annual peak flow data from gaging stations with more than 20 years of record were used for the analyses. Flood magnitudes having recurrence intervals of 10, 25, 50, and 100 years were related to physical and climatic indices of drainage basins by multiple regression analysis. Drainage basin area was the most important variable in explaining the variation of flood peaks in all regions. Mean basin elevation and mean annual precipitation were also significantly related to flood peaks in two regions in western Oregon. The prediction equations provide a better basis for culvert design on small forested watersheds than rules of thumb or empirical methods.

Case, A.B., and D.A. Rowe. 1978. *Environmental guidelines for resource road construction*. Canada Forestry Service, Fisheries and Environment, Newfoundland Forest Research Center, Information Report N-X-162. 41 pages.

Information on the effects of forest road construction on aquatic and terrestrial environments is presented in this document. In addition, construction guidelines are presented to aid in preventing or minimizing environmental disturbances associated with road construction. The report is designed principally for resource road development in Newfoundland and Labrador. While the focus of the paper is on protecting important habitat (e.g., fish spawning areas, moose yards, waterfowl breeding areas) generally and is not specific to forestry activities, the recommended guidelines are well outlined and include recommended buffer widths and other technical guidance. A table lists environmental effects associated with road construction activities.

Duncan, S.H., S.H. Bilby, J.W. Ward, and J.T. Heffner. 1987. Transport of road-surface sediment through ephemeral stream channels. *Water Resources Bulletin*. 23(1):113-119.

The majority of road drainage points in western Washington and Oregon enter small, rather than large, streams. The impact of road surface sediment on biota in larger streams, therefore, depends on transport through smaller watercourses. Experimental additions of sediment to two small streams were conducted. Small streams were found to store large amounts of sediment washed from road surfaces. Neither stream transported more than 45% of the added material to its mouth (95 m and 125 m). Larger particles were delivered at a lower rate than were finer particles. Significant differences in the transport of sediment in two larger sediment size categories were due to a greater amount of woody debris in the stream with the lower delivery rate

and a slightly longer and less steep channel.

Ferguson, R.I., and T.A. Stott. 1987. Forestry effects on suspended sediment and bedload yields in the Balquhidder catchments, Central Scotland. *Earth Sciences, Transactions of the Royal Society of Edinburgh*. 78:379-384.

Outputs of suspended sediment and bedload from the 7.7-km^2 moorland Monachyle basin and the 6.8-km^2, 40%-forested Kirkton basin near Balquhidder and inputs from tributary streams and mainstream bank erosion are compared. Sediment yield is about three times higher in the forested basin and varies more sensitively with streamflow, suggesting greater availability of erodible sediment. The output is predominantly suspended sediment and is derived mainly from tributary streams. Initial observations following partial moorland plowing and forest clearcutting in 1986 indicate that erosion of timber loading areas and logging roads is the main sediment source.

Fraley, J., T. Weaver, and J. Vashro. 1989. Cumulative effects of human activities on bull trout (*Salvelinus confluentus*) in the Upper Flathead Drainage, Montana. In: *Proceedings of the Symposium on Headwaters Hydrology*. American Water Resources Association, Bethesda, Maryland. pp. 111-120.

The potential cumulative effects of land management practices, such as timber harvest and road building in the Flathead Lake watershed, on the population of the bull trout are summarized. The authors provide evidence from other monitoring studies that suggests that the deposition of fine sediments from streamside disturbances and forest road construction activities have adversely affected and could continue to adversely affect the bull trout. Based on information summarized in this paper, the authors called for amendments of current management standards, including riparian guidelines and increased implementation of best management practices to reduce sediment delivery.

Fukushima, Y. 1987. Estimating discharge and sediment yield from a forest road. In: *Erosion and Sedimentation in the Pacific Rim, Proceedings of the Corvallis Symposium*. Oregon State University, August, 1987. R.L. Beschta et al. (eds.). IAHS Publication #165, Corvallis, Oregon. pp. 265-266.

This short paper presents a method for estimating sediment yield from a forest road using rainfall and soil properties. The paper presents information that may be useful for planning road sites; however, the degree of usefulness is limited by the lack of supporting data or calibration of method using other data.

Gardner, R.B. 1971. *Forest road standards as related to economics and the environment*. USDA Forest Service. Research Note INT-145.

This brief note discusses the problems related to planning a forest road system. Data needed for planning an optimum system were not available at the time, and the author discusses factors that should be taken into account to plan the best system possible in the absence of such data and to protect the quality of the environment. Cost data (annual road costs per mile for 10,000 vehicles per annum (VPA) and 20,000 to 40,000 VPA, and single lane versus double lane for 10,000, 20,000, and 40,000 VPA) are presented in tables.

Golden, M.S., C.L. Tuttle, J.S. Kush, and J.M. Bradley. 1984. *Forestry activities and water quality in Alabama: Effects, recommended practices, and an erosion-classified system*. Auburn University, Agricultural Experiment Station. Bulletin 555.

The report was prepared primarily as a source of information on the relationship between forestry practices and water quality, with orientation toward forestry practices prevalent in Alabama. Information on stream pollutants such as sediment, nutrients, pesticides, organic material, waste and litter, and temperature is provided. The review includes over 160 directly cited documents on these subjects. Also included in the report are recommendations of principles and practices designed to minimize the water quality impacts from Alabama forestry practices.

Grant, G. 1988. *The RAPID technique: A new method for evaluating downstream effects of forest practices on riparian zones*. USDA Forest Service, Pacific Northwest Forest and Range Experiment Station. General Technical Report PNW-220.

The RAPID (riparian aerial photographic inventory of disturbance) technique is a method for using measurements made on aerial photographs of patterns of riparian canopy disturbance to evaluate changes in channel conditions through time and to link such changes with their possible upstream causes. The RAPID technique provides resource specialists and managers with a relatively quick way of identifying stream reaches that are chronically or recently disturbed by a variety of channel processes, including increased peak flows and sedimentation from point and nonpoint sources. With examples from western Oregon, this paper describes how to apply the RAPID technique and analyze the results to evaluate downstream or cumulative effects of forest practices.

Guy, H.P., and G.E. Ferguson. 1970. Stream sediment: An environmental problem. *Journal of Soil and Water Conservation*. 25:217-221.

A general review of problems associated with sediment deposited in streams. The article tabulates sediment sources and their common environmental effects. Two case histories-one of sediment runoff from highway construction and one of residential construction-are reviewed. The authors suggest a number of research areas where data are needed to alleviate the problems of erosion and sedimentation.

Harr, R.D., and R.L. Fredriksen. 1988. Water quality after logging small watersheds within the Bull Run Watershed, Oregon. *Water Resources Bulletin*. 24(5):1103-1111.

The water quality impacts from clearcut practices and slash burning are presented. Logging significantly increased nitrate-nitrogen levels for up to 7 years after harvest; smaller increases were observed after slash burning. Suspended sediment also had a small increase attributed to construction of a permanent road that crossed streams. Annual stream temperatures increased 2-3 °C after logging but returned to pretreatment levels after 3 years. This watershed study presents significant data on the effects of forest harvest and slash burning on water quality.

Harr, R.D., and R.A. Nichols. 1993. Stabilizing forest roads to help restore fish habitats: A northwest Washington example. *Fisheries*. 18(4):18-22.

Due to increased landslide risk and sediment delivery from 30 to 40-year old forest roads in the Canyon Creek watershed, the roads were decommissioned by stabilizing fills, removing stream crossings, recontouring slopes, and reestablishing drainage patterns. The failure rate of the roads prior to recommissioning was 110 times higher than undisturbed forest and 6 times higher than logged forest. The average cost of decommissioning the roads was $3,500 per km where considerable earthmoving was necessary. Lower costs were associated with lesser earthmoving jobs; the highest costs resulted when fills at stream crossings or landings had to be removed. In contrast to unused roads not treated, decommissioned roads and landings were largely undamaged by rain on snow runoff that produced a 50-year flood in November 1989 and sustained little damage during rain on snow runoff in November 1990 that severely damaged main haul roads in northwest Washington. The authors concluded that reducing the landslide and failure rate of roads used in forestry operations would greatly improve conditions for salmonids.

Haupt, H.F. 1959. Road and slope characteristics affecting sediment movement from logging roads. *Journal of Forestry*. 57(5):329-332.

Two general means of controlling sediment runoff from logging roads are to (1) install culverts, paving, diversion trenches, etc. to carry water away to protected areas and (2) to reduce runoff from road surfaces and have enough natural slope distance below the road embankment to dissipate the eroded sediment. This study was conducted to determine the length of slope required to

dissipate this drainage from logging roads situated on steeply sloping granitic soils in southwestern Idaho. Road width, cross ditch interval, road cut height, road gradient, embankment slope length, slope obstruction index, and lower side slope gradient were studied on 75 sections of road. Each of these variables was analyzed mathematically for its contribution to sediment flow distance. Slope obstruction index, cross ditch interval squared, embankment slope length, and the product of the cross ditch interval and road gradient were found to influence sediment flow significantly. An equation using these variables was developed to determine the safe width of buffer strips necessary to protect lower roads or stream channels from sediment damage from road construction activities.

Helvey, J.D. 1981. *Flood frequencies and culvert sizes needed for small watersheds in the central Appalachians*. USDA Forest Service. General Technical Report NE-62. 7 pages.

This study builds on work done by Douglass (1974) in the Appalachians in North Carolina. Relationships for peak discharge, recurrence interval, drainage area, and elevation were necessary for the Central Appalachian area where hundreds of miles of logging road are built and thousands of culverts are installed each year. The objectives of the study were (1) to analyze streamflow data from forested watersheds in north-central West Virginia and compute flood frequencies for these areas and (2) to present culvert sizes necessary to carry the expected peak discharge for various drainage areas and computed flood frequencies. Seven watersheds in the Fernow Experimental Forest and two from the Clover Run area were studied in the Allegheny Mountain Range of the Appalachian Plateau. A table presents estimated culvert diameters needed to carry flood water from forested areas ranging from 30 to 100 acres and at recurrence intervals of 5 to 50 years.

Hewlett, J.D. 1978. *Forest water quality: An experiment in harvesting and regenerating a Piedmont forest*. School of Forest Resources, University of Georgia. 22 pages.

Two streams in Putnam County, Georgia, were selected to determine the effects that harvesting and regeneration have on water quality and flow in order to determine appropriate BMPs. Periodic samples were taken and flow recorded. The study indicated that 90% of the undesirable mass export of sediment resulted from poor access roads and streamside management.

Hornbeck, J.W. 1967. Clear cutting and the erosion hazard. *Northern Logger and Timber Processor*. 16:14-15,38-39,48.

Hornbeck dispels the myth that clearcutting forests creates soil erosion problems by tracing the soil erosion back to its source- poorly planned and constructed roads. He recommends setting high standards for roads, including following the contour of the land, using water bars, and building bridges at stream crossings.

Jones & Stokes Associates, Inc. 1973. *A method for regulating timber harvest and road construction activity for water quality protection in northern California, Volume II: Review and problem and annotated bibliography*. California State Water Resources Control Board.

The second volume of a two-part document reviews the problems associated with timber harvesting, road construction, and similar land-disturbing practices in northern coastal California. Volume II provides a good general discussion of the problems of erosion associated with forest activities and is intended primarily as background material for understanding the concepts and proposals discussed in Volume I.

Kidd, W.J., and J.N. Kochenderfer. 1973. Soil constraints on logging road construction on steep land east and west. *Journal of Forestry*. 71(5):284-286.

A review of road problems and solutions common to both the east and west coasts of the United States is presented. The problems briefly discussed include erosion, slumping, compaction, and drainage. The solutions mentioned are proper construction; use of culverts, ditches, and dips; and use of straw mulch to cover fill slopes.

Controlling erosion on skid trails is also mentioned briefly. The article is introductory, providing little technical information. It does list several related references applicable separately to steep lands west and east.

King, J.G. 1989. *Streamflow Responses to Road Building and Harvesting: A Comparison With the Equivalent Clearcut Area Procedure*. USDA Forest Service, Intermountain Research Station, Ogden, Utah. Research Paper INT-401. 13 pages.

Increases in annual streamflow and peak streamflows were determined on four small watersheds north-central Idaho after road building and timber harvest. These measured data were than compared to values predicted by the equivalent clearcut area procedure (ECA), a methodology commonly used to project hydrologic changes associated with timber management practices. The increase in average annual streamflow following harvesting and road building was much larger than predicted by the ECA procedure. The author notes that current procedures for estimating the hydrologic responses to timber removal of third to fifth order streams often ignore what may be hydrologically important modifications of low-order streams. Potential modifications to headwater basins should be considered when scheduling harvest entries and locating harvest units, especially when conditions are such that the stream system is likely to be sensitive to streamflow modification.

Kochenderfer, J.N., and J.D. Helvey. 1984. Soil losses from a "minimum-standard" truck road constructed in the Appalachians. In: *Mountain Logging Symposium Proceedings*. , June 5-7, 1984. P.A. Peters and J. Luckok (eds.). West Virginia University. pp. 215-225.

Soil losses from 11 road sections in the central Appalachians were measured. Nine of the sections were located on a newly constructed "minimum-standard" truck road, and two were on a graveled higher standard road. Pictures and data from this study are used to detail the differences in soil loss from the different road types.

Kochenderfer, J.N., and J.D. Helvey. 1987. Using gravel to reduce soil losses from minimum-standard forest roads. *Journal of Soil and Water Conservation*. 42(1):46-50.

This paper presents the results of a study conducted to compare the soil losses from graveled and ungraveled forest roads. Road sections were ungraveled, covered with 3 inches of clean gravel, or covered with 1 inch of crusher-run gravel. Average annual soil losses ranged from 47 tons/acre on ungraveled road sections to 6 tons/acre on sections surfaced with 3 inches of clean limestone gravel. After the first year, soil losses on graveled sections of minimum-standard roads were similar to those on the higher standard road. The authors recommend 3-inch clean gravel for new roads because larger gravel reduces the amount of soil exposed in roadbeds and provides a firm roadbed resistant to rutting. It also reduces the erosive force of overland flow across the roadbed by reducing runoff velocity.

Kochenderfer, J.N., G.W. Wendel, and H.C. Smith. 1984. *Cost of and soil loss on "minimum standard" forest truck roads constructed in the central Appalachians*. USDA Forest Service, Northeastern Forest Experiment Station. Research Paper NE-544. 8 pages.

A "minimum-standard" forest road is described, and cost data are presented for eight such roads constructed in the central Appalachians. The average cost per mile excluding gravel was $8, 119 (range $5,048 to $14,424). Soil loss was measured from several sections of a minimum-standard road. Traffic was regulated the first year and unrestricted the second year. Losses ranged from 44 tons per acre on ungraveled road sections to 5 tons per acre on graveled sections. Soil loss from the graveled sections on the minimum-standard road was about the same as that from higher standard graveled roads.

Krause, H.H. 1982. Effect of forest management practices on water quality—A review of Canadian studies. In: *Proceedings of the Canadian Hydrology Symposium - Associate Committee on Hydrology*. Fredericton, New Brunswick, June 14-15, 1982. National Research Council Canada, Canada. pp. 15-29.

The water quality effects of forest management practices are reviewed separately for the British Columbia Coastal Range, Rocky Mountains, Canadian shield, and Appalachian region. Sedimentation is a problem after road construction and occasionally after slash burning. Temperature increases are problematic at low altitudes in areas with warm summers. Changes in dissolved solids depend on the type of operation, forest cover, soils, and geologic substrate.

Lin, Y.L. 1987. Erosional effects of road construction in Pi-Lu Experimental Watershed. In: *Erosion and Sedimentation in the Pacific Rim, Proceedings of the Corvallis Symposium*. Oregon State University, August, 1987. R.L. Beschta (ed.). IAHS Publication No. 165, Corvallis, Oregon. pp. 267-268.

Some conservation forests in Taiwan are considered mature to overmature and in need of harvesting. This study was done to investigate the effects of the inevitable road construction that must accompany harvesting on sediment yield. Sediment was trapped in weirs for 4 years prior to road construction. A 4.5 m-wide contour road was built 2600 m above sea level. Local conditions in the area were as follows: average annual rainfall = 2256 mm, average slope = 78%, and black Tertiary slate bedrock. Road construction did not significantly change the average annual amount of sediment yield. Preconstruction yields at weirs were 129 and 113 m^3/yr. Postconstruction yields at the same weirs were 118 and 145 m^3/yr.

McCashion, J.D., and R.M. Rice. 1983. Erosion on logging roads in Northwestern California: How much is avoidable? *Journal of Forestry*. (1):23-26.

A study was made on 344 miles of logging roads in northwestern California to assess sources of erosion and the extent to which road-related erosion is avoidable. The authors found that 24% of the erosion measured on the logging roads could have been prevented by conventional engineering methods. The remaining 76% was caused by site conditions and choice of alignment. Forty percent of the total erosion on 30,300 acres of commercial timberland was derived from the road system and 60% from the harvested areas. The proportion of erosion from harvested areas is likely to increase over the years if harvested areas are reentered for subsequent harvests.

Megahan, W.F. 1981. Effects of silvicultural practices on erosion and sedimentation in the interior west-A case for sediment budgeting. In: *Interior West Watershed Management Symposium Proceedings*. D.M. Baumgartner (ed.). Washington State University, Cooperative Extension. pp. 169-182.

This paper is a review of research done in the interior western United States on the effects of timber removal, road construction, and fire on erosion and sedimentation. The author describes the processes of erosion-sedimentation, surface erosion, and mass erosion; the role of fire; and means to control erosion from roads. The author concentrates on erosion from roads because they have been found to be the greatest source of sediment discharge. The paper includes a figure of a sediment budget in forested watersheds and tables comparing the erosion control effectiveness of various management practices. Suggestions for future research are also discussed.

Megahan, W.F. 1987. Effects of forest roads on watershed function in mountainous areas. In: *Environmental Geotechnics and Problematic Soils and Rocks*. A.S. Balasubramaniam et al. (eds.). pp. 335-348.

A review of the effects of forest roads on watersheds in the interior western United States is presented. On-site effects include reduced forest productivity, increased runoff, and accelerated surface and mass erosion. Downstream effects include changes in stream flow rates, water

quality and channel characteristics. Erosion and sedimentation are the most common and damaging effects of road construction. Practices to reduce erosion and sedimentation are summarized into four principles. Megahan discusses these principles in detail.

Megahan, W.F. 1978. Erosion processes on steep granitic road fills in Central Idaho. *Soil Science Society of America Journal.* 42(2):350-357.

Thirty erosion plots were established to study erosion occurring on steep road fills constructed from granitic soil materials. The study, conducted in Idaho, determined that erosion was significantly reduced following mulch application and tree planting. Also, erosion in the plots was found to be highly dependent on wind and slope, and the particle size eroded during the summer months, but rapidly increased in October. Tables and figures that graphically demonstrate erosion rates and particle size change are included.

Megahan, W.F. 1986. *Recent studies on erosion and its control on forest lands in the United States.*

Recent research on erosion and erosion control conducted in the United States is reviewed. The effects of road construction, forest fire, and timber harvest are considered in relation to surface and mass erosion. Surface erosion has been predicted by using the Universal Soil Loss Equation (USLE), locally gathered data, and detailed mathematical models. The USLE is useful only when considering areas with gentle terrain. Empirical predictions are commonly used and mathematical models show promise. Mass erosion hazards are defined using landslide inventories from specific areas, statistical approaches, and stability analyses of given sites. The advantages and disadvantages of these approaches are discussed. The management applications of these approaches are discussed as well.

Megahan, W.F., and W.J. Kidd. 1972. *Effect of logging roads on sediment production rates in the Idaho Batholith.* USDA Forest Service. Research Paper INT-123. 14 pages.

Effects of logging road construction on sediment production rates were studied on small, ephemeral drainages in the Idaho Batholith, a large area of granitic rock characterized by steep slopes and highly erodible soils. For the 6-year study period, about 30% of the total accelerated sediment production from roads was caused by surface erosion; the remainder resulted from mass erosion. Surface erosion on roads decreased rapidly with time after extremely high initial rates. A mass failure of a road fill slope occurred about 4 years after construction, when surface erosion had fallen to a low rate. The sediment production rate attributed to erosion within the area disturbed by road construction averaged 770 times greater (220 due to surface erosion and 550 to mass erosion) than that for similar, undisturbed lands in the vicinity. Results suggest three guides to control surface erosion in the area: (1) erosion control measures should be applied immediately after road construction; (2) treatments must protect the soil surface until vegetation becomes established; and (3) downslope barriers should be used effectively to delay and reduce downslope movement of sediment.

Megahan, W.F., and P.N. King. 1985. Identification of critical areas of forest lands for control of nonpoint sources of pollution. *Environmental Management.* 9(1):7-18.

The authors present a critical areas approach to controlling NPS pollution from forestlands. Critical areas include sites with high mass and surface erosion hazards, overland flow areas, and the riparian zone. Most NPS pollution problems on forestlands can be controlled by identifying these critical areas and carefully planning their management. The discussion of these three critical areas is accompanied by guidelines for identifying them and examples of land use constraints that might be applied; for instance, limiting activities causing severe soil disturbance and road construction requiring large cutslopes where surface erosion hazards are high.

Megahan, W.F., S.B. Monsen, and M.D. Wilson. 1991. Probability of sediment yields from surface erosion on granitic roadfills in Idaho. *Journal of Environmental Quality*. 20(1):53-60.

Field plots were used to measure sediment yield from granitic roadfills on forest roads in the mountains of Idaho. Three years of data were collected from plots with slopes ranging from 34 to 41 degrees. Of the site-specific factors analyzed, only ground cover density and rainfall erosivity (of the USLE) were statistically significant. Using the prediction equation from the regression analysis and the data, a Monte Carlo simulation model was used to determine the probability of the occurrence of sediment yield from granitic roadfills under various ground cover conditions. A total of 5000 estimates of sediment yield were made using 10 ground cover densities ranging from 5 to 90 %. The authors presented this method as a tool for predicting soil loss from forest roads in the highly erodible Idaho batholith. This approach may help alleviate some of the cumulative downstream effects of sedimentation from roads.

NCASI. 1980. *Research and field investigation of the impact of southern forestry management practices on receiving water quality and utility*. National Council of the Paper Industry for Air and Stream Improvement. Technical Bulletin No. 337.

This is an assembly of papers and abstracts of presentations made at the 1980 NCASI Southern Regional Meeting. The papers describe work under way at universities, individual company programs, programs in the South being conducted by USDA Forest Service, and aquatic biology. Sample titles include: Regional Road Project-Management Options to Control Erosion; Assessment of NPS Pollution from Intensive Forest Practices in the South Central Region, Texas; Demonstration of Sensitive Area Mechanical Site Preparation; The Use of Macroinvertebrates as Indicators of Stream Quality Changes; and Report on Ongoing Programs and Information Needs Relating to Southern Forest Practices and Water Quality.

Nutter, W.L. 1982. Water quality and yield from the intensively managed forest. In: *Proceedings of the Society of American Foresters*. pp. 89-93.

A review of the impacts of intensive forest management, including timber harvest, site preparation, road construction, and forest fertilization, on water yield and water quality is presented. This short review presents an overview of the impacts of intensive forestry operations.

Patric, J.H. 1978. Harvesting effects on soil and water in the eastern hardwood forest. *Southern Journal of Applied Forestry*. 2(3):66-73.

For the eastern United States, there is overwhelming evidence that neither the productivity of forest soil nor the quality of forest water are substantially lessened during or after responsibly managed harvest of wood products. However, careless practices such as dragging logs across the forest floor (which disrupts organic cover) building more roads than are necessary, operating machinery in streams, and locating roads near streams damage both forest productivity and water quality. Proper management of forest roads is the key to minimizing the adverse impacts of forest activities. Forest roads cause little adverse effect on soil or water given proper location, drainage, traffic control, and maintenance. This paper provides an overall qualitative analysis of the problems associated with timber harvesting.

Reid, L.M., and T. Dunne. 1984. Sediment production from forest road surfaces. *Water Resources Research*. 20(11):1753-1761.

This paper presents the results of a study conducted to determine the runoff rates and sediment yields from different road segments subjected to a variety of traffic levels. The authors found that heavily used roads contributed 130 times as much sediment as an abandoned road. A paved road, where cut slopes and ditches were the only sources of sediment, yielded less than 1% as much sediment as a heavily used road

with a gravel surface. The study was conducted in the Cascade Mountains in eastern Washington State. Complete data on the roads used in the study are provided.

Rice, R.M., J.S. Rothacher, and W.F. Megahan. 1972. Erosional consequences of timber harvesting: An appraisal. In: *Watersheds in Transition Symposium Proceedings*. Urbana, Illinois. American Water Resources Association. pp. 321-329.

This paper summarizes current (1972) understanding of the effects of timber harvesting on erosion. Rates of erosion on mountain watersheds vary widely, but the relative importance of different types of erosion and the consequences of disturbance remain fairly consistent. The authors suggest that a number of conclusions are therefore valid for most circumstances. Among these conclusions are: sediment production declines rapidly following disturbance; cutting of trees does not significantly increase erosion, but clearcutting on steep unstable slopes may lead to increased mass erosion; accelerated erosion is a possible undesirable side effect of the use of fire in conjunction with logging; the road system built for timber harvesting far overshadows logging or fire as a cause of increased erosion; and potentially hazardous areas can be identified in advance of the timber harvest. Tables comparing the amount of soil disturbed by different logging practices and the amount of soil eroded from logging roads in different logging areas are provided.

Ryan, S.E., and G.E. Grant. 1991. Downstream effects of timber harvesting on channel morphology in Elk River Basin, Oregon. *Journal of Environmental Quality*. 20(1):60-72.

Downstream effects, a type of cumulative watershed effect, were identified using changes in the width and distribution of open riparian canopies measured from aerial photography taken between 1956 and 1979 in Elk River Basin, southwest Oregon. A causal link between downstream changes in channel morphology and upslope forestry activities was assumed where open reaches extended continuously downstream from clearcuts and roads or the timing and pattern of opening downstream varied in direct relation to the intensity of upslope forestry activities. Open riparian canopies were observed in first- through fifth-order channels, though only 11% of open reaches in low-order channels were spatially connected to open reaches in higher order channels. Open canopies in higher-order channels were restricted mainly to wide and low-gradient channel reaches. Open canopies in low-order tributaries were attributed to landslides and surface erosion generated from clearcuts and roads.

Stuart, G., and J. Vowell. 1989. Forest practices for controlling nonpoint source pollution. In: *National Nonpoint Conference*. St. Louis, Missouri, April 23-26, 1989.

This paper presents the various best management practices that may be used to prevent adverse water quality conditions or excessive erosion from forest road construction. General information on forest road construction and maintenance NPS controls is provided.

Swanson, F.J., and C.T. Dyrness. 1975. Impact of clearcutting and road construction on soil erosion by landslides in the western Cascade Range, Oregon. *Geology*. 3(7):393-396.

Susceptibility to erosion by rapid soil movement differed greatly between two zones of the H.J. Andrews Experimental Forest. A stable zone occurs where terrain is underlain by lava-flow bedrock. Only two small road-related slides have occurred there since 1950. An unstable zone underlain by altered volcaniclastic rock has had 139 slides in the same period. Slide erosion has been 30 times greater along road rights-of-way than on forested sites in the unstable zone.

Swift, L.W., Jr. 1986. Filter strip widths for forest roads in the southern Appalachians. *Southern Journal of Applied Forestry*. 10(1):27-34.

The objectives of this study were (1) to compare filter strip standards to field measurements of sediment movement in the southern Appalachian Mountains and (2) to determine the mitigating influences of mulch or grass on fill slopes and of obstructions to flow within filter strips. The author found that filter strip standards currently applied to forest roads in the southern Appalachian Mountains may specify greater widths than are necessary with prevailing construction practices. Measurements of the distance that sediment traveled downslope below newly constructed roads were less than previously reported. Distances were notably less if natural obstructions existed on the forest floor, brush barriers were at the edge of the right- of-way, road fills were grass-covered, or roads were outsloped and drained by broad-based dips. Filter strip slope distance in feet can be calculated as 43 + 1.39(slope %). A table of minimum filter strip widths for graveled forest roads is presented. Factors influencing sediment movement downslope include slope distance, natural vegetative cover, forest litter, presence of brush barriers, and whether sediment is being carried by diffuse flow or flow associated with a storm water discharge by a culvert.

Swift, L.W., Jr. 1984. Gravel and grass surfacing reduces soil loss from mountain roads. *Forest Science*. 30(3):657-670.

Soil loss from forest roads was measured on two soils in the southern Appalachian Mountains. Losses from a roadbed without surfacing (bare soil) and later with grass cover were compared with those from roadbeds surfaced with different types and amounts of rock. In the first 2 months after construction in a deep sandy loam, soil loss rates were eight times greater from the bare soil site than from roadbeds with 15-20 cm of gravel. Cumulative loss during the first 8 months after construction was over 200 tons/ha from the bare soil roadbed and less than 35 tons/ha from roadbeds surfaced with graded crushed rock or large washed stone. Losses rose as logging traffic began and road maintenance disturbed stabilized road surfaces and contributed to losses.

Swift, L.W., Jr. 1984. Soil losses from roadbeds and cut and fill slopes in the southern Appalachian mountains. *Southern Journal of Applied Forestry*. 8(4):209-215.

The differences in soil loss from road cut, fill, and roadbed surfaces were presented. Losses were greatest on cut (36% to 71%) and fill slopes (16% to 33%) and least on the roadbed surface (13% to 30%). Gravel placedon roadbeds reduced losses to about 20% of the initial rates, and established grass cover reduced losses to 1-3% of initial losses. The authors recommend that soil losses should be reduced by protecting disturbed surfaces and using storm water control BMPs. The article does not present comparative data for soil loss reduction attributable to various BMPs, but does recommend numerous BMPs.

Trettin, C.C., and P.J. Sheets. *Impacts of forest drainage on water quality*. Center for Intensive Forestry in Northern Regions. pp. 231-239.

The effects of a prescription-type forest drainage system on water quality in the upper peninsula of Michigan were evaluated. No significant differences in calcium, total nitrogen, pH, suspended sediment, or water temperature were observed between drainage water and river samples. Iron and magnesium concentrations were slightly higher in the drainage water. The drainage system appeared to serve its purpose by draining the high water table and not causing appreciable water quality impacts. The authors suggest following some basic best management practices, such as not driving across ditches and properly installing ditches, to prevent water quality impacts.

Trimble, G.R., and S. Weitzman. 1953. Soil erosion on logging roads. *Soil Science Society of America Proceedings*. 17:152-154.

Sample skid roads were studied before, during, and after experimental logging operations on the

Fernow Experimental Forest in West Virginia. Erosion was related to grade, length of slope, intensity of use, soil, vegetation, and climatic factors. Degree of erosion was determined for different skid road conditions. Proper road location, road construction techniques, road maintenance, and use are important to reducing erosion from forest roads. A table of recommended spacing between water bars to control erosion as a function of grade is presented.

Weitzman, S., and G.R. Trimble, Jr. 1952. Skid-road erosion can be reduced. *Journal of Soil and Water Conservation*. 7:122-124.

The preliminary results of a skid road experiment are presented. This experiment had four study sites with different qualities of skid roads. The "high-quality" road site had the fewest roads on the smallest slopes. The "good," "fair," and "poor" sites had progressively more road area and the roads ran over steeper slopes. The authors measured erosion rates off the sites and found significantly less erosion as the road quality increased.

Wright, K.A., K.H. Sendek, R.M. Rice, and R.B. Thomas. 1990. Logging effects on streamflow: Storm runoff at Casper Creek on Northwestern California. *Water Resources Research*. 26(7):1657- 1667.

The effects of road building and selective tractor harvesting on storm runoff were assessed for a small (424-ha) coastal watershed in northern California. Lag time (the time required for 50% of the input into the watershed to produce 50% of the output) and peak flows were analyzed. After road building and logging, lag time was decreased approximately 1.5 hours, and very small storm volumes and peak flows increased 132% and 111%, respectively. Storm volumes and peaks of large storms were not significantly increased by roads or logging. The authors conclude that in a rain-dominated hydrologic environment logging and forest road construction are not likely to change the flow regime of a stream adversely. These results conflict with others reported (Harr et al., 1975). The authors of this study compared the results of the two studies and speculated that the lack of large storm flows in the Harr study may account for the conflicting results.

Yoho, N.S. 1980. Forest management and sediment production in the south-A review. *Southern Journal of Applied Forestry*. 4(1):27-36.

The author reviews sediment yields from various forestry activities, finding that forest practices commonly result in small short-term increases and that significant increases are limited to practices conducted with heavy machinery. Yields from similar sites receiving the same type of disturbance vary by several hundred percent, and sediment yields are reduced when channel disturbance is avoided. Careful planning, design, construction, use, and maintenance of forest roads and skid trails achieve the greatest reductions. The author provides comparative soil loss data for a variety of land uses: less than 0.1 ton/acre/yr (undisturbed mixed forest, forest thinning); 0.1 - 1.0 ton/acre/yr (carefully clearcut forest, abandoned fields); 1.0 - 10.0 tons/acre/yr (annually burned forest, mechanical site preparation); 10 - 100 tons/acre/yr (carelessly cultivated or steep sloped fields); and 100 or more tons/acre/yr (active construction, gullies).

Adams, T.E., and R.M. Rice. 1989. Erosion and sedimentation concerns related to hardwood management in California. *Western Journal of Applied Forestry*. 4(1):31-33.

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Aubertin, G.M., and J.H. Patric. 1974. Water quality after clearcutting a small watershed in West Virginia. *Journal of Environmental Quality*. 3:243-249.

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Douglass, J.E. 1974. *Flood frequencies and bridge and culvert sizes for forested mountains in North Carolina*. USDA Forest Service. General Technical Report SE-4. 21 pages.

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Dyrness, C.T. 1967. *Mass soil movements in the H.J. Andrews Experimental Forest*. USDA Forest Service, Pacific Northwest Forest and Range Experiment Station, Portland, Oregon. Research Paper PNW-42. 12 pages.

Farrington, R.L., and M.E. Savina. 1977. *Off-site effects of roads and clearcut units on slope stability and stream channels: Fox planning unit*. Unpublished report. USDA Forest Service, Six Rivers National Forest. 76 pages.

Fredricksen, R.L. 1963. Sedimentation after logging road construction in a small western Oregon watershed. In: *Proceedings of the Federal Inter-Agency Sedimentation Conference*. U.S. Department of Agriculture, Miscellaneous Publication 970.

Fredriksen, R.L. 1963. *A case history of a mud and rock slide on an experimental watershed*. Research Note PNW-1. USDA Forest Service, Pacific Northwest Forest and Range Experiment Station. 4 pages.

Fredriksen, R.L. 1970. *Erosion and sedimentation after logging road construction in a small western oregon watershed*. Research Paper PNW-104. USDA Forest Service, Pacific Northwest Forest and Range Experiment Station. 15 pages.

Haupt, H.F. 1959. *A method for controlling sediment from logging roads*. USDA Forest

Service, Intermountain Forest and Range Experiment Station. Miscellaneous Publication 22. 22 pages.

Haupt, H.F., H.C. Rickard, and L.E. Finn. 1963. *Effect of severe rainstorms on insloped and outsloped roads*. USDA Forest Service. Research Note INT-1. 8 pages.

Krygier, J.T., and R.D. Harr. 1972. *Changes in storm hydrographs due to road building and clearcut logging on coastal watersheds in Oregon*. Water Resources Research Institute, Oregon State University, Corvallis, Oregon. 59 pages.

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BMPs AND SPECIFICATIONS

Anderson, L., and M. Bryant. 1980. *Fish passage at road crossings: An annotated bibliography*. USDA Forest Service, Pacific Northwest Forest and Range Experiment Station. General Technical Report PNW-117.

This annotated bibliography was prepared as a guide to the literature available on problems associated with fish passage at road crossings. It reviews 45 articles covering bridge installations, culvert installations, design criteria, economics, evaluations of installations, fish passage (swimming speeds and rates of passage, light, criteria, and velocities), hydraulic evaluation, and special applications (arch culverts, baffles, fishways, slot orifices, and other adaptations). Two bibliographies are also reviewed. The listing is intended to cover a broad spectrum of literature of interest to field biologists, engineers, and land managers.

Bauer, S.B., G.W. Harvey, and T.A. Burton. Idaho 319 Nonpoint source program summary: Forest roads inventory and stabilization report. In: *Proceedings of Technical Workshop on Sediments*. Corvallis, Oregon, February 3-7, 1992. U.S. Environmental Protection Agency and USDA Forest Service.

An inventory of forest road stability was conducted in the Idaho Clearwater basin. Roads causing the greatest impact on stream water quality were identified and priority stream segments and roads were selected based on the results of an empirical sedimentation model. The model simulated sediment yields using the following mitigation measures: full vegetation of fill slopes; full vegetation of cut slopes; cut slope gradient decreased 10%; cut slope gradient decreased 20%; road tread graveled; and road tread paved. In general, rehabilitation of cut slopes and relocation away from streams were the most effective measures for reducing sediment.

Beasley, R.S., E.L. Miller, and S.C. Gough. 1984. Forest road erosion in the Ouachita mountains. In: *Mountain Logging Symposium Proceedings*. West Virginia University, June 5-7, 1984. P.A. Peters and J. Luckok (eds.), (eds.) pp. 202-213.

The quantity and deposition of sediments eroded from four segments of an established forest road in the Ouachita Mountains of Arkansas were determined for each storm event that occurred between June 1, 1982, and May 31, 1983. Measurements included total discharge volume, discharge rates and peaks, deposited sediment, suspended sediment, and downslope movement of deposited sediments. Of 36 storm events, one storm (13 inches in 24 hours) accounted for about half of the total annual sediment yield. Most of the sediment was deposited a short distance downslope of the road. The results of this study may be very useful to managers of sites similar to those used in the study.

Berglund, E.R. 1976. *Seeding to control erosion along forest roads*. Oregon State University Extension Service, Circular 885. 19 pages.

Some accelerated erosion from forestland use is inevitable, but considerable loss of soil can be curbed by controlling erosion along forest roadsides. This study discusses soil erosion control techniques. One such control techniques

is to seed grasses and legumes to revegetate bare soil surfaces resulting from road construction. Other control techniques are reviewed as part of a revegetation erosion control program.

Burroughs, E.R. Jr., and J.G. King. 1989. *Reduction of soil erosion on forest roads*. USDA Forest Service, Intermountain Research Station. General Technical Report INT-264. 21 pages.

This document presents the expected reduction in surface erosion from selected treatments applied to forest road traveled ways, cutslopes, fillslopes, and ditches. Estimated erosion reduction in expressed as functions of ground cover, slope gradient, and soil properties whenever possible. A procedure is provided to select rock riprap size for protection of road ditches.

Case, A.B., and D.A. Rowe. 1978. *Environmental guidelines for resource road construction*. Canada Forestry Service, Fisheries and Environment, Newfoundland Forest Research Center, Information Report N-X-162. 41 pages.

Information on the effects of forest road construction on aquatic and terrestrial environments is presented in this document. In addition, construction guidelines are presented to aid in preventing or minimizing environmental disturbances associated with road construction. The report is designed principally for resource road development in Newfoundland and Labrador. While the focus of the paper is on protecting important habitat (e.g., fish spawning areas, moose yards, waterfowl breeding areas) generally and is not specific to forestry activities, the recommended guidelines are well outlined and include recommended buffer widths and other technical guidance. A table lists environmental effects associated with road construction activities.

Cook, M.J., and J.G. King. 1983. *Construction cost and erosion control effectiveness of filter windrows on fill slopes*. USDA Forest Service, Intermountain Forest and Range Experiment Station, Ogden, UT. Research Note INT-335. 5 pages.

This paper presents information on the cost and effectiveness of filter windrows (slash) for reducing sediment loss from road fill slopes. The authors estimated conservatively that the windrows had a trapping efficiency of 75 to 85% based on measurements of windrowed and non windrowed fill slopes. The construction cost was $59/100 feet of windrowed slope. The authors recommend the use of filter windrows because they are relatively inexpensive, efficient, and can be constructed simultaneous with road construction for immediate protection of water resources.

Cubbage, F.W., and C.E. DeForest. 1991. BMPs and harvesting regulations in the South. In: *Forestry and the Environment...Engineering Solutions*. New Orleans, Louisiana, June 4-6, 1991. American Society of Agricultural Engineers.

This paper provides an overview of best management practices that apply to forestry practices, including road construction, timber harvest, stream crossing, streamside management zones, and maintenance and retiring of structures. This paper presents basic information about the types of BMPs that may be used. The paper introduces regulatory trends in the states of Florida, North Carolina, West Virginia, and Maryland, as well as regulatory trends in forested wetlands.

Dunford, E.G. 1962. Logging methods in relation to stream flow and erosion. *5th World Forestry Congress, 1960 Proceedings*. 3: 1703-1708.

This paper provides a general description of logging operations and discusses the effects of logging on soil properties (compaction and erosion) and the importance of the area disturbed. The effects of logging on streams, including temperature changes, increased sediment loads, and alteration of general hydraulic characteristics,

are discussed. Remedial measures (prelogging plans, proper location and maintenance of logging roads, and providing proper dispersion of surface runoff) are seen as essential to proper environmental forest protection.

Eubanks, S.T. 1980. Full-restoration method for closing spur roads. *Journal of Forestry*. 78:644-645.

Restoration of a temporary forest road should meet all or most of the following objectives: (1) reduce or eliminate soil erosion; (2) reduce the cost of maintenance when the road is not in use; (3) provide forage for cattle or big game; (4) reestablish the natural appearance of the land; and (5) prevent or discourage motor vehicle use. The most common method of restoration-scarification, waterbarring, and revegetation - is effective in meeting objectives 1-3, but not 4 and 5. This article describes a restoration method that has proven effective in central Washington State that meets all five objectives. It consists of reshaping the takeoff and a predetermined length of roadbed to original ground profile, followed by revegetation. Then the usual scarification, etc. are done. This full restoration method should be taken into consideration at the original planning stage of road construction. Experience in the Tieton Ranger District in Washington has shown that full restoration requires approximately the same amount of time and effort as original construction, and costs are developed accordingly.

Gebhards, S., and J. Fisher. 1972. *Fish passage and culvert installations*. Idaho Fish and Game Department.

Idaho law provides that anyone proposing to alter a stream channel must first obtain authority to do so from the Idaho Department of Water Administration. The Idaho Department of Fish and Game reviews applications and ensures that installations will not interfere with the passage or habitat of any species of fish. This document reviews the passage and spawning requirements of important fish species in Idaho and culvert designs that inhibit passage and spawning. Culvert design and installation that ensure successful fish passage are then reviewed. Important design features include gradients that are as flat as possible, water velocities that do not prevent passage, minimum water depth for the species involved, and minimum clear width of baffled sections. Fishways should be provided where necessary due to physical limitations. The important factors to consider are reviewed here and should be adapted to specific species and conditions for other parts of the country.

Groves, F.D., R.K. Baughman, M.E. Hundley, and R.L. Sherman. 1979. Timber haul road construction in southern mountains. *Southern Journal of Applied Forestry*. 3(1):68-76.

A discussion of the factors to be considered when planning and building forest roads. Road construction standards (grade, dimensions, stabilization, cut and fill, and drainage structures) applicable to West Virginia and costs of road construction in the area are presented. Costs range from $5,000 to $35,000 per mile of completed road, depending on steepness and difficulty of terrain.

Hartung, R.E., and J.M. Kress. 1977. *Woodlands of the Northeast: Erosion and sediment control guides*. USDA Soil Conservation Service, Northeast Technical Service Center and Forest Service, Northeast Area S and PF. 26 pages.

This is a guidance manual for forestry activities in the northeastern United States. Extensive measures for erosion and sediment control are described, and structural design criteria are provided. Water control on roads, seeding of roadbanks, building of logging road bridges, and the need for adequate filter strips are described.

Haupt, H.F. 1959. *A method for controlling sediment from logging roads*. USDA Forest Service, Intermountain Forest and Range Experiment Station. Miscellaneous Publication 22. 22 pages.

This publication describes a method of protecting downslopes, downhill roads, and stream channels from the damaging effects of sediment that originates primarily from roads high on slopes. Information used to develop the method was collected in 1956 from an experimental area on the Little Owl Creek tributary of the Boise River. Site characteristics amenable to control or alteration by a road planner selected for the development of a multiple regression equation relating these characteristics to sediment flow. The site characteristics chosen were road width, cross ditch interval, road cut height, road gradient, embankment slope length, slope obstruction index, and lower side slope gradient. The application of the equation that was developed for the experimental watershed is fully detailed. Tables list specifications for the chosen site characteristics for a full range of site conditions.

Helvey, J.D. 1981. *Flood frequencies and culvert sizes needed for small watersheds in the central Appalachians*. USDA Forest Service. General Technical Report NE-62. 7 pages.

This study builds on work done by Douglass (1974) in the Appalachians in North Carolina. Relationships for peak discharge, recurrence interval, drainage area, and elevation were necessary for the Central Appalachian area where hundreds of miles of logging road are built and thousands of culverts are installed each year. The objectives of the study were (1) to analyze streamflow data from forested watersheds in north-central West Virginia and compute flood frequencies for these areas and (2) to present culvert sizes necessary to carry the expected peak discharge for various drainage areas and computed flood frequencies. Seven watersheds in the Fernow Experimental Forest and two from the Clover Run area were studied in the Allegheny Mountain Range of the Appalachian Plateau. A table presents estimated culvert diameters needed to carry flood water from forested areas ranging from 30 to 100 acres and at recurrence intervals of 5 to 50 years.

Huff, J.L., and E.L. Deal. 1982. *Forestry and water quality in North Carolina: A voluntary program for the control of nonpoint sources of pollution from logging and silvicultural activities*. North Carolina Agricultural Extension Service and North Carolina State University. 8 pages.

This extension service publication discusses BMPs for forest road construction to control erosion. General headings include planning logging roads, constructing logging roads, harvesting, maintenance of logging roads, maintenance of logging roads after logging, and regenerating a new stand. BMPs are listed and briefly discussed under each heading.

Hynson, J., P. Adams, S. Tibbetts, and R. Darnell. 1982. *Handbook for protection of fish and wildlife from construction of farm and forest roads*. U.S. Fish and Wildlife Service. FWS/OBS-82/18. 153 pages.

One requirement for an exemption from the requirement for a section 404 (CWA) permit is that farm and forest roads be constructed and maintained in accordance with acceptable BMPs. This handbook describes 54 such BMPs for planning road and facility layout and design, erosion control, construction and maintenance operations, and restoration to natural conditions. The BMPs are evaluated as to their environmental, institutional, technical, and economic effectiveness. A discussion of the purpose, description, performance, and limitations is also provided for each BMP, and an approach is developed that guides handbook users in the selection of BMPs applicable to site- specific conditions.

Kidd, W.J., and J.N. Kochenderfer. 1973. Soil constraints on logging road construction on steep land east and west. *Journal of Forestry*. 71(5):284-286.

A review of road problems and solutions common to both the east and west coasts of the United States is presented. The problems briefly discussed include erosion, slumping, compaction, and drainage. The solutions mentioned are proper construction; use of culverts, ditches, and dips; and use of straw mulch to cover fill slopes. Controlling erosion on skid trails is also mentioned briefly. The article is introductory, providing little technical information. It does list several related references applicable separately to steep lands west and east.

Kochenderfer, J.N. 1970. *Erosion control on logging roads in the Appalachians*. USDA Forest Service, Northeastern Forest Experiment Station. Research Paper NE-158. 28 pages.

This general Forest Service report discusses problems related to erosion and sedimentation from forest roads. Information on planning the road system, logging road location, drainage, maintenance, traffic regulation, care after logging, and seeding is included. Common BMPs (e.g., culverts, filter strips, stream crossings) are discussed. Tables provide specifications for distance between water bars and dips versus road grade, and for culvert diameters required for drainage areas in the southern Appalachian forests. The list of references is not extensive.

Kochenderfer, J.N., and J.D. Helvey. 1987. Using gravel to reduce soil losses from minimum-standard forest roads. *Journal of Soil and Water Conservation*. 42(1):46-50.

This paper presents the results of a study conducted to compare the soil losses from graveled and ungraveled forest roads. Road sections were ungraveled, covered with 3 inches of clean gravel, or covered with 1 inch of crusher-run gravel. Average annual soil losses ranged from 47 tons/acre on ungraveled road sections to 6 tons/acre on sections surfaced with 3 inches of clean limestone gravel. After the first year, soil losses on graveled sections of minimum-standard roads were similar to those on the higher standard road. The authors recommend 3-inch clean gravel for new roads because larger gravel reduces the amount of soil exposed in roadbeds and provides a firm roadbed resistant to rutting. It also reduces the erosive force of overland flow across the roadbed by reducing runoff velocity.

Lantz, R.L. 1971. *Guidelines for stream protection in logging operations*. Oregon State Game Commission, Portland, Oregon. 29 pages.

This report reviews why certain logging practices in the West Coast Douglas fir region are more desirable than others for protecting fish habitat and water quality. Streams can be protected to a large extent by (1) keeping streamside vegetation intact and (2) taking precautions to eliminate or minimize soil disturbance and erosion, particularly that resulting from roads. The report emphasizes the need to change or eliminate some traditional logging practices due to the resource conflicts between and interdependence of fisheries and timber production. The report addresses the freshwater requirements of salmon and trout, the importance of protecting stream habitat, and forestry practices that can be used to protect fish habitat. The author discusses streamside management areas and road location, construction, and maintenance practices.

Lotspeich, F.B. 1971. *Environmental guidelines for road construction in Alaska*. Environmental Protection Agency, Alaska Water Laboratory College. Report No. 1610 GOI.

This report compiles and describes the BMPs required to ensure environmental protection during road construction under cold climate conditions. General topics are route selection, engineering design, construction activities, maintenance, and problems of the true arctic. Numerous figures illustrate BMPs. An appendix

includes the National Environmental Policy Act (NEPA) of 1969, Executive Order 11514 (Protection and Enhancement of Environmental Quality), and a series of instructional memorandums by the U.S. Department of Transportation dealing with highway construction in response to EO 11514.

McClimans, R.J. 1980. Best management practices for forestry activities. In: *Watershed Management*. Boise, Idaho, July 21-23, 1980. C.W. Johnson (ed.). American Society of Civil Engineers, Irrigation and Drainage Division, Committee on Watershed Management. pp. 694-705.

This paper defines critical combinations of site conditions for which BMPs are needed to minimize adverse impacts on soil and water resources. The document also includes assessment methodologies, as well as charts and graphs for the selection and application of appropriate BMPs. Forest practices are grouped according to their capacity to cause water pollution, the nature of the more commonly applied BMPs to control pollution, and site considerations. Guides, based on slope of land and distance from water, are provided to determine whether a particular BMP is necessary for the particular group of activities. Graphs developed to determine BMP applicability are presented, and the selected BMPs are discussed for each group of forest activities. Specifications for some BMPs are also presented.

Megahan, W.F. 1978. Erosion processes on steep granitic road fills in Central Idaho. *Soil Science Society of America Journal*. 42(2):350-357.

Thirty erosion plots were established to study erosion occurring on steep road fills constructed from granitic soil materials. The study, conducted in Idaho, determined that erosion was significantly reduced following mulch application and tree planting. Also, erosion in the plots was found to be highly dependent on wind and slope, and the particle size eroded during the summer months, but rapidly increased in October. Tables and figures that graphically demonstrate erosion rates and particle size change are included.

Megahan, W.F., and W.J. Kidd. 1972. *Effect of logging roads on sediment production rates in the Idaho Batholith*. USDA Forest Service. Research Paper INT-123. 14 pages.

Effects of logging road construction on sediment production rates were studied on small, ephemeral drainages in the Idaho Batholith, a large area of granitic rock characterized by steep slopes and highly erodible soils. For the 6-year study period, about 30% of the total accelerated sediment production from roads was caused by surface erosion; the remainder resulted from mass erosion. Surface erosion on roads decreased rapidly with time after extremely high initial rates. A mass failure of a road fill slope occurred about 4 years after construction, when surface erosion had fallen to a low rate. The sediment production rate attributed to erosion within the area disturbed by road construction averaged 770 times greater (220 due to surface erosion and 550 to mass erosion) than that for similar, undisturbed lands in the vicinity. Results suggest three guides to control surface erosion in the area: (1) erosion control measures should be applied immediately after road construction; (2) treatments must protect the soil surface until vegetation becomes established; and (3) downslope barriers should be used effectively to delay and reduce downslope movement of sediment.

Mumma, J.W., and J.S. Tixier. 1988. *Soil and water conservation practices handbook*. USDA Forest Service R-1 Missoula, Montana and R-4, Ogden, Utah. Handbook 2509.22.

The primary purpose of this document is to present BMPs for use in minimizing adverse impacts from forestry practices. It describes the application, monitoring, evaluation, and adjustment of these practices. Examples of BMPs that have been field-tested and are known to provide protection under specific circumstances are also presented. This general forestry BMP

document includes definitions and the purposes for each practice.

Neuman, L. 1987. Silviculture and best management practices. In: *Erosion Control: You're Gambling Without it*. International Erosion Control Association. pp. 145-155.

This report presents information on the types of impairments typical of forestry activities and provides information on management techniques that may be used to minimize the impacts. The practices presented in this paper include timber harvesting, site preparation, and road construction and drainage. Erodibility factors, assigned to Florida soils by the SCS, and slope determine a site's sensitivity to erosion, and the paper presents site sensitivity classes for Florida soils. This classification is related to suggested BMP usage and implementation. Many useful tables of specifications for when and how to construct the practices are presented.

Ontario Ministry of Natural Resources. 1990. *Environmental guidelines for access roads and water crossings*. Queen's Printer for Ontario, Ontario, Canada. 63 pages.

This document presents the best management practices for road construction suggested for use by the Ontario Ministry of Natural Resources. Information on the design criteria, construction, maintenance, and retirement of the structures is presented. The document provides many pictures and explains each structure and usage in detail.

Oregon State University. 1984. *Forest roads conference*. Corvallis, Oregon, May 1-3, 1984. Oregon State University, College of Forestry.

This document is the proceedings of a forest roads conference held in May 1984. Topics included in the document include road planning, road design, road drainage, road construction, and road maintenance. This document provides a significant amount of data and information on forest road design and construction.

Packer, P.E. 1967. Criteria for designing and locating logging roads to control sedimentation. *Forest Science*. 13:2-18.

A study was conducted by the Intermountain Forest and Range Experiment Station in the northern Rocky Mountains to develop specific criteria for locating and designing secondary logging roads. The separate effects of a number of watershed and road characteristics that can influence erosion of forest roads were studied mathematically. Packer found that the following factors were important in determining the spacing between cross drains to prevent rills from eroding deeper than 1 inch: road grade, road surface soil aggregates, topographic position, exposure, and upper slope steepness. A table presents recommended spacings for road grades and soil types. The distance sediment moves downslope from logging roads was found to depend most on obstruction spacing and kind of obstruction, undisturbed slope soil aggregates, cross drain spacing intervals, distance to first obstruction, age of roads, and fill slope cover density. A table presents recommended protective strip widths based on obstruction spacing and type of obstruction. Packer discusses site characteristics that were not considered in this study that could have a significant effect on erosion but for which data were insufficient to analyze effects.

Pope, P.E. 1978. Forestry and water quality: Pollution control practices. *Forestry and Natural Resources*. Purdue University Cooperative Extension Services. FNR 88. 6 pages.

Best management practices (BMPs) for forestry activities are presented, stressing that feasible BMPs must depend on site- specific, case-by-case information such as management objectives and natural conditions. Information on the effectiveness of BMPs is not provided. The principal types of erosion control practices and qualitative positive and negative features, based on EPA Technical Report 37 (1977) are included.

Rothwell, R.L. 1971. *Watershed management guidelines for logging and road construction.* Canadian Forestry Service, Department of Fisheries and Forestry, Forest Research Laboratory, Edmonton, Alberta, Canada. Information Report A-X-42. 78 pages.

This guidance document was prepared to minimize the impacts to water quality resulting from silviculture in North America. The document covers virtually all activities from start to finish of a logging event. These activities include road construction and maintenance. Appropriate best management practices are graphically described.

Rothwell, R.L. 1978. *Watershed management guidelines for logging and road construction in Alberta.* Canadian Forest Service, Northern Forest Research Center. Information Report NOR-X-208. 43 pages.

This document presents information on general guidelines to follow when constructing and maintaining a forest road. Information provided in the document includes the following: road gradient, road width, aspect, stream protection, stream crossings, cuts and fills, drainage, and retirement. This paper presents specifications for many of the best management practices suggested.

Stuart, G., and J. Vowell. 1989. Forest practices for controlling nonpoint source pollution. In: *National Nonpoint Conference.* St. Louis, Missouri, April 23-26, 1989.

This paper presents the various best management practices that may be used to prevent adverse water quality conditions or excessive erosion from forest road construction. General information on forest road construction and maintenance NPS controls is provided.

Swift, L.W., Jr. 1988. Chapter 23: Forest access roads: design, maintenance, and soil loss. In: *Proceedings of Symposium: Forest Hydrology and Ecology at Coweeta.* Athens, Georgia, October 1984. W.T. Swank and D.A. Crossley, Jr. (eds.). Springer-Verlag New York. pp. 313-324.

The chapter gives a history of road-related research at Coweeta and summarizes the findings of that research. Roads and skid trails are recognized as major sources of sediment from forestry- related activities. Related research at Coweeta has included roadbank stabilization tests (1934-58), exploitative logging demonstrations (1941-56), integrated forest and watershed management demonstration (1954-55), management tests (1956-60), multiresource management demonstrations (1962-64), BMPs, transportation planning, bridge and culvert size, operational application of road design guidelines (1976-84), and road maintenance. This research has led to certain conclusions regarding forestry roads. The most effective road system results from a transportation plan developed to serve an entire basin rather than the short-term needs of individual road projects. Exposed soil should be revegetated quickly. Storm water should be removed from the road at frequent intervals and in small amounts. Contour roads and gentle grades produce less sediment and require less maintenance. Gravel surfacing is best, and a grassed roadbed is good where traffic is light. The stream crossing is the most critical part of the entire road, and every effort should be made to protect and vegetate fill slopes and divert storm waters on the road away from the stream. Unnecessary maintenance should be avoided.

Swift, L.W., Jr. 1986. Filter strip widths for forest roads in the southern Appalachians. *Southern Journal of Applied Forestry.* 10(1):27-34.

The objectives of this study were (1) to compare filter strip standards to field measurements of sediment movement in the southern Appalachian Mountains and (2) to determine the mitigating influences of mulch or grass on fill slopes and of obstructions to flow within filter strips. The author found that filter strip standards currently applied to forest roads in the southern

Appalachian Mountains may specify greater widths than are necessary with prevailing construction practices. Measurements of the distance that sediment traveled downslope below newly constructed roads were less than previously reported. Distances were notably less if natural obstructions existed on the forest floor, brush barriers were at the edge of the right- of-way, road fills were grass-covered, or roads were outsloped and drained by broad-based dips. Filter strip slope distance in feet can be calculated as 43 + 1.39(slope %). A table of minimum filter strip widths for graveled forest roads is presented. Factors influencing sediment movement downslope include slope distance, natural vegetative cover, forest litter, presence of brush barriers, and whether sediment is being carried by diffuse flow or flow associated with a storm water discharge by a culvert.

Swift, L.W., Jr. 1985. Forest road design to minimize erosion in the southern Appalachians. In: *Forestry and Water Quality-A Mid- south Symposium*. University of Arkansas, May 8-9, 1985. B.G. Blackmon (ed.). University of Arkansas, Cooperative Extension Service, Little Rock, Arkansas. pp. 141-151.

Excessive erosion and low serviceability of roads are problems associated with forest management in the mountains of the southeastern United States. Results of research at the Coweeta Hydrologic Laboratory in western North Carolina on developing and demonstrating low-cost, low-maintenance road design are presented. The most effective road systems result from a transportation plan developed to serve an entire basin rather than short-term needs of individual locations. Soil should be revegetated quickly. Outsloping and dips should be used to remove storm water at frequent intervals and in small amounts. Contour roads and gentle slopes require less maintenance and produce less sediment. The stream crossing is the most critical part of the entire road, and special efforts should be made to protect and vegetate fill slopes and divert storm water on the road away from streams.

Swift, L.W., Jr. 1984. Gravel and grass surfacing reduces soil loss from mountain roads. *Forest Science*. 30(3):657-670.

Soil loss from forest roads was measured on two soils in the southern Appalachian Mountains. Losses from a roadbed without surfacing (bare soil) and later with grass cover were compared with those from roadbeds surfaced with different types and amounts of rock. In the first 2 months after construction in a deep sandy loam, soil loss rates were eight times greater from the bare soil site than from roadbeds with 15-20 cm of gravel. Cumulative loss during the first 8 months after construction was over 200 tons/ha from the bare soil roadbed and less than 35 tons/ha from roadbeds surfaced with graded crushed rock or large washed stone. Losses rose as logging traffic began and road maintenance disturbed stabilized road surfaces and contributed to losses.

Trimble, G.R., and R.S. Sartz. 1957. How far from a stream should a logging road be located? *Journal of Forestry*. 55(5):339-341.

Observations were made along a forest road that traverses a well- stocked northern hardwood forest of somewhat uneven age in the Hubbard Brook Experimental Forest in the White Mountains of New Hampshire. Data are plotted as a relationship between degree of slope and distance sediment is carried by storm runoff, yielding recommended widths of filter strips for various conditions. A rule of thumb is a filter strip 25 feet wide on level ground with a 2-foot increase in width for each 1% increase in slope of the land between road and stream.

Trimble, G.R., and S. Weitzman. 1953. Soil erosion on logging roads. *Soil Science Society of America Proceedings*. 17:152-154.

Sample skid roads were studied before, during, and after experimental logging operations on the Fernow Experimental Forest in West Virginia. Erosion was related to grade, length of slope, intensity of use, soil, vegetation, and climatic factors. Degree of erosion was determined for

different skid road conditions. Proper road location, road construction techniques, road maintenance, and use are important to reducing erosion from forest roads. A table of recommended spacing between water bars to control erosion as a function of grade is presented.

USDA Forest Service. 1992. *Investigating Water Quality in the Pacific Southwest Region, Best Management Practices Evaluation Program (BMPEP): A User's Guide*. USDA Forest Service, Region 5, San Francisco, California.

This document is the result of a continuous loop of on-site evaluations, BMP prescription development, implementation, monitoring, and feedback. The monitoring/evaluation program described in this user's guide provides the feedback loop to obtain and document observations of how well BMPs protect water quality and also helps to identify deficiencies and their causes and necessary corrective actions. On-site evaluations were made on the following activities: streamside management zones, skid trails, suspended yarding, landings, meadow protection, special erosion control and revegetation, timber administration, road surface, drainage, slopes protection, stream crossings, servicing and refueling, in-channel construction practices, temporary roads, rip-rap, snow removal, protection of roads during wet periods, pioneer road construction, prescribed fire, revegetation of surface disturbed areas, and location of stock facilities in wilderness. In addition, assistance in accessing the Best Management Practices Evaluation Program database (BMP- DB) is provided.

Weitzman, S., and G.R. Trimble, Jr. 1952. Skid-road erosion can be reduced. *Journal of Soil and Water Conservation*. 7:122-124.

The preliminary results of a skid road experiment are presented. This experiment had four study sites with different qualities of skid roads. The "high-quality" road site had the fewest roads on the smallest slopes. The "good," "fair," and "poor" sites had progressively more road area and the roads ran over steeper slopes. The authors measured erosion rates off the sites and found significantly less erosion as the road quality increased.

Windsor, C.L. 1989. Recommended management practices for forested wetlands road construction. In: *Proceedings of the Symposium on the Forested Wetlands of the Southern United States*. Orlando, Florida, July 12-14, 1988. USDA Forest Service, Southeast Forest Experiment Station. General Technical Report SE-50. pp. 51-53.

This paper lists the provisions of section 404 of the CWA and BMPs developed by Georgia, Florida, and South Carolina relating to wetland road construction. An example of a wetland road system in Georgia that incorporated many of the BMPs is reviewed. Four commonly used bad management practices are also discussed: filling intermittent streams with unstabilized fill material; placing culverts in the wrong place or using the wrong size culvert; using a long fill with an inadequate number of culverts; and grading roads flat and leaving the berm along the outside edges of the road. Beavers stopping up culverts are also a common problem in the South.

Yee, C.S., and T.D. Roelofs. 1980. *Planning forest roads to protect salmonid habitat*. USDA Forest Service, Pacific Northwest Forest and Range Experiment Station. General Technical Report PNW-109. 260 pages.

This document presents information on alleviating the environmental impacts, particularly on anadromous fish and their habitats, associated with forest road construction. The document provides design, construction, and maintenance guidelines for roads to minimize impacts. Sections on sedimentation, road- stabilizing additives, and roads, and fish migration are included.

Adams, P.W. 1991. *Maintaining woodland roads*. Oregon State University Extension Service,

Extension Circular 1139.

Arnold, J.F. 1963. Road location to retain maximum stability. In: *Symposium on Forest Watershed Management*. March 25-28, 1963. Society of American Foresters and Oregon State University. pp. 215-224.

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Bethlahmy, N., and W.J. Kidd, Jr. 1966. *Controlling soil movement from steep road fills*. USDA Forest Service Research Note, INT-45. 4 pages.

Blackmon, B.G. (ed). 1985. *Forestry and water quality: A mid- south symposium*. Little Rock, Arkansas, May 8-9, 1985. Arkansas Cooperative Extension Service, University of Arkansas.

Burroughs, E.R., G.R. Chalfant, and M.A. Townsend. 1973. *Guide to reduce road failures in western Oregon*. Bureau of Land Management, Oregon State Office, Portland, Oregon, 111 pages.

Campbell, A.J., R.C. Sidle, and H.A. Froehlich. 1982. *Prediction of peak flows for culvert design on small watersheds in Oregon*. Oregon State University, Water Resources Research Institute, WRRI-74. 98 pages.

Carr, W.W., and T.M. Ballard. 1980. Hydroseeding forest roadsides in British Columbia for erosion control. *Journal of Soil and Water Conservation*. 35(1):33-35.

Carson, W.W., and D.P. Dykstra. 1978. *Programs for road network planning*. USDA Forest Service, Pacific Northwest Forest and Range Experiment Station. General Technical Report PNW-67. 21 pages.

Crumrine, J.P. 1977. Best management practices for the production of forest products and water quality. In: *Proceedings of the 208 Symposium on Non-Point Sources of Pollution from Forested Land*. Southern Illinois University, Carbondale, Illinois. G.M. Aubertin (ed.). pp. 267-274.

Dissmeyer, G.E., and G.R. Foster. 1980. *A guide for predicting sheet and rill erosion on forest land*. USDA Forest Service. Technical Publication R8-P6. 40 pages.

Douglass, J.E. 1974. *Flood frequencies and bridge and culvert sizes for forested mountains in North Carolina*. USDA Forest Service. General Technical Report SE-4. 21 pages.

Dyrness, C.T. 1970. *Stabilization of newly constructed road backslopes by mulch and grass legume treatments*. USDA Forest Service, Pacific Northwest Forest and Range Experiment Station. Research Note PNW-123. 5 pages.

Enberg, P. 1963. Design of roadway drainage to prevent erosion on forest watersheds. In: *Symposium on Forest Watershed Management*. March 25-28, 1963. Society of American Foresters and Oregon State University. pp. 233-252.

Furniss, M.J., T.D. Roelofs, and C.S. Yee. 1991. *Road construction and maintenance*, In: Influences of forest and rangeland management on salmonid fishes and their habitats. Meehan, W.R., (ed.) American Fisheries Society Special Publication 19:297-324.

Gardner, R.B. 1978. *Cost, performance, and aesthetic impacts of an experimental forest road in Montana*. USDA Forest Service. Research Paper INT-203. 28 pages.

Gardner, R.B. 1967. Major environmental factors that affect the location, design, and construction of stabilized forest roads. *Logger's Handbook*. 27:12-13, 170-173. Pacific Logging Congress, Portland, Oregon.

Gardner, R.B., W.S. Hartsog, and K.B. Dye. 1978. *Road design guidelines for the Idaho batholith based on the China Glen road study*. USDA Forest Service. Research Paper INT-204. 20 pages.

Golden, M.S., C.L. Tuttle, J.S. Kush, and J.M. Bradley. 1984. *Forestry activities and water quality in Alabama: Effects, recommended practices, and an erosion-classified system*. Auburn University, Agricultural Experiment Station. Bulletin 555.

Haupt, H.F., and W.J. Kidd, Jr. 1965. Good logging practices reduce sedimentation in central Idaho. *Journal of Forestry*. 63(9):664-670.

Haussman, R.F., and E.W. Pruett. 1978. *Permanent logging roads for better woodlot management*. USDA Forest Service, Eastern Region. 45 pages.

Helvey, J.D., and J.N. Kochenderfer. 1988. Culvert sizes needed for small drainage areas in the central Appalachians. *Northern Journal of Applied Forestry*. 5(2):123-127.

Larse, R.W. 1971. Prevention and control of erosion and stream sedimentation from forest roads. In: *Proceedings of the Symposium: Forest Land Uses and the Stream Environment*. Oregon State University, October 19-21, 1970. J.T Krygier and J.D. Hall (eds.). OSU, Corvallis, Oregon. pp. 76-83.

McCashion, J.D., and R.M. Rice. 1983. Erosion on logging roads in Northwestern California: How much is avoidable? *Journal of Forestry*. (1):23-26.

McDonald, P.M., and R.V. Whiteley. 1972. Logging a roadside stand to protect scenic values. *Journal of Forestry*. 70:80-82.

McEvoy, T.J. 1989. Private forests: Common sense erosion control. *American Forests*. 95:32-34,66-67.

Megahan, W.F. 1983. Appendix C: Guidelines for reducing negative impacts of logging. In: *Tropical watersheds: Hydrologic and soils response to major uses or conversions*. L.S. Hamilton and P.N. King (eds.). Westview Press, Boulder, Colorado. pp. 143-154.

Megahan, W.F. 1974. *Deep-rooted plants for erosion control on granitic road fills in the Idaho Batholith*. USDA Forest Service, Intermountain Forest and Range Experiment Station. Research Paper INT-161.

Megahan, W.F. 1977. Reducing erosional impacts of roads: Guidelines for watershed management. In: *FAO Conservation Guide*. Food and Agriculture Organization of the United Nations, Rome. pp. 237-261.

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Mitchell, W.C., and G.R. Trimble, Jr. 1959. How much land is needed for the logging transport system? *Journal of Forestry*. 57(1):10-12.

NCASI. 1984. *Forestry management practices and cumulative effects on water quality and utility*. National Council of the Paper Industry for Air and Stream Improvement. Technical Review Bulletin No. 435.

Noble, E.L., and L.J. Lundeen. 1971. Analysis of rehabilitation treatment alternatives for sediment control. In: *Proceedings of the Symposium: Forest Land Uses and Stream Environment*. Oregon State University, Oct. 19-21, 1970. J.T. Krygier and J.D. Hall (eds.). OSU, Corvallis, Oregon. pp. 86-96.

Oregon Department of Forestry, Forest Practices Section. 1979. *Forest practices notes-Waterbars*.

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Ponce, S.L. 1986. Controlling diffuse-source pollution associated with forest practices in North America. In: *Effects of land use on fresh waters: agriculture, forestry, mineral exploitation, urbanization.* L.G. Solbe (ed,). Water Research Centre, Chichester, England. pp. 432-443.

Rasmussen, W.O., R.N. Weisz, P.F. Ffolliott, and R.D. Carder. 1980. Planning for forest roads-A computer-assisted program for selection of alternative corridors. *Journal of Environmental Management.* 11:93-104.

Roby, K., J. Rector, and M. Furniss. 1991. *PSW region of the Forest Service about to launch BMP evaluation process.* USDA Forest Service, Pacific Southwest Region. White paper. 2 pages.

Rothwell, R.L. 1983. Erosion and sediment control at road-stream crossings (forestry). *The Forestry Chronicle.* 59(2):62-66.

Smith, A.C. 1963. Tractor roads and trails planning, use and post treatment. In: *Symposium on Forest Watershed Management.* March 25-28, 1963. Society of American Foresters and Oregon State University. pp. 283-290.

Svinth, J.F. 1963. Revegetation of cut and fill Slopes. In: *Symposium on Forest Watershed Management.* March 25-28, 1963. Society of American Foresters and Oregon State University. pp. 253-258.

USDA Forest Service. 1989. *Annotated bibliography on soil erosion and erosion control in subarctic and high-latitude regions of North America.* USDA Forest Service, Pacific Northwest Forest and Range Experiment Station. General Technical Report PNW-GTR-253.

Whitman R. 1989. Clean water of multiple use? Best management practices for water quality control on the national forests. *Ecology Law Quarterly.* 16(4):909.

Winkelaar, P. 1971. *Forest Road Location and Erosion Control on Northern New Hampshire Soils.* Cooperative Extension Service, University of New Hampshire, Extension Publication No. 2. 19 pages.

COST AND EFFECTIVENESS OF BMPs

Benson, R.E., and M.J. Niccolucci. 1986. What does it cost to protect nontimber resources during logging? *American Forests.* 92(6):26-28 and 53-54.

This paper presents an analysis of the major cost components associated with managing and protecting nontimber resources in National Forests. Data from 187 timber sales in the northern Rocky Mountains between 1975 and 1981 were used to test different ways of assigning costs to nontimber resources. The average cost of protecting nontimber resources was $26/1000 board-feet of timber sold. Broken down, costs were $12.69 for road construction and maintenance, $8.77 for log hauling, and $4.46 in other activities such as felling trees, log skidding, and slash disposal. These costs cover soil, water, habitat, and other resources. The opportunity costs and administrative costs associated with protection on nontimber resources are not included. The authors conclude that determining exact costs associated with protection of natural resources will not be possible until methods of estimating opportunity and administrative costs are developed.

Burroughs, E.R. Jr., and J.G. King. 1989. *Reduction of soil erosion on forest roads*. USDA Forest Service, Intermountain Research Station. General Technical Report INT-264. 21 pages.

This document presents the expected reduction in surface erosion from selected treatments applied to forest road traveled ways, cutslopes, fillslopes, and ditches. Estimated erosion reduction in expressed as functions of ground cover, slope gradient, and soil properties whenever possible. A procedure is provided to select rock riprap size for protection of road ditches.

Cook, M.J., and J.G. King. 1983. *Construction cost and erosion control effectiveness of filter windrows on fill slopes*. USDA Forest Service, Intermountain Forest and Range Experiment Station, Ogden, UT. Research Note INT-335. 5 pages.

This paper presents information on the cost and effectiveness of filter windrows (slash) for reducing sediment loss from road fill slopes. The authors estimated conservatively that the windrows had a trapping efficiency of 75 to 85 percent based on measurements of windrowed and non windrowed fill slopes. The construction cost was $59/100 feet of windrowed slope. The authors recommend the use of filter windrows because they are relatively inexpensive, efficient, and can be constructed simultaneous with road construction for immediate protection of water resources.

Cubbage, F.W., and P. Lickwar. 1990. *Estimating the costs of water quality protection on private forest lands in Georgia*. Georgia Forestry Commission, Research Division.

The purpose of the information presented in this paper is to quantify the operational costs of implementing various forestry best management practices, with emphasis placed on practices associated with road construction. This paper presents very good cost information on the following: road construction, stream crossings, broad-based dips, water bars, seed, fertilizer, mulch. The information is useful because the costs are based on various physiographic classifications (i.e., coastal plain, piedmont, or mountain).

Curtis, J.G., D.W. Pelren, D.B. George, V.D. Adams, and J.B. Layzer. 1990. *Effectiveness of best management practices in preventing degradation of streams caused by silvicultural activities in Pickett State Forest, Tennessee*. Center for the Management, Utilization and Protection of Water Resources, Tennessee Technological University for the Tennessee Department of Conservation, Division of Forestry and the Tennessee Wildlife Resources Agency. 197 pages.

This study was undertaken to evaluate the effectiveness of BMPs applied to timber harvest operations in Pickett Forest. The effects on water quality, fish production, and macroinvertebrates, and the presence of herbicides in streams were studied. The BMPs employed were SMZs, road placement on ridgetops and high elevations, skid trails kept at least 14 m from streams, harvest during the driest season and maximum soil stability, logging of small, dispersed stands, seeding and mulching of disturbed areas, broad-based dips on the haul road, and a period of 10 years before the area would be logged again. Herbicides were applied to two stands. Hardwoods 75 mm dbh or less were thin line sprayed with a mixture of Garlon (active ingredients triclopyr and 2,4-D), Sidekick, and diesel fuel. Picloram was injected into all hardwoods 255 mm dbh or greater. Concentrations of herbicides in streams following the treatments was low: 2,4-D @ <0.02-0.08l. Based on available toxicity data, the levels detected were not biologically harmful. However, care is needed during application to minimize transport to surface waters. Extensive data relating to all of the BMPs employed during the study are presented in the paper .

Dissmeyer, G.E., and B.B. Foster. 1987. Some economic benefits of protecting water quality. In: *Managing Southern Forests for Wildlife and Fish: A Proceedings*. USDA Forest Service, Southern Forest Experiment Station. General Technical Report SO-65. pp. 6- 11.

Many of the practices used to protect water quality are the same ones used to improve soil productivity. Protecting soil productivity has economic benefits for the landowner in terms of timber produced per acre, and lowered road construction and maintenance costs. Increased fisheries production in forest streams is another economic benefit of protecting forest soils. The effects of sediment on fish habitats, and the principles and economic benefits of soil productivity, are reviewed. Tables present the economic returns of implementing various forest BMPs. For instance, skid trail rehabilitation yielded a real return of from 2.4%to 4.8%. The benefit/cost ratio of rehabilitating cut- and-fill slopes ranged from 2.4 to 4.4 in studies reviewed. Erosion control confers economic benefits on landowners and protects water quality and fisheries.

Dissmeyer, G.E., and E. Frandsen. 1988. The economics of silvicultural best management practices. In: *Nonpoint Source Pollution: 1988 - Policy, Economics, Management, and Appropriate Technology*. Milwaukee, Wisconsin, November 6-11, 1988. V. Novotony (ed.). American Water Resources Association, Bethesda, Maryland. pp. 77-86.

Matrices were developed to estimate the economic benefits of implementing nonpoint BMPs. Through three examples, this study illustrates incremental outputs and values of induced goods and services to investments in soil and water resource management on forestland and rangeland.

Duggleby, J. 1980. Drainage structures: The cost of inadequacy. *British Columbia Lumberman*. 64(8):12,15.

This article summarizes a presentation by Richard Kosick of Tahsis on road drainage structures and provides reasons for road structure failure. They include improper site selection, improper site preparation, improper workmanship, inadequate size, inadequate consideration of future activity, and inadequate maintenance. Kosick cited numerous costs, indirect and direct, of building inadequate drainage structures initially. Direct costs include evaluation of damage, moving equipment to site, loss of production, and loss of work for logging crew. Indirect costs include loss of personnel due to layoffs during repair, increased road maintenance, and slower hauling speed through the affected area. Kosick estimated that the overall cost of inadequate running surface could amount to 5% to 10% of logging costs. The costs of inadequately maintained culverts and ditches resulting from a single storm are tabulated. The percent increase in cost per kilometer of road ranged from 2% to 34%.

Ellefson, P.V., and P.D. Miles. 1984. Economic implications of managing nonpoint forest source of water pollutants: A midwestern perspective. In: *Mountain Logging Symposium Proceedings*. West Virginia University, June 5-7, 1984. P.A. Peters and J. Luchok (eds.). pp. 107-119.

Economic evaluations of 6 forest practices designed to enhance water quality from 18 timber harvesting operations in the Midwest were carried out. Net revenue reductions ranged from 1.2% with redesign of landing and skid trail locations to 26.4% with buffer strip requirements. Nine operations were profitable with application of all six practices. Limited production function information hinders such analyses.

Gardner, R.B. 1978. *Cost, performance, and aesthetic impacts of an experimental forest road in Montana*. USDA Forest Service. Research Paper INT-203. 28 pages.

This paper presents the results of a study conducted to evaluate the costs and environmental impacts associated with single-lane forest road

design and construction and compares these costs with the costs of alternative designs. The paper presents information on the costs of various road designs and includes significant data on construction specifications.

Gardner, R.B. 1971. *Forest road standards as related to economics and the environment.* USDA Forest Service. Research Note INT-145.

This brief note discusses the problems related to planning a forest road system. Data needed for planning an optimum system were not available at the time, and the author discusses factors that should be taken into account to plan the best system possible in the absence of such data and to protect the quality of the environment. Cost data (annual road costs per mile for 10,000 vehicles per annum (VPA) and 20,000 to 40,000 VPA, and single lane versus double lane for 10,000, 20,000, and 40,000 VPA) are presented in tables.

Groves, F.D., R.K. Baughman, M.E. Hundley, and R.L. Sherman. 1979. Timber haul road construction in southern mountains. *Southern Journal of Applied Forestry*. 3(1):68-76.

A discussion of the factors to be considered when planning and building forest roads. Road construction standards (grade, dimensions, stabilization, cut and fill, and drainage structures) applicable to West Virginia and costs of road construction in the area are presented. Costs range from $5,000 to $35,000 per mile of completed road, depending on steepness and difficulty of terrain.

Harr, R.D., and R.A. Nichols. 1993. Stabilizing forest roads to help restore fish habitats: A northwest Washington example. *Fisheries*. 18(4):18-22.

Due to increased landslide risk and sediment delivery from 30 to 40-year old forest roads in the Canyon Creek watershed, the roads were decommissioned by stabilizing fills, removing stream crossings, recontouring slopes, and reestablishing drainage patterns. The failure rate of the roads prior to recommissioning was 110 times higher than undisturbed forest and 6 times higher than logged forest. The average cost of decommissioning the roads was $3,500 per km where considerable earthmoving was necessary. Lower costs were associated with lesser earthmoving jobs; the highest costs resulted when fills at stream crossings or landings had to be removed. In contrast to unused roads not treated, decommissioned roads and landings were largely undamaged by rain on snow runoff that produced a 50-year flood in November 1989 and sustained little damage during rain on snow runoff in November 1990 that severely damaged main haul roads in northwest Washington. The authors concluded that reducing the landslide and failure rate of roads used in forestry operations would greatly improve conditions for salmonids.

Kochenderfer, J.N., G.W. Wendel, and H.C. Smith. 1984. *Cost of and soil loss on "minimum standard" forest truck roads constructed in the central Appalachians*. USDA Forest Service, Northeastern Forest Experiment Station. Research Paper NE-544. 8 pages.

A "minimum-standard" forest road is described, and cost data are presented for eight such roads constructed in the central Appalachians. The average cost per mile excluding gravel was $8,119 (range $5,048 to $14,424). Soil loss was measured from several sections of a minimum-standard road. Traffic was regulated the first year and unrestricted the second year. Losses ranged from 44 tons per acre on ungraveled road sections to 5 tons per acre on graveled sections. Soil loss from the graveled sections on the minimum-standard road was about the same as that from higher standard graveled roads.

Koger, J.L. 1978. *Factors affecting the construction and cost of logging roads.* Tennessee Valley Authority, Division of Forestry, Fisheries and Wildlife Development. Technical Note B-27. 130 pages.

Factors affecting road construction, construction

time, and construction cost are discussed and related to the logging operation. A regression equation is presented for predicting construction times and costs for low-volume logging roads. Variables found to affect construction times significantly were road length, cleared width, earthwork volumes, road slope, and equipment horsepower. Equations and tables for road construction times and costs are given for varying conditions. Partial contents: (1) general problem description, (2) review of pertinent literature, (3) common road locations, (4) procedures for measuring variables, (5) approaches to estimating bulldozer production, (6) analysis of production data, (7) equipment operating costs and replacement policies, (8) application of results, (9) drainage, (10) bridges, (11) rock, (12) maintenance practices on logging roads, (13) planning the road network, and (14) environmental guidelines for road construction. Numerous cost tables relating to road construction and a complete list of references are provided.

Lickwar, P.M., C.A. Hickman, and F.W. Cubbage. 1991. Costs of protecting water quality during harvesting on private forestlands in the Southeast. ***Southern Journal of Applied Forestry.***

Data on harvest volumes, topography, and other site and area characteristics were obtained from 22 private forest timber harvests in Alabama, Florida, and Georgia. An economic analysis was then used to estimate the marginal costs of implementing each state's recommended BMPs and a set of "enhanced" BMPs that offered increased water quality protection. Collectively, the costs of using the recommended BMPs averaged 2.9% of gross timber sale revenue, $2.34 per 1000 board feet (MBF) of timber harvested, or $12.45 per acre. The cost of implementing enhanced BMPs averaged 5.1% of gross stumpage value, $4.13 per MBF, or $21.94 per acre. Seed, fertilizer, and mulch; broad-based dips; and water bars were the most expensive practices on a total cost basis. Culvert installation, SMZs, and road relocation were less expensive for most tracts. A literature review of related studies is provided. Site location maps, site characteristics (physiographic, size, harvest method) are also given, and the economic analysis breaks the sites down by topography and BMPs implemented. This is one of the few studies available on forestry BMP implementation costs.

Lynch, J.A., and E.S. Corbett. 1981. Effectiveness of best management practices in controlling nonpoint pollution from commercial clearcuts. In: ***Nonpoint Pollution Control - Tools and Techniques for the Future, Proceedings of a Technical Symposium.*** **pp. 213-224.**

This paper reports an evaluation of the effectiveness of Pennsylvania's BMPs for controlling NPS pollution on public and private forestlands. This study was done following a commercial clearcut in central Pennsylvania. The paired watershed method was used to evaluate changes in water quality and quantity. The commercial clearcut produced a water yield increase of 5.39 area- inches the first year following cutting. Stream turbidity on the clearcut watershed was generally higher than that on the control watershed prior to cutting, and no major increase in turbidity occurred as a result of cutting. No serious channel erosion was found on the clearcut watershed. Increases in stream temperature were generally slight. The authors conclude that the BMPs required in Pennsylvania are sufficient to control NPS pollution during and following logging.

Lynch, J.A., and E.S. Corbett. 1990. Evaluation of best management practices for controlling nonpoint pollution from silvicultural operations. ***Water Resources Bulletin.*** **26(1):41-52.**

Fifteen years of streamflow and water quality data were evaluated to determine the effectiveness of BMPs in controlling nonpoint source pollution from a 110-acre commercial clearcut located in the Ridge and Valley Province of central Pennsylvania. In general, the BMPs analyzed effectively reduced water quality impacts associated with timber harvest. Although some

increases in water quality constituents were observed, most were well below the drinking water standards although they may violate EPAs antidegradation policy. The authors suggest that buffer strips of unharvested timber provided the most protection to the streams and that improved performance may be possible through annual inspections and increasing the width of buffer strips if necessary. The information presented in this report demonstrates the potential for reductions in nonpoint source pollution possible with various BMPs.

Mussallem, K.E., and J.A. Lynch. 1980. Controlling nonpoint source pollution from commercial clearcuts. In: *Watershed Management 1980*. C.W. Johnson (ed.). American Society of Civil Engineers, Irrigation and Drainage Division, Committee on Watershed Management. pp. 669-681.

This study was designed to evaluate the effectiveness of Pennsylvania's BMPs. It compared measurements of stream quality at a control site that was not logged, a site logged using BMPs, and a site logged without BMPs that was treated with herbicides to eliminate the effect of regrowth. The use of BMPs reduced the impact of logging activities on stream quality.

Rasmussen, W.O., R.N. Weisz, P.F. Ffolliott, and R.D. Carder. 1980. Planning for forest roads-A computer-assisted program for selection of alternative corridors. *Journal of Environmental Management*. 11:93-104.

A methodology for incorporating economic and aesthetic criteria within a recreational forest road corridor selection process is described. Computer graphics are used to store, analyze, integrate, and display information needed for corridor decision-making. Economic costs are based on an accounting of the total dollar costs of each alternative. Scenic beauty estimates, based on a systematic public participation process, are used to quantify aesthetics. Scenic beauty is used as an example of how environmental parameters can be taken into account in the location of a road corridor. Other considerations, such as potential sediment production and visibility, could be taken into consideration in future versions of the program.

USDA Forest Service. 1992. *Investigating Water Quality in the Pacific Southwest Region, Best Management Practices Evaluation Program (BMPEP): A User's Guide*. USDA Forest Service, Region 5, San Francisco, California.

This document is the result of a continuous loop of on-site evaluations, BMP prescription development, implementation, monitoring, and feedback. The monitoring/evaluation program described in this user's guide provides the feedback loop to obtain and document observations of how well BMPs protect water quality and also helps to identify deficiencies and their causes and necessary corrective actions. On-site evaluations were made on the following activities: streamside management zones, skid trails, suspended yarding, landings, meadow protection, special erosion control and revegetation, timber administration, road surface, drainage, slopes protection, stream crossings, servicing and refueling, in-channel construction practices, temporary roads, rip-rap, snow removal, protection of roads during wet periods, pioneer road construction, prescribed fire, revegetation of surface disturbed areas, and location of stock facilities in wilderness. In addition, assistance in accessing the Best Management Practices Evaluation Program database (BMP- DB) is provided.

USDA Forest Service. 1987. *Soil and water resource management: A cost or a benefit? Approaches to watershed economics through example*. 99 pages.

Analysis procedures for estimating the economic benefits of soil and water resource management have been developed. This report discusses the procedures and the data and information required to employ them. The analysis procedures focus on the following management areas: timber, forage, fish, enhanced water quality, and road

construction and maintenance. The procedures and economics of soil and water management are demonstrated in this document with 16 examples.

Ellefson, P.V., and P.D. Miles. 1985. Protecting water quality in the Midwest: Impact on timber harvesting costs. *Northern Journal of Applied Forestry*. 2:57-61.

Gardner, R.B. 1979. Some environmental and economic effects of alternative forest road designs. *Transactions of American Society Agricultural Engineers*. 22(1):63-68.

Haupt, H.F., H.C. Rickard, and L.E. Finn. 1963. *Effect of severe rainstorms on insloped and outsloped roads*. USDA Forest Service. Research Note INT-1. 8 pages.

Hickman, C.A., and B.D. Jackson. 1979. Economic impacts of controlling soil loss from silvicultural activities in east Texas. *Forest Science*. 25(4):627-640.

Kochenderfer, J.N., and G.W. Wendel. 1980. *Costs and environmental impacts of harvesting timber in Appalachia with a truck-mounted crane*. USDA Forest Service, Northeastern Forest Experiment Station. Research Paper NE-456. 9 pages.

Lickwar, P.M. 1984. *Estimating the costs of water quality protection on private forest lands in the south*. Master's Thesis, University of Georgia.

Lynch, J.A., and E.S. Corbett. 1989. Effectiveness of BMP's in controlling nonpoint pollution from silvicultural operations. In: *Proceedings of the Symposium on Headwaters Hydrology*. American Water Resources Association, Bethesda, Maryland. pp. 149-157.

Lynch, J.A., W.E. Sopper, E.S. Corbett, and D.W. Aurand. 1975. Effects of management practices on water quality and quantity: The Penn State Experimental Watersheds. In: *Municipal Watershed Management Symposium Proceedings*. USDA Forest Service. General Technical Report NE-13. pp. 32-46.

Peters, P.A., and J. Luchok (eds). 1984. *Mountain Logging Symposium Proceedings*. West Virginia University, June 5-7, 1984. 372 pages.

USEPA. 1977. *Silvicultural activities and non-point pollution abatement: A cost-effectiveness analysis procedure*. U.S. Environmental Protection Agency. EPA 600/8-77-018. 121 pages.

5. TIMBER HARVEST

IMPACTS ON WATER QUALITY

Amaranthus, M.P., R.M. Rice, N.R. Barr, and R.R. Ziemer. 1985. Logging and forest roads related to increased debris slides in southwestern Oregon. *Journal of Forestry*. 83(4):229-233.

This article presents data from a study of mass erosion in the Siskiyou National Forest in southwestern Oregon. The effects of forest activities on soil mass movement frequency and volumes and information on the conditions at landslide sights which might aid in the prediction of future slides was identified. The slide frequency during the study period was one slide every 4.3 years per 1000 acres. Erosion from roads was approximately 100 times those on undisturbed areas, while erosion from harvested areas was 7 times that of undisturbed areas. About 75% of slides occurred on slopes steeper than 70%.

Anderson, B., and D.F. Potts. 1987. Suspended sediment and turbidity following road construction and logging in western Montana. *Southern Journal of Applied Forestry*. 23(4):681-690.

Suspended sediment production and turbidity following forest management activities are well documented for areas where soils are highly erodible or where terrain is unstable. Areas with stable sediments may require less stringent forest practice regulations for logging and road construction than areas with unstable soils. This study investigated the relationships between suspended sediment production, turbidity, and discharge in a watershed characterized by stable sediments and the changes in these parameters associated with logging and road construction. Sediment yields increased 7.7-fold in the first year following road construction in a second-order drainage and twofold in the second year following logging. Sediment supply limitations resulted in poor correlations between sediment concentrations and discharge. Turbidity was much better correlated with discharge and serves as a better indicator of sediment concentration.

Anderson, H.W. 1971. Relative contributions of sediment from source areas, and transport processes. In: *Proceedings of the Symposium: Forest Land Uses and Stream Environment*. Oregon State University, Corvallis, Oregon, October 19-21, 1970. T. Krygier and J.D. Hall, (eds.) pp. 55-63.

This paper reports new findings and summarizes pertinent results from the literature on the contribution and movement of sediment from various timber practices. Multiple methods of sediment introduction are discussed, and their relative impacts on streams are quantified. This is not a case study for one particular watershed or stream, but a summary of the expected effects of timber harvest activities on sediment discharge. Overall, the author provides a general review of limited data for sediment transport processes.

Askew, G.R., and T.M. Williams. 1984. Sediment concentrations from intensively prepared wetland sites. *Southern Journal of Applied Forestry*. 8(3):152-157.

This study was designed to evaluate the drainage and conversion process used by a major forest industry and to determine which aspect of the conversion process, if any, was a primary source of sediment. Suspended sediment concentrations were measured in water draining from a 5,900-acre Carolina bay undergoing conversion to loblolly pine plantations. Samples were collected during the first stormflow event of each month between January 1981 and December 1982 from subwatersheds involved in some of several phases of conversion. Suspended sediment concentration in water leaving the bay averaged only 16 mg/l for 13 storms. Road erosion and ditch installation produced the highest suspended sediment concentrations. Suspended sediment concentrations decreased substantially with increasing distance from the sediment source.

Logging and site preparation activities did not cause an appreciable increase in suspended sediment when equipment did not operate in the drainage ditches. This study indicates that main haul roads and new drainage ditches are the sources of much of the increased suspended sediments found in drainage from managed forests in the lower coastal plain. The authors conclude that the impact of these activities can be minimized by using a drainage system that contains a length of main channel between sediment sources and sensitive areas.

Aubertin, G.M., and J.H. Patric. 1972. Quality water from clearcut forest land. *Northern Logger and Timber Processor.* 20(8):14-15, 22-23.

A study was conducted on adjacent watersheds, one clearcut using "common sense" practices to reduce water quality impacts and the other left uncut as a control. Specific conductance and nutrient concentrations were monitored for the first year after harvest. No significant differences in specific conductance or nutrient concentrations were observed between the two watersheds. The authors concluded that harvest techniques that leave stream buffers (selectively harvested) and also allow natural revegetation (no herbicide treatment of remaining vegetation) prevented significant water quality impacts.

Aubertin, G.M., and J.H. Patric. 1974. Water quality after clearcutting a small watershed in West Virginia. *Journal of Environmental Quality*. 3:243-249.

The water quality impacts resulting from clearcutting a forested watershed are summarized in this paper. The authors found that streamflow increased significantly the first year after harvest, but returned to near normal levels by the second year. Negligible effects were observed on nutrient concentrations, water temperature, and pH. The authors attributed the success to careful road planning and retention of a forest strip along the stream. This paper provides 10 years of preharvest data and 3 years of postharvest data, as well as data from control (forested) watershed.

Baker, M.B. 1975. Modeling management of ponderosa pine forest resources. In: *Proceedings of the Watershed Management Symposium*. Logan, Utah, August 11-13, 1975. American Society of Civil Engineers, Division of Irrigation and Drainage. pp. 478-493.

In response to water use demands, the Forest Service initiated a number of watershed management studies to evaluate the effects of vegetation changes on water yield, soil, forage, wildlife, and recreation. This paper presents preliminary estimates of the expected water yields from different basal areas.

Bauer, S.B. 1985. Evaluation of nonpoint source impacts on water quality from forest practices in Idaho: Relation to water quality standards. In: *Perspectives on Nonpoint Source Pollution: Proceedings of a National Conference*. Kansas City, Missouri, May 19-22, 1985. U.S. Environmental Protection Agency. pp. 455-458.

The results of an interdisciplinary task force appointed to determine the impacts of forest operations on water quality are presented. Twenty-five forestry sites, operated by state, federal, and private ownership, were reviewed. Seven of the sites had major impacts on salmonid habitat due to direct delivery of sediment from skid trails or roads. The remaining sites had impacts prevented by low geologic hazards, streams with no protected uses, or good practices. Other task force findings are also presented in the paper.

Beasley, R.S., and A.B. Granillo. 1988. Sediment and water yields from managed forests on flat coastal plain sites. *Water Resources Bulletin*. 24(2):361-366.

Sediment losses and water yields were measured for 5 years on nine forested watersheds in the Gulf Coastal Plain of Arkansas. Treatment watersheds included clearcut, selective cut, and controls. Sediment loss and water yields were similar for the selective and control watersheds during all years. Clearcut resulted in significantly higher sediment losses and water yields compared

to the other watersheds. The authors present several tables and figures that demonstrate that the relatively low sediment losses observed in this study were attributable to the flat terrain and the relatively low flow discharge rates that typify these sites.

Beschta, R.L. 1978. Long-term patterns of sediment production following road construction and logging in the Oregon Coast Range. *Water Resources Research*. 14(6):1011-1016.

This paper presents an analysis of post-harvest sediment data collected in the Alsea watershed in Oregon. Three experimental watersheds were used, near complete clearcut, 25% patchcut, and control. Suspended sediment after road construction, logging, and slash disposal was significantly increased on the two treatment watersheds. The erosional losses were greater during 3 of 8 post-treatment years in the 25% patchcut watershed, with most loss attributed to roads. Surface erosion from a severe slash burn, was the primary cause of increased sediment yields for 5 posttreatment years on the clearcut watershed.

Bethlahmy, N. 1967. *Effect of exposure and logging on runoff and erosion*. USDA Forest Service, Intermountain Forest and Range Experiment Station, Ogden, Utah. Research Note INT-61.

A study was conducted to investigate the effects of logging and differences in exposure on runoff and erosion under high- intensity simulated rainfall. The author reported erosion to be directly related to runoff, and plots with a southwest exposure yielded more runoff than plots with a northeast exposure. The difference in erosion by exposure was due to the reduced number of trees found on the slopes with southwest exposure.

Bilby, R.E., and P.A. Bisson. 1992. Allochthonous versus autochthonous organic matter contributions to the trophic support of fish populations in clear-cut and old-growth forested streams. *Canadian Journal of Fisheries and Aquatic Science*. 49(3):540-551.

Annual organic matter inputs and production of stocked coho salmon, coastal cutthroat, and shorthead sculpin from spring to autumn was monitored for 2 years in two headwater tributaries of the Deschutes River, Washington. One site was bordered by old- growth coniferous forest and the other an area clearcut without buffer strips 7 years before. Although organic inputs were nearly twice as high in the old-growth stream, the clearcut stream experienced greater fish production. The differences in fish production were most prevalent during early summer. The authors hypothesized that fish populations depended on food derived from autotrophic pathways during spring and summer in the presence or absence of forest canopy.

Blackburn, W.H., R.W. Knight, J.C. Wood, and H.A. Pearson. 1990. Stormflow and sediment loss from intensively managed forest watersheds in east Texas. *Water Resources Bulletin*. 26(3):465- 477.

Several small watersheds in East Texas were instrumented to determine the effect of forest harvesting, mechanical site preparation, and livestock grazing on stormflow, peak discharge rate, and sediment loss and the results were compared with pre- treatment levels. The treatments included clearcutting followed by roller chopping; clearcutting followed by shearing and windrowing; clearcutting followed by shearing, windrowing, and continuous grazing; and clearcutting followed by shearing, windrowing, and rotational grazing. The data indicated significantly greater stormflow, peak discharge rate, and sediment from clearcut harvesting and site preparation compared to undisturbed watersheds. Among the treatments, the sheared/ windrowed watersheds generally yielded the greatest stormflow and peak discharge rate, followed by the chopped watershed. This paper presents a significant amount of data on water quality impacts of timber harvest and site preparation activities.

Blackburn, W.H., and J.C. Wood. 1990. Nutrient export in stormflow following forest harvesting and site-preparation in east Texas. *Journal of Environmental Quality*. 19:402-408.

A watershed study was conducted to determine the effects on stormflow water quality from the following practices: (1) clearcutting, shearing, windrowing, and burning; (2) clearcutting, roller chopping, and burning; and (3) undisturbed control. The clearcut treatments had higher nutrient concentrations the first year following harvest and site preparation. During the second and third years, only the clearcut (shearing) treatment resulted in higher nutrient concentrations than the control. After 5 years, no significant difference in nutrient concentrations, except potassium, were observed among any treatment. Although the nutrient concentrations observed in this study were small, shearing and windrowing had the greatest impact on nutrient export. Roller chopping had a minimal impact on stormflow nutrient concentrations. The results of this study indicate the reduction in water quality impacts that can be derived from different management practices.

Blackmon, B.G. (ed). 1985. *Forestry and water quality: A mid- south symposium*. Little Rock, Arkansas, May 8-9, 1985. Arkansas Cooperative Extension Service, University of Arkansas.

This document contains papers from a symposium on forestry and water quality. Topics addressed in the symposium include historical perspectives on forestry and water quality, legislative trends, physical and chemical elements of forest hydrology, education programs, and results of original research. Because of the importance of forest road construction in reducing forestry-related water quality problems, a section is also included on the hydrology of forest roads. The symposium proceedings contain nearly 20 individual papers addressing these topics.

Bormann, F.H., G.E. Likens, T.G. Siccama, R.S. Pierce, and J.S. Eaton. 1974. The export of nutrients and recovery of stable condition following deforestation at Hubbard Brook. *Ecological Monographs*. 44(3):255-277.

The effects of deforestation on the export of organic and inorganic particulate matter, erodibility, and the importance of dissolved substances in exported materials are presented in this paper. At the Hubbard Brook Experimental Forest, a forested watershed was clearcut and left in place. For the next 3 years, vegetative regeneration was controlled via the use of herbicides. Large increases (15 times) in particulate matter export were observed in the clearcut watershed, although little difference was observed the first 2 years and a dramatic difference was observed during the third year. In addition, the average ratio of export of dissolved substances to particulate matter was 2.3 for undisturbed and >8.0 during the first two years for clearcut. This paper provides significant amounts of data comparing deforested and undisturbed forested watersheds over several years. The temporal changes in water quality due to changes in vegetative cover provides significant evidence of the impacts of deforestation on water quality.

Bormann, F.H., G.E. Likens, D.W. Fisher, and R.S. Pierce. 1968. Nutrient loss accelerated by clear cutting of a forest ecosystem. *Science*. 159:882-884.

The effect of forest clearcut on nutrient loss was examined. The nutrient concentration in runoff water was compared to concentrations observed in an undisturbed forested watershed. Data from the study indicated significantly higher nutrient losses from the clearcut watershed. The results of this study suggest the following about nutrient depletion due to clearcut: reduced transpiration and increased runoff lead to greater export; reducing root surfaces reduces uptake and storage, removal of nutrients in forest products, and increased mineralization of exposed soils. This paper provides good data for comparison to other similar studies conducted within the Hubbard Brook Experimental Forest.

Brown, G.W. 1972. Logging and water quality in the Pacific Northwest. In: *Watersheds in Transition Symposium Proceedings*. Urbana, Illinois. American Water Resources Association. pp. 330- 334.

This paper summarizes the research findings describing the impact of logging and road construction on water quality in the Pacific Northwest. The review of logging and road construction impacts includes information on sediment, nutrients, water temperature, and dissolved oxygen. In addition, the problems associated with implementation and enforcement of Oregon's water quality standards on small headwater streams are described. The water quality standards are based on deviation from normal levels, which are difficult to determine for small streams with highly variable conditions. The authors suggest controlling the impact of forestry activities on water quality through standardization of practices.

Brown, G.W. 1970. Predicting the effect of clearcutting on stream temperature. *Journal of Soil and Water Conservation*. 25:11-13.

This paper presents a methodology for predicting the effects of clearcutting on stream water temperature. The author states that predicting the effects could be done by estimating maximum daily changes, rather than hourly changes which would require experience in micrometeorology and additional equipment. This paper presents a simple model for estimating the daily maximum changes assuming the following: the stream surface is uniformly exposed to direct sunlight, direct solar radiation dominates the net heat gain in small streams, maximum temperature will occur during midday hours on a clear day, and predicted solar input can be used to estimate heat input. Model equations are also presented in this paper. Much of the background to this work was published in Brown 1969 and Brown and Kryger 1970.

Brown, G.W., A.R. Gahler, and R.B. Marston. 1973. Nutrient losses after clear-cut logging and slash burning in the Oregon Coast Range. *Water Resources Research*. 9:1450-1452.

The impact of two patterns of clearcut logging on the nutrient losses from two Oregon watersheds was studied. With the exception of nitrate-nitrogen, no nutrient concentrations increased after clearcut. Nitrate-nitrogen concentrations significantly increased after clearcut logging and slash burning. No significant changes in nitrate concentrations were observed after patch-cut logging. Nitrate-nitrogen concentrations returned to prelogging levels within 6 years of harvest.

Brown, G.W., and J.T. Krygier. 1971. Clear-cut logging and sediment production in the Oregon coast range. *Water Resources Research*. 7(5):1189-1198.

The impact of road construction, two patterns of clear-cut logging, and controlled slash burning on the suspended sediment yield and concentration from three small watersheds was studied for 11 years. Sediment production was doubled after road construction but before logging in one watershed and was tripled after burning and clearcutting of another watershed. Felling and yarding did not produce statistically significant changes in sediment concentration. Variation in the relation between sediment concentration and water discharge on small undisturbed streams was large. Conclusions about the significance of all but very large changes in sediment concentrations are limited because of annual variation for a given watershed, variation between watersheds, and variation with stage at a given point. Tables present sediment concentrations in the two altered watersheds and one control watershed for the duration of the study.

Brown, G.W., and J.T. Krygier. 1970. Effects of clearcutting on stream temperature. *Water Resources Research*. 6(4):1133-1140.

This study examined the effects of three forest management practices: fully clearcut, patch-cut with buffer strips, and unlogged on stream temperatures. Significant increases in stream temperature were observed in the clearcut watershed. The patch- cut watershed, which had buffer strips along the stream, did not have

significantly greater water temperatures than the unlogged watershed. The results presented in this paper have been duplicated by many studies conducted since. Evidence suggests that leaving streamside buffers strips alleviates much of the temperature increase associated with timber harvest. Stream production impacts were not assessed in this study.

Burns, R.G., and J.D. Hewlett. 1983. A decision model to predict sediment yield from forest practices. *Water Resources Bulletin*. 19(1):9-14.

The authors propose a sediment hazard index based on the amount of exposed mineral soil and its proximity to streams as a means to choose among BMPs. Forest managers need to predict sediment yield to perennial streams following forestland operations, but the universal soil loss equation (USLE) is not directly applicable to forest operations because of the heterogeneous soil surface conditions left by harvesting, site preparation, and planting. The model described includes rainfall erosivity, soil erodibility and average land slope, together with the sediment hazard index (W). A paired watershed experiment in the central Georgia Piedmont was used to estimate parameters in the model. The 80-acre experimental basin was clearcut, drum roller chopped twice, and machine planted. The standard error of estimate of sediment yield was computed to be about 50 lb/ac per 4-month sampling period. Use of William's erosivity index (storm flow times peak flow) reduced the standard error to 33 lb/ac. A graph of sediment delivery versus sediment hazard index is provided, and the index can be used to design and evaluate forest operations in advance. The authors note that application of the method presumes the use of streamside management zones and sensible roading standards.

Campbell, I.C., and T.J. Doeg. 1989. Impact of timber harvesting and production on streams: A review. *Australian Journal of Marine and Freshwater Research*. 40(5):519-539.

The various stream impacts associated with timber harvest activities are reviewed in this paper. More than 100 references describing effects on stream flow, water quality (sediment, nutrients, dissolved solids, dissolved oxygen, organic matter, light availability, and temperature), and stream biota are presented. Other activities not directly part of timber harvest, such as pesticides, fertilizers, and fire and fire management, are also reviewed. From the review, the authors concluded that the major impacts of forestry operations on stream biota occur through sediment and debris deposition and alteration of riparian vegetation.

Chatwin, S.C., D.E. Howes, J.W. Schwab, and D.N. Swanston. 1991. *A guide for management of landslide-prone terrain in the Pacific Northwest*. British Columbia Ministry of Forests. Land Management Handbook No. 18. 212 pages.

This guide was prepared for personnel operating in areas with existing or potential land stability problems. The document was developed for use in the Pacific Northwest; however, the principles presented may be applicable to other areas. Four topics are addressed: slope movement processes, recognition of landslide-prone areas, measures to manage unstable terrain during forestry activities (especially road construction and timber harvest), and road deactivation and revegetation on unstable terrain. Detailed definitions and techniques for determining potential instability and methods for preventing landslides from forestry roads are included.

Corbett, E.S., J.A. Lynch, and W.E. Sopper. 1978. Timber harvesting practices and water quality in the eastern United States. *Journal of Forestry*. 76(8):484-488.

Descriptions of the nature and extent of changes to water quality from forest harvesting practices are provided. Data from several forested watersheds in the eastern United States are included to provide examples of water quality impacts of forestry operations, especially clearcutting. Topics discussed and their implications include nutrient concentrations, stream water temperature, stream turbidity and sedimentation, and the use of buffer strips.

Cornish, P.M., and D. Binns. 1987. Streamwater quality following logging and wildfire in a dry sclerophyll forest in southeastern Australia. *Forest Ecology and Management*. 22:1-28.

A study was conducted to compare the cationic composition of streamwater draining two forested watersheds in southeast Australia. The cationic concentrations decreased for the first several years from small subcatchments subjected to logging and wildfire, but became greater than prelogging and wildfire levels after 3-4 years. The authors suggest that hydrologic changes resulting from a protracted drought and logging/wildfire may have influenced cationic concentrations. Streamwater turbidity also increased in the logging/wildfire-treated subcatchment.

Cromack, K., Jr., F.J. Swanson, and C.C. Grier. 1978. A comparison of harvesting methods and their impact on soils and environment in the Pacific Northwest. In: *Forest Soils and Land Use, Proceedings of the Fifth North American Forest Soils Conference*. Colorado State University, Fort Collins, Colorado. C.T. Youngberg (ed.). pp. 449-478.

The effects of various harvesting methods on soils and the environment in the Pacific Northwest are reviewed in this paper. Topics reviewed include effects on subsequent vegetation, effects on nutrient losses, effects of fertilization, effects on soil integrity and erosion, nutrient restitution following harvesting, and effects on streams. An example of the effects is presented as a case of study in the Cascade Range of Oregon. Nearly 70 references are cited in the review.

DeBano, L.F. 1977. Influences of forest practices on water yield, channel stability, erosion, and sedimentation in the Southwest. In: *Proceedings of the Society of American Foresters*. pp. 74-78.

This paper presents information on the climate and hydrologically important vegetation types in the Southwest, the basin hydrologic processes affecting water yield and erosion, and the effect of cover manipulations, such as timber harvesting. Results are presented suggesting that water yield is not significantly improved by tree harvest unless small clearings or strips are created. In addition, clearing of trees increases the amount of erosion if storms of high intensity occur. The authors also recommend leaving dead and dying trees along the stream channel to control erosion into streams.

DeHart, D.B. 1982. *The effects of timber harvesting on erosion and sedimentation in New Hampshire*. 36 pages. New Hampshire Division of Forests and Lands, Department of Resources and Economic Development.

The results of a survey of the impacts of forest harvest practices on soil loss and water quality are presented in this document. Overall, commercially clearcut sites had higher erosion rates and greater water quality impacts than sites harvested by other methods. A glossary of forestry terms and an explanation of various forestry best management practices are also included in the document.

DeHaven, M.G., W.H. Blackburn, R.W. Knight, and A.T. Weichert. 1984. *The impact of harvesting and site preparation on stormflow and water quality in east Texas*. Report TR-130. Texas Water Resources Institute, Texas A&M University. 147 pages.

Nine small watersheds in east Texas were used to determine the water quality effects of timber harvest and site preparation operations. The 3 treatments included clearcutting followed by shearing and windrowing, clearcutting followed by roller chopping, and undisturbed control. The roller chopped treatment exposed 16% of the soil and the shearing and windrowing exposed 57% of the soil. Higher stormflow and sediment loss was observed during the first three years post-treatment, although the differences decreased after the first year. During the second year, exposed decreased to 20 and 4% on sheared and chopped watersheds, respectively. Nutrient concentrations were also highest from the sheared treatment. The authors concluded that temporary increases in nutrient, sediment, and stormflow would occur on sheared and chopped watersheds,

although greater losses would occur from sheared due to increased duration of soil exposure. Roller chopping appeared to cause minor changes compared to shearing and windrowing.

Douglass, J.E., and W.T. Swank. 1975. Effects of management practices on water quality and quantity: Coweeta Hydrologic Laboratory, North Carolina. In: *Municipal Watershed Management Symposium Proceedings*. USDA Forest Service, Northeastern Forest Experiment Station. General Technical Report NE-13. pp. 1-13.

A summary of 40 years of water quality and quantity data collected at the Coweeta Hydrologic Laboratory is provided. Descriptions of the effects of various timber treatments, including harvest and conversion, on water yield and water quality are presented. Models for predicting changes in water yields based on basal areas remaining are also presented. This paper provides information on the effects of timber harvest practices in the southeastern United States from a continuously monitored watershed.

Dyrness, C.T., and C.T. Youngberg. 1957. The effect of logging and slash burning on soil structure. *Soil Science Society of America Proceedings*. 21(4):444-447.

The effects of logging and slash burning on soil structure were investigated in soils in the Coast Range of western Oregon. Soil samples were collected from clearcut and undisturbed forested areas. The soil surface after logging and slash burning were as follows: lightly burned (45%), severely burned (8%), unburned (30%), and undisturbed (17%). Severe burning was the only treatment that had a significant effect on the soil structure. The authors concluded that because logging and slash burning resulted in only 8% severely burned area, high-lead logging and slash burning in the fall after rainfall would have no significant detrimental effect on soil structure.

Eschner, A.R., and J. Larmoyeaux. 1963. Logging and trout: Four experimental forest practices and their effect on water quality. *Progress in Fish Culture*. 25:59-67.

Studies were done to determine how four different timber harvesting practices affect water quality and streamflow. The four practices investigated were a commercial clearcut, a diameter limit (all trees over 17 in dbh), extensive selection (selected trees over 11 in dbh), and intensive selection (selected trees over 5 in dbh). Five contiguous, forested watersheds in the Fernow Experimental Forest west of the Allegheny Front in West Virginia served as study sites. Streamflow, precipitation, and water quality were studied on the watersheds for 6 years prior to four of the five watersheds being logged. Prediction equations were formulated from the data obtained. Stream discharge was increased by the treatments, low flow was significantly augmented, and water quality was damaged. Growth on remaining trees and new cover appeared immediately following the treatments, and improvements in water quality and a return to normal flow occurred. Tables detailing the treatments and their effects on the four logged watersheds, corresponding to the four practices studied, are included.

Feller, M.C. 1981. Effects of clearcutting and slash burning on stream temperature in southwestern British Columbia. *Water Resources Bulletin*. 17(5):863-866.

Two watersheds were studied for the effect of logging practices on summer and winter water temperatures. One of the watersheds was clearcut and then planted, and the other was clearcut, slash burned, and then planted.Tables of watershed characteristics and duration of temperature effects are included. Both practices were found to increase stream temperature, but slash burning increased the temperature effect beyond that of clearcutting alone. This is attributed to burning the slash that remains at streamside after clearcutting. Clearcutting was found to increase minimum and maximum winter stream temperatures during the second winter following the cutting. Slash burning decreased minimum and maximum winter stream temperatures in the first winter following the burning. The effect on stream temperature of clearcutting and slash burning lasted longer (>7 years) than that of clearcutting alone.

Ferguson, R.I., and T.A. Stott. 1987. Forestry effects on suspended sediment and bedload yields in the Balquhidder catchments, Central Scotland. *Earth Sciences, Transactions of the Royal Society of Edinburgh*. 78:379-384.

Outputs of suspended sediment and bedload from the 7.7-km^2 moorland Monachyle basin and the 6.8-km^2, 40%-forested Kirkton basin near Balquhidder and inputs from tributary streams and mainstream bank erosion are compared. Sediment yield is about three times higher in the forested basin and varies more sensitively with streamflow, suggesting greater availability of erodible sediment. The output is predominantly suspended sediment and is derived mainly from tributary streams. Initial observations following partial moorland plowing and forest clearcutting in 1986 indicate that erosion of timber loading areas and logging roads is the main sediment source.

Foggin, G.T., III, and L.K. Forcier. 1974. *Cation concentrations in small streams draining match forested and clearcut watersheds in western Montana*. Montana State University, Joint Water Resources Research Center, Bozeman, Montana. Res. Report 58. 54 pages.

The impacts of clearcutting practices on the nutrient output of forested ecosystems and the effect on stream water quality are examined in this study. Fifteen clearcut basins in western Montana were selected and their morphometric characteristics determined. Water samples from these watersheds were analyzed for nutrients and other water quality parameters. It was determined that the clearcut basin produced higher dissolved nutrient loads, as well as increased flow.

Fowler, W.B., T.D. Anderson, and J.D. Helvey. 1988. *Changes in water quality and climate after forest harvest in central Washington State*. USDA Forest Service, Pacific Northwest Research Station. Research Paper PNW-RP-388. 12 pages.

This report presents a case history of the changes in streamflow quality and temperature as affected by timber harvest activities. During three pretreatment and posttreatment years, only calcium and sodium concentrations increased compared to the control. Mean maximum air temperatures increased during the posttreatment period, but stream temperatures were relatively unaffected. There was no mention of whether riparian buffer strips were maintained during harvest although stream temperatures typically increase when streamside vegetation is removed.

Fraley, J., T. Weaver, and J. Vashro. 1989. Cumulative effects of human activities on bull trout (*Salvelinus confluentus*) in the Upper Flathead Drainage, Montana. In: *Proceedings of the Symposium on Headwaters Hydrology*. American Water Resources Association, Bethesda, Maryland. pp. 111-120.

The potential cumulative effects of land management practices, such as timber harvest and road building in the Flathead Lake watershed, on the population of the bull trout are summarized. The authors provide evidence from other monitoring studies that suggests that the deposition of fine sediments from streamside disturbances and forest road construction activities have adversely affected and could continue to adversely affect the bull trout. Based on information summarized in this paper, the authors called for amendments of current management standards, including riparian guidelines and increased implementation of best management practices to reduce sediment delivery.

Frear, S.T. 1982. Timber harvesting and water quality in the Bull Run Municipal Watershed. In: *Forestry Research West*. USDA Forest Service, pp. 4-8.

Timber harvesting and its effects on the Bull Run Municipal Watershed are discussed. The watershed contains significant silvicultural activity and also serves as a large source of drinking water for the region. The interaction between the two amenities was studied. The study included three watersheds: one was a control, and two were used for various timber management practices including road construction, timber harvest, and site preparation. The author concludes that timber harvest activities in this

watershed do not cause appreciable degradation in water quality.

Fredriksen, R.L. 1971. Comparative chemical water quality-Natural and disturbed streams following logging and slash burning. In: *Proceedings of a Symposium: Forest Land Uses and Stream Environment*. Oregon State University, October 19-21, 1970. J.T. Krygier and J.D. Hall (eds.). OSU, Corvallis, Oregon. pp. 125- 137.

The loss of nutrients from an old growth Douglas fir forest was measured in streams following timber harvest and slash burning. Nutrient cation losses increased 1.6 to 3.0 times the loss of the undisturbed watershed. The surge of nutrients following slash burning contained ammonia and manganese concentrations greater than federal water quality standards for 12 days after burning. The authors conclude that nitrogen losses can be minimized by avoiding slash burning when possible. This paper presents many figures and tables with the data from the study.

Glasser, S.P. 1989. *Summary of water quality effects from forest practices in the South*. USDA Forest Service Southern Region, Atlanta, Georgia. 50 pages.

The results of watershed studies within 13 Forest Service Southern Region states are summarized for the reported effects of common forestry practices on water quality. The results indicate that sediment yields from poorly conducted logging and road construction activities can be 100 times higher than those from undisturbed forests for brief periods although recovery to pre-disturbance levels occurs within 3 years. Various BMPs were reported to minimize water quality impacts. Monitoring of nutrient and herbicide concentrations in stream water indicate little threat from forestry activities. This document is a good condensation of the results of forestry water quality studies conducted from the 1960s to the 1980s.

Golden, M.S., C.L. Tuttle, J.S. Kush, and J.M. Bradley. 1984. *Forestry activities and water quality in Alabama: Effects, recommended practices, and an erosion-classified system*. Auburn University, Agricultural Experiment Station. Bulletin 555.

The report was prepared primarily as a source of information on the relationship between forestry practices and water quality, with orientation toward forestry practices prevalent in Alabama. Information on stream pollutants such as sediment, nutrients, pesticides, organic material, waste and litter, and temperature is provided. The review includes over 160 directly cited documents on these subjects. Also included in the report are recommendations of principles and practices designed to minimize the water quality impacts from Alabama forestry practices.

Grant, G. 1988. *The RAPID technique: A new method for evaluating downstream effects of forest practices on riparian zones*. USDA Forest Service, Pacific Northwest Forest and Range Experiment Station. General Technical Report PNW-220.

The RAPID (riparian aerial photographic inventory of disturbance) technique is a method for using measurements made on aerial photographs of patterns of riparian canopy disturbance to evaluate changes in channel conditions through time and to link such changes with their possible upstream causes. The RAPID technique provides resource specialists and managers with a relatively quick way of identifying stream reaches that are chronically or recently disturbed by a variety of channel processes, including increased peak flows and sedimentation from point and nonpoint sources. With examples from western Oregon, this paper describes how to apply the RAPID technique and analyze the results to evaluate downstream or cumulative effects of forest practices.

Gray, J.R.A., and J.M. Edington. 1969. Effect of woodland clearance on stream temperature. *Journal of the Fisheries Research Board of Canada*. 26:399-403.

This paper presents the results of a study quantifying the differences in stream temperature after clearance of the adjacent woods. The

authors observed significantly greater water temperatures in the cleared areas than in undisturbed areas. The temperatures in the forested stream were also compared to temperatures in stream flowing through an open farm to demonstrate the cooling affect of forests.

Gurtz, M.E., and J.B. Wallace. 1984. Substrate-mediated response of stream invertebrates to disturbance. *Ecology*. 65(5):1556-1569.

The response of aquatic invertebrates to clearcutting was examined in a second order stream in the southern Appalachian mountains. For 21 months after clearcut, invertebrates were sampled in the following substrates: rock face, cobble riffles, pebble riffles, and sand. In the clearcut watershed, more taxa increased in rock substrate, followed by cobble riffles, pebble riffles, and sand. The most significant reductions in taxa was observed in sand substrate. The authors noted, based on differences among function groups of insects, that biological stability was closely linked with physical stability.

Hansmann, E.W., and H.K. Phinney. 1973. Effects of logging on periphyton in coastal streams of Oregon. *Ecology*. 54:194-199.

Prelogging and postlogging oxygen levels, temperature, and sedimentation loads were analyzed in a study of small watersheds in Oregon. Clearcut logging was applied to one watershed of 71 hectares, while a second watershed was patch-cut leaving a buffer-strip of vegetation along the stream channel. A third watershed remained as a control. The study showed that a close relationship exists between watershed practices and floral characteristics of the drainage system and that stream characteristics can maintain themselves if adequate protection is given to stream vegetation.

Harr, R.D., and R.L. Fredriksen. 1988. Water quality after logging small watersheds within the Bull Run Watershed, Oregon. *Water Resources Bulletin*. 24(5):1103-1111.

The water quality impacts from clearcut practices and slash burning are presented. Logging significantly increased nitrate- nitrogen levels for up to 7 years after harvest; smaller increases were observed after slash burning. Suspended sediment also had a small increase attributed to construction of a permanent road that crossed streams. Annual stream temperatures increased 2-3 °C after logging but returned to pretreatment levels after 3 years. This watershed study presents significant data on the effects of forest harvest and slash burning on water quality.

Harr, R.D., A. Levno, and R. Mersereau. 1982. Streamflow changes after logging 130-year old Douglas fir in two small watersheds. *Water Resources Research*. 18(3):637-644.

This report summarizes a case history of changes in streamflow observed after harvesting in two small experimental watersheds in western Oregon. Harvest in the watersheds containing 130-year old timber increased annual water yield up to 42 cm. For 4 years after logging, yield increases averaged 38 cm and 20 cm in the clearcut and shelterwood harvested watersheds, respectively. The increased summer flows were indicated by much fewer low-flow days after logging, particularly in the clearcut watershed. Neither the size or the timing of peak flows changed significantly after logging at either watershed.

Hartman, G., J.C. Scrivener, L.B. Holtby, and L. Powell. 1987. Some effects of different streamside treatments on physical conditions and fish population processes in Carnation Creek, a coastal rain forest stream in British Columbia. In: *Streamside Management: Forestry and Fishery Interactions*. E.O. Salo and T.W. Cundy (eds). University of Washington, College of Forest Resources, Seattle, Washington. pp. 330-372.

Carnation Creek has been studied continuously since 1971. During this time 41% of the watershed was logged. Three different streamside treatments conducted in the alluvial floodplain portion were evaluated: (1) an intensive treatment of clearcutting, felling of streambank alder, and yarding of felled trees and merchantable timber;

(2) a careful treatment of clearcutting to the margin of the stream and felling of streambank alder, with no in-channel activity; and (3) a leave strip treatment in which a variable width strip of vegetation was left along the stream. Stream temperature increased due to logging. The decrease in volume and stability of large debris was accompanied by streambank erosion and straightening of the channel. This in turn caused a change in gravel quality in the lower sections of the stream. Coho and chum salmon egg-to-fry survival was lower following the first major storm following logging. Trout smolt numbers decreased, but coho smolts increased by 76% between 1976 and 1983. Afterward they decreased to prelogging levels.

Hatchell, G.E., C.W. Ralston, and R.R. Foil. 1970. Soil disturbance in logging: Effects on soil characteristics and growth of loblolly pine in the Atlantic Coastal Plain. *Journal of Forestry*. 68:772-775.

The effect of compaction on wet and dry southern coastal soils was researched. The density of soils before and after tractor crossing, the rate of soil recovery, and the effect of dense soils on seedling growth were determined. Greatest soil disturbance occurred during wet weather on sites with medium- to fine-textured soils. The damage that results from traversing wet sites can cause conditions detrimental to tree growth. The authors recommend not traversing wet soils and not traversing dry soils more than once or twice.

Heede, B.H. 1987. Overland flow and sediment delivery five years after timber harvest in a mixed conifer forest, Arizona. *Journal of Hydrology*. 91:205-216.

An erosion study outlining the effects of timber harvesting and subsequent sediment transport is presented. The area of study is located in the White Mountains of eastern Arizona, with mixed conifer as the predominant vegetation type. Following statistical analysis, it was determined that sediment delivery from the disturbed forest floor did not differ significantly from that of an undisturbed floor. This paper presents information on the numerous factors that influence sediment movement within a watershed.

Heede, B.H. 1991. Response of a stream in disequilibrium to timber harvest. *Environmental Management*. 15(2):251-255.

The influence of timber harvest on streamflow was demonstrated in this study. Increases in flow were observed during and after harvest, resulting in increases in erosion from the site. Data are presented from samples collected preharvest, during harvest, and postharvest.

Heifetz, J., M.L. Murphy, and K.V. Koski. 1986. Effects of logging on winter habitat of juvenile salmonids in Alaskan streams. *North American Journal of Fisheries Management*. 6:52- 58.

This study was conducted in southeastern Alaska to determine the effects of logging on winter habitat of juvenile salmonids. The types of streams studied were located in the following areas: undisturbed old-growth forest, clearcut with riparian buffer strips, and clearcut logged along at least one bank. The authors found that most fish species resided in pools, and riffles and glides were avoided. The types of pools utilized varied widely during the study. Also, the amount of woody debris, which caused over 70% of the pools, was significantly greater in occupied pools. Several tables of data quantifying salmonid numbers for each stream type and pool type are included.

Hetherington, E.D. 1976. *Dennis Creek: A look at water quality following logging in the Okanagan Basin*. Rac. For. Res. Cen., Canada Forest Service. Information Report BX-X-147. 33 pages.

The impact of clearcutting activities (25% of the watershed) in the Dennis Creek watershed in British Columbia on water quality was monitored during the second year after clearcut. The monitoring data indicated negligible impacts on water quality parameters, with only slight increases in potassium, sodium chloride, electrical conductivity, total organic carbon, and dissolved solids observed. Sediment concentrations

increased, but remained at very low levels. Because the monitoring was relatively short-term, the author concluded that increasing the percentage of watershed cut-over would result in increased degradation of water quality.

Hewlett, J.D. 1978. *Forest water quality: An experiment in harvesting and regenerating a Piedmont forest*. School of Forest Resources, University of Georgia. 22 pages.

Two streams in Putnam County, Georgia, were selected to determine the effects that harvesting and regeneration have on water quality and flow in order to determine appropriate BMPs. Periodic samples were taken and flow recorded. The study indicated that 90% of the undesirable mass export of sediment resulted from poor access roads and streamside management.

Hewlett, J.D., and J.D. Helvey. 1970. Effects of forest clear- felling on the storm hydrograph. *Water Resources Research*. 6: 768-782.

The effects of forest clearcut on the storm hydrograph and whether clearcut increases the size and frequency of floods was examined. After clearcut, stormflow volume was increased by 11% over pre-clearcut volumes. Peak discharge also increased after felling, although not as much as the stormflow volume. This paper substantiates many hypotheses regarding increased floodwater potential after clearcut of forested watersheds. Significant amounts of data are presented, and correlation coefficients relating variables to treatment effects are provided.

Hicks, B.J., R.L. Beschta, and R.D. Harr. 1991. Long-term changes in streamflow following logging in western Oregon and associated fisheries implications. *Water Resources Bulletin*. 27(2):217-226.

The long-term effects of logging on low summer streamflow was investigated using data collected from 1953-1988. Three watersheds in western Oregon were clearcut and burned, unlogged, and 25% patch cut and burned. Monitoring occurred for 9- 10 years pre-logging and 21-25 years post-logging and burning. August streamflows, which were the lowest of any month, increased by 159% after clearcutting watershed 1 but the effects lasted for only eight years. August streamflow increased by 59% in watershed three after 25% patch cut and burning. This paper presents important data on the changes in water yield during periods of summer low flow conditions. Some evidence was presented which suggests that conifer species in the riparian zone maintain summer water yields better than hardwoods.

Holtby, L.B. 1988. Effects of logging on stream temperatures in Carnation Creek, B.C. *Canadian Journal of Fisheries and Aquatic Sciences*. 45:502-515.

The objectives of this study were to quantify the effects of clearcut logging on stream temperatures in Carnation Creek and to quantify the effects of the logging-related component of those temperature changes on the coho salmon population. Forty-one percent of the basin of the creek was clearcut, increasing stream temperatures in all months of the year. As a result, coho salmon emerged earlier and increased the length of their summer growing season by up to 6 weeks. Over-winter survival improved as a result of increased growth by the fall. Warmer spring temperatures were also associated with earlier seaward migration of smolts, probably resulting in decreased smolt-to-adult survivals. For this analysis, the author used a linked series of models to predict the effects of logging on stream temperatures and then the effects of those temperatures on critical coho life history events. A life history model was used to quantify the effects of stream temperature changes related to logging on the population size of adult coho salmon. The author concludes: (1) habitat perturbations can have quantifiable effects on fish populations; (2) habitat alteration can affect more than one life stage simultaneously and in opposite directions; (3) the effects of perturbations at one life stage can persist throughout the remainder of the life cycle; and (4) for anadromous fish species, the effects of habitat perturbations during freshwater rearing can persist into the marine phase.

Hoover, M.D. 1952. Water and timber management. *Journal of Soil and Water Conservation* 7:75-78.

This paper presents a historical perspective on the proper management of timber stands for water yield and water quality and flash flood prevention. The paper presents information on forestry impacts on water quality, vegetation influences, streamflow increases, soil disturbances, and road and trail locations.

Hornbeck, J.W. 1968. Protecting water quality during and after clearcutting. *Journal of Soil and Water Conservation* 23(1):19- 20.

This paper provides a follow-up study to Hornbeck and Reinhart (1964). In this study two watersheds were harvested using selection cutting and carefully planned logging operations that exposed less than 1% of the watershed's mineral soil. Turbidity levels from this study were lower than those reported in 1964. As with the 1964 study, skid roads were considered the primary source of the turbidity from the watershed. The author concludes that water quality impacts associated with timber harvest activities can be reduced if sound practices are used.

Hornbeck, J.W., G.E. Likens, R.S. Pierce, and F.H. Bormann. 1975. Strip cutting as a means of protecting site and streamflow quality when clearcutting northern hardwoods. In: *Forest Soils and Forest Land Management, Proceeding of the Fourth North American Forest Soils Conference*. B. Bernier and C.H. Winget (eds.). pp. 209-224.

The results of a progressive strip cutting (a form of clearcutting) experiment in northern hardwoods at the Hubbard Brook Experimental Forest are presented in this paper. Various changes to the ecosystem, including vegetation response, and changes in water yield and water quality are discussed. The following conclusions are made: (1) small increases in water yield were observed during two succeeding growing seasons; (2) stream temperature, pH, and turbidity showed minor changes after strip cutting; and (3) large increases in nitrate and calcium were observed although the losses were smaller than those typical of conventional clearcutting. The paper also presents data on other nutrients monitored during the experiment.

Hornbeck, J.W., C.W. Martin, and C.T. Smith. 1986. Protecting forest streams during whole-tree harvesting. *Northern Journal of Applied Forestry*. 3(3):97-100.

The effects of whole-tree harvests in the Northeast on stream turbidity, temperature, and chemistry in three watersheds are presented in this paper. The data indicate that the use of BMPs during whole-tree harvest can limit water quality impacts to levels typical of bole-only harvest. The paper lists eight BMPs that the authors suggest to minimize stream damage from all forms of tree harvesting: use streamside buffer strips of 15 to 30 m; select logging methods that minimize road construction; maximum grade on roads of 10% (except for short stretches); install cross drains and dips to move water from roads and trails; minimize rutting by skidders by avoiding repeat trips over the same route; exhibit flexibility in planning operations (e.g., build roads and trails during dry weather); finish the operation as soon as possible; and remove temporary bridges and culverts, and revegetate problem areas.

Hornbeck, J.W., and K.G. Reinhart. 1964. Water quality and soil erosion as affected by logging in steep terrain. *Journal of Soil and Water Conservation*. 19(1):23-27.

The effects of four different logging practices on water quality and soil erosion from five watersheds in West Virginia were studied. The four logging practices were commercial clearcut (all merchantable above 6-inch dbh), diameter limiting cutting (17-inch dbh and killing of unmerchantable trees by poison), extensive selection cutting (selected trees above 11-inch dbh and unmerchantable trees killed), and intensive selection cutting (selected trees above 5-inch dbh and unmerchantable trees killed). No permanent roads were constructed in the watersheds; only skid trails were present. Turbidity was significantly greater in the commercial clearcut,

with a maximum value of 56, 000 ppm reported although all treatments had higher turbidities than the control watershed. The authors suggest that the large increase in soil erosion from the harvested sites was due to the haphazard methods of logging and lack of controls for the skid trails.

Johnson, M.G., and R.L. Beschta. 1980. Logging, infiltration capacity, and surface erodibility in western Oregon. *Journal of Forestry*. 78(6):334-337.

The impact of forestry activities on the infiltration capacity and surface erosion in western Oregon were examined in this study. The harvesting treatments analyzed included harvest with tractor skidding, clearcutting with cable yarding, clearcutting with tractors used for skidding and windrowing, and undisturbed. The time between harvest operation and the study varied from 3 to 6 years. The average infiltration capacities after 6 years were not significantly different than those of the undisturbed watershed for most watersheds. However, the treatment with tractor harvesting, windrowing of slash, and burning of slash on high-clay-content soils resulted in a reduction of nearly 1 inch per hour. This same treatment also had a significantly higher suspended sediment concentration than the other treatments. This study indicates that timber harvest practices may have a profound effect on infiltration and erosion. The data were collected for 6 years after treatment, and it is likely that effects would have been greater immediately after harvest.

Johnston, R.S. 1984. *Effect of small aspen clearcuts on water yield and water quality*. USDA Forest Service, Intermountain Forest and Range Experiment Station.Research Paper INT-333. 9 pages.

Mature aspen were removed from a watershed in Utah, with subsequent monitoring of water quality and flow changes from the effects of this disturbance. The data are effectively presented with the use of tables and figures. The lack of significant effects from the harvest may be attributed to the small size of the area cut and other geomorphologic factors. The author concludes that anticipated water yield increases should not be simply extrapolated to the other areas of harvest due to the complex set of criteria involved.

Jones, R.C., and B.H. Holmes. 1985. *Effects of land use practices on water resources in Virginia*. Virginia Polytechnic Institute and State University, Water Resources Research Center. VPI-VWRRC-BULL-144.

This report presents a review of forestry, agriculture, and urban land uses in Virginia and how they affect water resources. A review of hydrologic changes and water quality impacts from forestry operations is included. In addition, a review of forestry water quality management programs in the state is presented. This report presents generalized information on how a specific state manages water resources that may be affected by forestry activities.

King, J.G. 1989. *Streamflow Responses to Road Building and Harvesting: A Comparison With the Equivalent Clearcut Area Procedure*. USDA Forest Service, Intermountain Research Station, Ogden, Utah. Research Paper INT-401. 13 pages.

Increases in annual streamflow and peak streamflows were determined on four small watersheds north-central Idaho after road building and timber harvest. These measured data were than compared to values predicted by the equivalent clearcut area procedure (ECA), a methodology commonly used to project hydrologic changes associated with timber management practices. The increase in average annual streamflow following harvesting and road building was much larger than predicted by the ECA procedure. The author notes that current procedures for estimating the hydrologic responses to timber removal of third to fifth order streams often ignore what may be hydrologically important modifications of low-order streams. Potential modifications to headwater basins should be considered when scheduling harvest entries and locating harvest units, especially when conditions are such that the stream system is likely to be sensitive to streamflow modification.

Kochenderfer, J.N., and G.M. Aubertin. 1975. Effects of management practices on water quality and quantity: Fernow Experimental Forest, West Virginia. In: *Municipal Watershed Management Symposium Proceedings*. USDA Forest Service, Northeastern Forest Experiment Station. General Technical Report NE-13. pp. 14-24.

The data from 22 years of research into the influence of forestry practices on the quantity and timing of streamflow and on water quality parameters such as turbidity, temperature, specific conductance, pH, alkalinity, and nutrient concentrations are reviewed in this paper. Water quality degradation was observed from clearcut experimental watersheds, whereas minor changes in water quality were observed when forestry practices were well planned and conducted. The authors conclude that at the time of this paper, forests could not be managed for timber products and water yield and that water quality degradation could easily be avoided by using erosion control management practices. Data from the research are presented, although no statistical analysis of the data is provided.

Krause, H.H. 1982. Effect of forest management practices on water quality - a review of Canadian studies. In: *Proceedings of the Canadian Hydrology Symposium - Associate Committee on Hydrology*. Fredericton, New Brunswick, June 14-15, 1982. National Research Council Canada, Canada. pp. 15-29.

The water quality effects of forest management practices are reviewed separately for the British Columbia Coastal Range, Rocky Mountains, Canadian shield, and Appalachian region. Sedimentation is a problem after road construction and occasionally after slash burning. Temperature increases are problematic at low altitudes in areas with warm summers. Changes in dissolved solids depend on the type of operation, forest cover, soils, and geologic substrate.

Lawrence, G.B., R.D. Fuller, and C.T. Driscoll. 1987. Release of aluminum following whole-tree harvesting at the Hubbard Brook Experimental Forest, New Hampshire. *Journal of Environmental Quality*. 16(4):383-390.

This study investigated aluminum concentrations before and after timber harvest. An experimental watershed in the Hubbard Brook Experimental Forest was clearcut and stream chemistry was monitored 1 year prior to, and 2 years after, harvest. An initial increase in basic cations and nitrate concentration was observed, with a decrease in pH. The lower pH allowed the release of potentially toxic levels of inorganic aluminum. This work suggests the potential for severe impact on aquatic communities following whole-tree harvest where pools of aluminum exist.

Likens, G.E., F.H. Bormann, N.M. Johnson, D.W. Fisher, and R.S. Pierce. 1970. Effects of forest cutting and herbicide treatment on nutrient budgets in the Hubbard Brook watershed-ecosystem. *Ecological Monographs*. 40(1):23-47.

All vegetation on watershed 2 of the Hubbard Brook Experimental Forest in New Hampshire was cut in November and December 1965. Vegetation regrowth was inhibited by periodic herbicide applications. Annual stream flow was increased above normal values by 39% the first year and 28% the second year. Large increases in all major ions except NH_4^+, SO_4^- and HCO_3^- were observed for 5 months after deforestation. Nitrate concentrations in stream water were 41- and 56-fold higher during the first and second years following deforestation, respectively. Stream temperatures following deforestation were higher than normal and fluctuated 3-4 °C during the day during summer, in contrast to normally constant daytime temperatures. Turbidity increases were negligible, but particulate matter output increased 4-fold. Overall, the deforestation experiment resulted in significant pollution of the drainage stream from the ecosystem; this was largely due to the interruption of the nutrient cycle caused by the loss of vegetation.

Lynch, J.A., W.E. Sopper, E.S. Corbett, and D.W. Aurand. 1975. Effects of management practices on water quality and quantity: The Penn State Experimental Watersheds. In: *Municipal Watershed Management Symposium Proceedings*. USDA Forest Service. General Technical Report NE-13. pp. 32-46.

A three-phase experiment was conducted to determine the effects of timber harvest treatments on water quality and quantity. The different treatments included lower and middle slope harvests. Turbidity and water temperature measurements indicated a greater impact from lower slope harvest, with a maximum turbidity concentration of 550 ppm and a maximum water temperature increase of 7 °F. Water yield was also greater after lower slope harvest. This paper presents significant amounts of data concerning forestry impacts on a Pennsylvania forested watershed.

Mann, L.K., D.W. Johnson, D.C. West, D.W. Cole, J.W. Hornbeck, C.W. Martin, H. Reikerk, C.T. Smith, W.T. Swank, L.M. Tritton, and D.H. Van Lear. 1988. Effects of whole-tree and stem-only clearcutting on postharvest hydrologic losses, nutrient capital, and regrowth. *Forest Science*. 34(2):412-428.

The effects of whole-tree and stem-only clearcutting by comparative studies of uncut and clearcut stands at eight sites in the major timber harvesting areas of the United States was examined. The objectives of the study were to (1) estimate probable changes in nutrient capital due to direct removal by harvest, (2) estimate nutrient removal from harvested stands via hydrologic mechanisms, and (3) examine subsequent regrowth biomass following harvest. A combination of data from the current study and data from previously published studies were used in the analysis. These data indicate potential net loss of Ca and K at most sites without harvest and net losses of N, P, K, and Ca with either whole-tree or sawlog harvest. Total stem biomass and nutrients were significantly correlated with total above-stump biomass, providing a means for estimating nutrient removals with sawlog or whole-tree harvest from commercial forests. Limited data from harvested stands indicated greater regrowth biomass with sawlog harvest than with whole-tree harvest on some sites.

Marion, D.A., and S.J. Ursic. Sediment production in forests of the Coastal Plain, Piedmont, and Interior Highlands. In: *Proceedings of Technical Workshop on Sediments*. Corvallis, Oregon, February 3-7, 1992. U.S. Environmental Protection Agency and USDA Forest Service.

This paper presents a discussion of sediment production from small catchments in various physiographic regions and provides information on the magnitude and duration of the changes associated with silvicultural activities. Higher sediment delivery was reported from Coastal Plain soils than the Piedmont and Interior Highlands because of the high erosion potential of the soils and channelization of flow. The authors also reported on the effects of timber harvest activities on sediment delivery. No long-term increases (greater than 3 years) in sediment production were observed in harvested and burned watersheds. In contrast, persistent increases in sediment production can occur when intensive mechanical site preparation is employed. Harvest activities which minimized ground disturbance and protect channel areas were identified as practices that would not increase on- site sediment production.

Martin, C.W., D.S. Noel, and C.A. Federer. 1985. Clearcutting and the biogeochemistry of streamwater in New England. *Journal of Forestry*. pp. 686-689.

This paper presents the results of a survey conducted in New England to determine the effects of clearcutting on stream chemistry and water temperature. In this survey, clearcutting included conventional clearcutting and whole-tree harvest. All watersheds included in the survey contained skid trails, and most contained landings and truck roads. The results of the survey showed that clearcutting may increase nutrients, especially nitrate-nitrogen, calcium, and potassium. Increases in water temperature were also noted, with a corresponding increase in some

stream insect populations. The survey concluded that clearcutting does affect water chemistry although the magnitude of the changes is variable.

Martin, C.W., D.S. Noel, and C.A. Federer. 1984. Effects of forest clearcutting in New England on stream chemistry. *Journal of Environmental Quality*. 13(2):204-210.

Differences in stream chemistry in water samples collected from clearcut (6), partially clearcut (32) and uncut (18) watersheds are presented. Water samples collected from one clearcut watershed had significantly greater nutrient concentrations than those from a nearby uncut watershed. Only minor changes in stream water chemistry were observed in all other watersheds although clearcutting less than the entire watershed appeared to reduce the magnitude of the changes.

Martin, C.W., R.S. Pierce, G.E. Likens, and F.H. Bormann. 1986. *Clearcutting affects stream chemistry in the White Mountains of New Hampshire*. USDA Forest Service, Northeastern Forest Experiment Station. Research Paper NE-579.

Stream water samples were collected from watersheds that were completely harvested and from uncut watersheds. Differences in stream chemistry were monitored over a 4-year period. Constituents sampled for included specific conductance, pH, nitrate, ammonium, calcium, magnesium, sodium, potassium, sulfate, and chloride.

McClurkin, D.C., P.D. Duffy, and N.S. Nelson. 1987. Changes in forest floor and water quality following thinning and clearcutting of 20-year-old pine. *Journal of Environmental Quality*. 16(3):237-241.

This paper presents the results of a study conducted in small plots to determine the differences in runoff, sediment transport, and chemical quality of infiltrating water from clearcut, thinning, and no-cut practices. Sediment concentrations leaving the plots were proportionate to cutting treatment. Nutrient concentrations (N and P) in runoff and percolation from all treatments were less than the nutrient input from precipitation.

McClurkin, D.C., P.D. Duffy, S.J. Ursic, and N.S. Nelson. 1985. Water quality effects of clearcutting upper Coastal Plain loblolly pine plantations. *Journal of Environmental Quality*. 14(3):329-332.

The differences in sediment and nutrient concentrations from cut and uncut forested experimental plots were examined. Significantly more sediment and sediment-bound N and P were removed from the clearcut plots; no significant differences in solution-phase N and P concentrations were found between treatments. The paper presents the data to support the authors' conclusions and offers a meaningful comparison of clearcut to uncut in a controlled experiment (plots).

Megahan, W.F. 1982. Channel sediment storage behind obstructions in forested drainage basins draining the granitic bedrock of the Idaho batholith. In: *Sediment Budgets and Routing in Forested Drainage Basins*. F.J. Swanson, R.J. Janda, T. Dunne, and D.N. Swanston, (eds.) USDA Forest Service, Pacific Northwest Forest and Range Experiment Station. General Technical Report PNW-141. pp. 114-121.

This paper presents data from a study conducted to quantify sediment trapped behind obstructions in forested watersheds in the Idaho batholith region. Logs were the most important type of obstruction observed in this study. Logging of the watersheds reduced the amount of stored sediment because many obstructions were destroyed by felling and clearing operations. The authors suggest storage behind obstructions is a major component of sediment routing and sediment monitoring interpretations should account for this. Guidelines and suggestions for minimizing impact to storage ability are presented.

Megahan, W.F. 1981. Effects of silvicultural practices on erosion and sedimentation in the interior west-A case for sediment budgeting. In: *Interior West Watershed Management Symposium Proceedings*. D.M. Baumgartner (ed.). Washington State University, Cooperative Extension. pp. 169-182.

This paper is a review of research done in the interior western United States on the effects of timber removal, road construction, and fire on erosion and sedimentation. The author describes the processes of erosion-sedimentation, surface erosion, and mass erosion; the role of fire; and means to control erosion from roads. The author concentrates on erosion from roads because they have been found to be the greatest source of sediment discharge. The paper includes a figure of a sediment budget in forested watersheds and tables comparing the erosion control effectiveness of various management practices. Suggestions for future research are also discussed.

Megahan, W.F. 1987. Increased sedimentation following helicopter logging and prescribed burning on granitic soil. In: *Erosion and Sedimentation in the Pacific Rim, Proceedings of the Corvallis Symposium*. Oregon State University, August, 1987. R.L. Beschta (ed.). IAHS Publication No. 165, Corvallis, Oregon. pp. 259-260.

The effects of helicopter clearcut logging and prescribed burning on sediment yields in central Idaho are presented. Streamflow and sediment yield data were collected for 10 years prior to clearcut and for 10 years after clearcut and prescribed burning. Significant increases in annual sediment yields were observed. No data from the study are presented in this short paper.

Megahan, W.F. 1986. *Recent studies on erosion and its control on forest lands in the United States*.

Recent research on erosion and erosion control conducted in the United States is reviewed. The effects of road construction, forest fire, and timber harvest are considered in relation to surface and mass erosion. Surface erosion has been predicted by using the Universal Soil Loss Equation (USLE), locally gathered data, and detailed mathematical models. The USLE is useful only when considering areas with gentle terrain. Empirical predictions are commonly used and mathematical models show promise. Mass erosion hazards are defined using landslide inventories from specific areas, statistical approaches, and stability analyses of given sites. The advantages and disadvantages of these approaches are discussed. The management applications of these approaches are discussed as well.

Meyer, J.L., and C.M. Tate. 1983. The effects of watershed disturbance on dissolved organic carbon dynamics of a stream. *Ecology*. 64(1):33-44.

Two second-order streams in the Coweeta Hydrologic Laboratory, North Carolina, were studied for annual dissolved organic carbon (DOC) export. One of the watersheds was completely clearcut 2 years prior to the beginning of the study, while the other was left undisturbed. The document provides excellent analytical data for DOC transport during baseflow and storm periods. Lower DOC export from the clearcut watershed was concluded to be the result of lower inputs in subsurface water as well as in stream generation.

Mikalsen, K.T. 1986. Preliminary results of Georgia nonpoint source impact assessment study: Commercial forestry. In *Research on the Effects of Forest Harvesting, Drainage, Mechanical Site Preparation, and Prescribed Fire on Water Quality*.

Commercial forestry activities adjacent to five streams throughout physiographic regions in Georgia resulted in varying degrees of water quality impact. Beneficial use was denied in one stream, impaired in two streams, and not substantially affected in two streams. The major impairment observed in the streams was an increase in sediment deposition,which altered or destroyed aquatic habitats. It was concluded that the implementation of BMPs must be continued and sampling must also be continued to ensure

that high water quality standards are maintained.

Miller, E.L., R.S. Beasley, and E.R. Lawson. 1988. Forest harvest and site preparation effects on streamflow and peakflow of ephemeral streams in the Ouachita Mountains. *Journal of Environmental Quality*. 17(2): 212-218.

Soil erosion and sedimentation effects of three treatments- clearcutting, selective cutting, and no disturbance (control)- were measured and compared in watersheds in the Ouachita Mountains of Arkansas. After clearcut harvest, a drum chopper crushed the residual vegetation prior to burning; stream channels were not buffered from chopping or burning. The harvest and site preparation activities had no specific BMPs; however, "reasonable care" was used while conducting the activities. Sediment yield during the first year of the study was significantly higher in the clearcut treatment, but the differences between the treatments decreased the next 2 years. Even though the annual sediment yield was greater from the clearcut treatment, the yields were relatively low and appeared to have little impact on water quality. The document provides concise methodology for the experimental design and presents significant amounts of data collected during the experiment.

Miller, J.H., and D.L. Sirois. 1986. Soil disturbance by skyline yarding vs. skidding in a loamy hill forest. *Soil Science Society of America Journal*. 50(6):1579-1583.

Soil disturbance was assessed on harvested units of mature southern pines (*Pinus spp.*), where a part of each unit was logged with a cable skyline system and a part with rubber-tired ground skidders. The effects of the two methods of harvesting were studied by aerial and ground surveys. Cable yarding required 2% less acreage in landing than skidding, and yarding corridors occupied 12% less area than did skid trails. Physical and chemical analyses of surface soils (upper 15 cm) showed that loam soils with clay subsoils were most severely affected by the displacement of topsoil after both methods of logging. On 8% to 14% of both logged areas, harvesting activities resulted in significant reductions in organic matter; available moisture holding capacity; and available P, Ca, and K. Silt loam soils were severely compacted by cable yarding in the corridors that consistently ran upslope, creating the greatest erosion potential. The authors conclude that the carefully planned use of skyline cable systems would minimize the area affected by severe soil disturbance and should be considered for future harvesting in this locale.

Murphy, M.L., and J.D. Hall. 1981. Varied effects of clear-cut logging on predators and their habitat in small streams of the Cascade Mountains, Oregon. *Canadian Journal of Fisheries and Aquatic Sciences*. 38:137-145.

The differences in predator numbers in a stream draining a logged and forested area are presented in this paper. Stream inventories of the predators including fishes, salamanders, and certain invertebrates were conducted. Varied results were obtained. Newly logged areas exposed to sunlight had greater biomass of predators than did old growth forest areas. However, second-growth logged areas reshaded by deciduous forest canopy had lower biomass than the old growth forest. This journal article provides a detailed discussion of the predator-prey interactions that may be occurring in the old growth and logged forests and also provides significant data and results.

Murphy, M.L., J. Heifetz, S.W. Johnson, K.V. Koski, and J.F. Thedinga. 1986. Effects of clear-cut logging with and without buffer strips on juvenile salmonids in Alaskan streams. *Canadian Journal of Fisheries and Aquatic Sciences*. 43(8):1521-1533.

To assess short-term effects of logging on juvenile *Oncorhynchus kisutch*, *Salvelins malma*, *Salmo gairdneri*, and *Salmo clarki* in southeastern Alaska, the fish density and habitat in summer and winter were compared in 18 streams in old-growth forest and in clearcuts with and without buffer strips. The study concludes that clearcutting may increase fry abundance in summer in some streams by increasing primary production, but may reduce abundance of parr in

winter if debris is removed. Use of buffer strips maintains or increases debris, protects habitat, allows increased primary production, and can increase abundance of fry or parr. The report also contains references to more than 50 other papers.

Narver, D.W. 1971. Effects of logging debris on fish production. In: *Proceedings of the Symposium: Forest Land Uses and Stream Environment.* , 19-21 October, 1970. J.T. Krygier and J.D. Hall (eds.). Oregon State University, Corvallis, Oregon. pp. 100-111.

Stream salmonids (eight species of Pacific salmon, trout, and char) are discussed in relation to their environmental requirements and the possible impact of logging debris on their production. The emphasis is on small streams because of their great importance as nursery and spawning areas for certain species and because they may be more susceptible to damage than larger streams or rivers. Extensive use is made of pertinent literature. The author concludes that accumulations of logging debris in small streams can have serious effects on the production of salmonid fishes.

NCASI. 1980. *Research and field investigation of the impact of southern forestry management practices on receiving water quality and utility.* National Council of the Paper Industry for Air and Stream Improvement. Technical Bulletin No. 337.

This is an assembly of papers and abstracts of presentations made at the 1980 NCASI Southern Regional Meeting. The papers describe work under way at universities, individual company programs, programs in the South being conducted by USDA Forest Service, and aquatic biology. Sample titles include: Regional Road Project-Management Options to Control Erosion; Assessment of NPS Pollution from Intensive Forest Practices in the South Central Region, Texas; Demonstration of Sensitive Area Mechanical Site Preparation; The Use of Macroinvertebrates as Indicators of Stream Quality Changes; and Report on Ongoing Programs and Information Needs Relating to Southern Forest Practices and Water Quality.

NCASI. 1979. *A review of current knowledge and research on the impact of alternative forest management practices on receiving water quality.* National Council of the Paper Industry for Air and Stream Improvement. Technical Bulletin No. 322. 141 pages.

This bulletin reviews research on the impact of forest management practices on water quality. Ninety-three projects are reviewed. Separate chapters briefly discuss forest practice effects on loadings of sediment, nutrient, and organic debris, and changes in temperature and water quality changes due to the use of forest chemicals. Current knowledge is assessed, and a reference list of 410 related papers is provided. Appendices provide information on the application of the universal soil loss equation for predicting sediment loading, erosion rates, and predictive equations for stream nutrient concentrations.

Neary, D.G. 1977. Impact of timber harvesting on nutrient losses in stream flow. *New Zealand Journal of Forestry*. 22(1):53-63.

This is a review of studies conducted in the United States to investigate the impacts of forest harvesting on the nutrient concentration of streamflow. The studies support the concept that harvest operation occurring with proper planning and management produces a relatively small increase in nutrient outputs. The paper summarizes eight studies conducted by six different research groups.

Nicolson, J.A. 1988. Alternate strip clearcutting in upland black spruce. V. The impact of harvesting on the quality of water flowing from small basins in shallow-soil boreal ecosystems. *The Forestry Chronicle*. pp. 52-58.

This paper presents the results of a study comparing the water quality in streams from the following treatments: unharvested, patch-cut, clearcutting, and stripcut. Greater water yield was observed from the harvested basins. The author speculates that because infiltration capacity remained high, the water discharged as shallow

subsurface flow and that the greater discharge was due to eliminated precipitation interception and reduced evapotranspiration. Water quality changes after harvest included a small increase in pH during several years and a decrease in sulfate and nitrate concentrations.

Nutter, W.L. 1982. Water quality and yield from the intensively managed forest. In: *Proceedings of the Society of American Foresters*. pp. 89-93.

A review of the impacts of intensive forest management, including timber harvest, site preparation, road construction, and forest fertilization, on water yield and water quality is presented. This short review presents an overview of the impacts of intensive forestry operations.

Patric, J.H. 1980. Effects of wood products harvest on forest soil and water relations. *Journal of Environmental Quality*. 9(1):73-80.

This report presents the results of nearly three decades of research on a watershed in the Fernow Experimental Forest in north-central West Virginia. Selection harvests between 1958 and 1968 had a negligible effect on water properties. A clearcut leaving a buffer strip in 1969-70 had no effect on stormflow or stream temperature, but increased water yield by 38% the first year after cutting. Concentrations of sediment, nitrate, Ca, Mg, K, and Na in streamflow increased slightly. The buffer strip was cut and the stream channel cleared in 1972, increasing water yield by 9% and raising stream temperature by as much as 7.8 °C. Regrowth over the entire watershed reduced all effects on water within 2 years after each treatment. Historical data from the studies reviewed are presented for parameters such as turbidity and precipitation.

Patric, J.H. 1978. Harvesting effects on soil and water in the eastern hardwood forest. *Southern Journal of Applied Forestry*. 2(3):66-73.

For the eastern United States, there is overwhelming evidence that neither the productivity of forest soil nor the quality of forest water are substantially lessened during or after responsibly managed harvest of wood products. However, careless practices such as dragging logs across the forest floor (which disrupts organic cover) building more roads than are necessary, operating machinery in streams, and locating roads near streams damage both forest productivity and water quality. Proper management of forest roads is the key to minimizing the adverse impacts of forest activities. Forest roads cause little adverse effect on soil or water given proper location, drainage, traffic control, and maintenance. This paper provides an overall qualitative analysis of the problems associated with timber harvesting.

Patric, J.H. 1984. Some environmental effects of cable logging in the eastern hardwoods. In: *Mountain Logging Symposium Proceedings*. West Virginia University, June 5-7, 1984. P.A. Peters and J. Luchok (eds.). West Virginia University, Morgantown, West Virginia. pp. 99-106.

A literature survey related to cable yarding in partially-cut stands indicates that damage to residual trees, understory reproduction, and soil and water quality from well-planned cable operations is comparable to, or less than, that from rubber-tired skidder or tractor logging. In even-aged management, damage to small trees and the understory is not as critical as in uneven-aged management. Even in uneven-aged management, however, the younger trees (growing stock) can be adequately protected if damage is minimized through careful planning of the yarding operation and proper training of loggers.

Patton, D.R. 1973. *A literature review of timber harvesting effects on stream temperatures: Research needs for the Southwest*. USDA Forest Service, Rocky Mountain Forest and Range Experiment Station. Research Note RM-249. 4 pages.

The paper focuses on the effect of temperature on fisheries. Water temperature affects fish by changing their metabolic rate and the oxygen

content of water, and influencing hatching and development time and migration. Creating a more open forest in the water-producing zone can change water temperature in shallow, low-volume streams. The author concludes that research is needed on how timber harvesting affects water temperature to produce guidelines to meet FWPCA standards for cold-water fish. Suggested research topics are identification of perennial streams with temperature marginally high; the effect of timber harvesting on water temperature; determination of temperature ranges of rare and endangered fish; and the importance of riparian vegetation in maintaining aquatic habitat.

Ponce, S.L. 1974. The biochemical oxygen demand of finely divided logging debris in stream water. *Water Resources Research.* 10(5): 983-988.

The impact of Douglas fir needles and twigs, western hemlock needles, and red alder leaves on dissolved oxygen and th: ›n the quality of mountain stream water w.. examined. The leaf material exposed to fluctuating temperature exerted a 5 day BOD of 4.0, 2.4 and 4.2 times greater than the standard temperature BOD for Douglas fir needles, western hemlock needles,and red alder leaves, respectively. Oxygen depletion was more likely to cause aquatic disruptions than were leachate effects.

Ponce, S.L. 1986. Controlling diffuse-source pollution associated with forest practices in North America. In: *Effects of land use on fresh waters: agriculture, forestry, mineral exploitation, urbanization.* L.G. Solbe (ed.). Water Research Centre, Chichester, England. pp. 432-443.

This paper provides an overview of strategies used within the United States to control the degradation of water quality from forest practices. The document includes information on regulations, source impacts, and control opportunities. Several excellent tables are presented with information on silvicultural activities and their associated impacts and control practices.

Reinhart, K.G. 1964. Effects of commercial clearcutting in West Virginia on overland flow and storm runoff. *Journal of Forestry.* 62:167-171.

The effects of clearcutting and construction of skid roads without water control measures on overland flow and infiltration were examined in this study. Two watersheds, one clearcut and the other undisturbed, were gaged to record the amount of overland flow. Infiltration rates remained higher than typical storm intensities for both watersheds. Overland flow occurred only from the skid roads and interception from road cuts. The author concludes that runoff could be controlled by using water and sediment control management measures on skid roads during timber harvest.

Reinhart, K.G. 1973. *Timber-harvest clearcutting and nutrients in the north-eastern United States.* USDA Forest Service, Northeastern Forest Experiment Station. Research Note NE-170. 5 pages.

This paper is a summarization of results from studies conducted to evaluate nutrient losses from clearcut watersheds. From various studies conducted in the northeastern United States, little evidence was found to suggest that clearcut increased nutrient transport and loss. The losses that did occur were deemed too low to reduce water quality below drinking water standards.

Rice, R.M., J.S. Rothacher, and W.F. Megahan. 1972. Erosional consequences of timber harvesting: An appraisal. In: *Watersheds in Transition Symposium Proceedings.* Urbana, Illinois. American Water Resources Association. pp. 321-329.

This paper summarizes current (1972) understanding of the effects of timber harvesting on erosion. Rates of erosion on mountain watersheds vary widely, but the relative importance of different types of erosion and the consequences of disturbance remain fairly consistent. The authors suggest that a number of conclusions are therefore valid for most circumstances. Among these conclusions are:

sediment production declines rapidly following disturbance; cutting of trees does not significantly increase erosion, but clearcutting on steep unstable slopes may lead to increased mass erosion; accelerated erosion is a possible undesirable side effect of the use of fire in conjunction with logging; the road system built for timber harvesting far overshadows logging or fire as a cause of increased erosion; and potentially hazardous areas can be identified in advance of the timber harvest. Tables comparing the amount of soil disturbed by different logging practices and the amount of soil eroded from logging roads in different logging areas are provided.

Riekerk, H. 1983. Environmental impacts of intensive silviculture in Florida (forest soil degradation, water quality, watersheds). In: *I.U.F.R.O. Symposium on Forest Site and Continuous Productivity*. USDA Forest Service, Pacific Northwest Forest and Range Experiment Station. General Technical Report PNW-163. pp. 264-271.

Runoff and water quality from two different timber harvest practices, minimum and maximum disturbance, were compared to an undisturbed flatwood watershed. Significantly greater water yield was observed for both treatments, with the greatest increase in the maximum disturbance treatment. Water yield increases lasted for a single year. As with water yield, the greatest degradation in water quality was observed from the maximum disturbance treatment although the impact was also of short duration. The author concludes that silvicultural activities in flatwoods would not result in any long-term degradation of water quality.

Riekerk, H. 1983. Impacts of silviculture on flatwoods runoff, water quality, and nutrient budgets. *Water Resources Bulletin*. 19(1)73-80.

Runoff and water quality from two different timber harvest practices, minimum and maximum disturbance, were compared to an undisturbed flatwood watershed. The maximum disturbance consisted of machine harvesting, slash burning, windrowing, bedding, and machine planting and the minimum disturbance treatment included manual harvesting, slash chopping, bedding, and machine planting. Significantly greater water yield was observed for both treatments, with the greatest increase in the maximum disturbance treatment. Water yield increases lasted for a single year. As with water yield, the greatest degradation in water quality was observed from the maximum disturbance treatment although the impact was also of short duration. The author concludes that silvicultural activities in flatwoods would not result in any long-term degradation of water quality.

Riekerk, H. 1989. Influence of silvicultural practices on the hydrology of pine flatwoods in Florida. *Water Resources Research*. 25(4):713-710.

A study was conducted in a pine flatwoods to determine the effect of minimum and maximum disturbance timber harvest on the hydrology of the forest. The maximum disturbance was machine harvesting, slash burning, windrowing, bedding, and machine planting and the minimum disturbance treatment was manual harvesting, slash chopping, bedding, and machine planting. The results indicated that the maximum disturbance harvest had a significant impact on the hydrology. An increase in the water table and runoff after timber harvest was observed. The increases were due to decreased evapotranspiration after harvest. The changes in hydrology could lead to future problems in already poorly drained flatwoods.

Riekerk, H. 1985. Water quality effects of pine flatwoods silviculture. *Journal of Soil and Water Conservation*. 40(3):306- 308.

This study was done to assess the impacts of intensive silvicultural management practices on nonpoint source pollution in Florida's poorly drained pine flatwoods. Three watersheds in the flatwoods region of north central Florida were monitored for 6 years. Three treatments were imposed during the second year: harvest with minimum disturbance and site preparation, harvest with maximum disturbance and site preparation, and an undisturbed control. The minimum

treatment included manual shortwood harvesting, slash chopping, soil bedding, and machine planting. The maximum treatment included machine tree-length harvesting, slash burning, windrowing, soil bedding, and machine planting. There were small but significant increases in pH, suspended sediment, Ca, and K, proportional to the degree of disturbance during the treatment year. Only K and Ca levels remained significant during the first posttreatment year. The author concludes that minimum disturbance practices with protective stream management zones will minimize NPS pollution.

Riekerk, H., D.G. Neary, and W.J. Swank. 1989. The magnitude of upland silviculture nonpoint source pollution in the south. In: *Proceedings of the Symposium on the Forested Wetlands of the Southern United States*. Orlando, Florida, July 12-14, 1988. USDA Forest Service, Southeast Forest Experiment Station. General Technical Report SE-50. pp. 8-18.

Streamflow water quality data from intensive silvicultural practices in the southern United States are summarized and discussed with respect to regional differences of nonpoint source pollution, and BMPs. Suspended sediment production by silviculture was low in the mountains and lower coastal plain, but high in the Piedmont and upper coastal plain regions. This was due to a combination of site preparation intensity and topographic relief. Nutrient exports in the Piedmont and upper coastal plain regions were controlled by the degree of soil disturbance and by the recovery rate of vegetation. Nutrient exports in the lower coastal plain were not much affected by intensive silviculture. Research is needed on the effects of silvicultural practices in wetlands and on the actual effectiveness of BMPs. Research and analyses of cumulative effects are also needed to determine the impacts of multiple silvicultural practices on downstream wetlands.

Rishel, G.B., J.A. Lynch, and E.S. Corbett. 1982. Seasonal stream temperature changes following forest harvesting. *Journal of Environmental Quality*. 11(1):112-116.

The objectives of this study were to document changes in water temperature of small headwater streams following a clearcut- herbicide treatment and a commercial clearcut harvest. The study was designed to provide data on the maximum expected change in stream temperature following forest cover removal and to evaluate the effectiveness of a buffer zone on the commercial clearcut site in controlling stream temperature changes. The average monthly maximum temperature change in the clearcut-herbicide treatment stream was 4.4 °C, and the highest recorded temperature in the stream was 32 °C, compared to 22 °C on an adjacent forested watershed. On the clearcut watershed with a buffer strip, only slight changes in stream temperature were observed. The average monthly maximum stream temperature increase was < 1 °C, and the highest temperature recorded was 23 °C.

Rothacher, J., and W. Lopushinsky. 1974. Soil stability and water yield, and water quality. In: *Environmental effects of forest residues management in the Pacific Northwest*. pp. D1-D23.

The effects of forest harvest activities on soil and water resources are reviewed. Over 50 references on soil erosion from different practices, water yield, and water quality are provided. A summary of the overall trends in environmental impact of forestry activities is included.

Ryan, S.E., and G.E. Grant. 1991. Downstream effects of timber harvesting on channel morphology in Elk River Basin, Oregon. *Journal of Environmental Quality*. 20(1):60-72.

Downstream effects, a type of cumulative watershed effect, were identified using changes in the width and distribution of open riparian canopies measured from aerial photography taken between 1956 and 1979 in Elk River Basin, southwest Oregon. A causal link between downstream changes in channel morphology and upslope forestry activities was assumed where open reaches extended continuously downstream from clearcuts and roads or the timing and pattern

of opening downstream varied in direct relation to the intensity of upslope forestry activities. Open riparian canopies were observed in first- through fifth-order channels, though only 11% of open reaches in low-order channels were spatially connected to open reaches in higher order channels. Open canopies in higher-order channels were restricted mainly to wide and low-gradient channel reaches. Open canopies in low-order tributaries were attributed to landslides and surface erosion generated from clearcuts and roads.

Schwab, J.W., and W.J. Watt. 1981. *Logging and soil disturbance on steep slopes in the Quesnel Highlands, Caribou Forest Region.* British Columbia, Ministry of Forests, Research Branch. No. 88. 15 pages.

A study was undertaken in the Quesnel Highlands to compare soil disturbance associated with crawler tractor and running skyline logging methods. Soil disturbance types were recorded at point samples along transects within 15 cutblocks. Additional detailed road measurements were also made. Point samples were categorized into five classes: no disturbance, forest floor disturbed but no mineral soil exposed, shallow disturbance less than 25 cm, deep disturbance greater than 25 cm, and a grouping of shallow and deep mineral soil disturbances. The total disturbance on running skyline-yarded clearcuts averaged 34.7% and on crawler tractor- logged clearcuts averaged 62.6%. The effects of soil disturbance on erosion susceptibility, regeneration establishment and soil productivity are discussed.

Scrivener, J.C., and B.C. Anderson. 1984. Logging impacts and some mechanisms that determine the size of spring and summer populations of coho salmon fry in Carnation Creek, B.C. *Canadian Journal of Fisheries and Aquatic Sciences*. 41:1097-1105.

The effects of forestry practices on salmonid resources in British Columbia are analyzed in this paper. The Coho fry movement, distribution,and growth for spring and summer were recorded over a 2-year period prior to and following logging. Interestingly, growth rates tended to be high following streamside logging. It was found that a complex number of factors affect the physical parameters of Coho fry and that they are not necessarily dependent exclusively on silvicultural activity.

Sidle, R.C. 1980. *Impacts of forest practices on surface erosion.* Pacific Northwest Extension Publication PNW 195. 15 pages.

A summary of the impacts of various timber harvest activities on surface erosion is presented. The summary includes information on basic erosion processes and the impacts of timber harvest, road construction, and site preparation. No references are included for the conclusions made.

Silsbee, D.G., and G.L. Larson. 1983. A comparison of streams in logged and unlogged areas of Great Smoky Mountains National Park (Tennessee). *Hydrobiologia*. 102(2):99-111.

This study compared stream quality in a never-logged watershed and a primitively-logged (50 years ago) watershed in the Great Smokey Mountains National Park. Water quality, stream channel characteristics, and macroinvertebrates were evaluated. The water from the unlogged stream was higher in nitrate, sulfate, phosphate, and calcium than that of the logged stream. This paper provides information on the long-term water quality impacts associated with logging.

Singer, M.J., X. Huang, and C. Epifanio. 1990. Selective oak removal does not harm water quality. *California Agriculture*. 44(2):17-19.

The effects of selective oak tree removal in the Sierra foothills on water quality and yield in a watershed were studied. The researchers conclude that a small amount of carefully controlled oak removal has little statistical effect on the runoff/rainfall ratio and on the concentration of sediments and nutrients in the streams. The overall disturbance in the watershed was small and did not pose a water-quality hazard.

Snyder, G.G., H.F. Haupt, and G.H. Belt, Jr. 1975. *Clearcutting and burning slash alter quality of stream water in northern Idaho.* USDA Forest Service. Research Paper INT-168. 34 pages.

The effect of logging on water quality in three watersheds in Idaho was determined. Water samples were collected upstream, on- site, and downstream from clearcut and slash-burned sites. Buffer strips were left along the streams upstream and downstream of the harvest site. Increases in cation concentrations were observed, with larger increases observed at the on-site stations. The authors suggest the use of stream buffer strips as a management tool to reduce water quality impacts.

Sopper, W.E. 1975. Effects of timber harvesting and related management practices on water quality in forested watersheds. *Journal of Environmental Quality*. 4(1):24-29.

The results of selected studies are presented to provide an overview of the types of water quality investigations undertaken on forested watersheds. Studies from timber harvesting activities, fertilization, and herbicide use are included. Many tables of data from the various studies, and very general conclusions based on the information, are provided.

Spangenberg, N.E., and R. McLennan. 1983. *Effects of silvicultural practices on water quality in Northern Wisconsin.* Wisconsin Water Resources Center, Madison, Wisconsin. Technical Completion Report, WIS/WRC. 24 pages.

This report presents the results of a study conducted to determine the effect of clearcutting and selection cutting on water quality. Clearcutting was found to increase the erosion potential but no significant differences in water quality were observed. This report presents significant data on the differences in water quality from two harvesting methods.

Stevens, P.A., J.K. Adamson, M.A. Anderson, and M. Hornung. 1988. Effects of clearfelling on surface water quality and site nutrient status. In: *Ecological Change in the Uplands.* British Ecological Society. Special Publication Number 7.

Two forest sites were studied in North Wales, Great Britain, to determine whether clearcutting resulted in increased concentrations of major nutrients in streams. Taking into account substrate and dilution from unfelled areas, an insignificant impact on water quality was measured.

Stone, E. 1973. The impact of timber harvest on soils and water. In *Report of the President's Advisory Panel on Timber and the Environment.* pp. 427-467.

The impacts of timber harvest and removal on water quality and soil stability are addressed. Review topics include soil erosion from timber harvest, roads, and slash disposal and burning; water quality impacts; and hydrologic impacts. Watershed studies conducted at Hubbard Brook Experimental Forest are reviewed. More than 100 references are cited in this comprehensive review.

Stone, E.L., W.T. Swank, and J.W. Hornbeck. 1978. Impacts of timber harvest and regeneration systems on stream flow and soils in the eastern deciduous region. In: *Forest Soils and Land Use, Proceedings of the Fifth North American Forest Soils Conference.* C.T. Youngberg (ed.). Colorado State University. pp. 516-535.

A review of the impacts of forest harvest activities on soil and water resources is presented. The review concentrates on the principles associated with impacts and therefore presents generalized conclusions from a sampling of the research efforts. Topics covered include water yield, water table changes, low and peak flow, soil moisture, stream temperature, sedimentation, and nutrients.

Swank, W.T., L.F. DeBano, and D. Nelson. 1989. Effects of timber management practices on soil and water. In: *The Scientific Basis for Silvicultural and Management Decisions in the National Forest System*. R.M. Burns (ed.). USDA Forest Service. General Technical Report WO-55. pp. 79-106.

This paper presents a detailed review of the effects of various forest management practices on soil and water characteristics. The major topics reviewed include forest management practices, general effects on soil and water, and effects on different forest types. The section on general effects on soil and water includes review of water quantity, water quality, erosion, nutrient loss/change, fire, and herbicides. The different forest types, including western inland conifers, pacific coast conifers, northeastern conifers, eastern hardwoods, and southern conifers, are reviewed for water yield, streamflow timing, erosion and sedimentation, water quality and temperature, and soil and soil nutrients. This review cites over 100 references.

Swanson, F.J., and C.T. Dyrness. 1975. Impact of clearcutting and road construction on soil erosion by landslides in the western Cascade Range, Oregon. *Geology*. 3(7):393-396.

Susceptibility to erosion by rapid soil movement differed greatly between two zones of the H.J. Andrews Experimental Forest. A stable zone occurs where terrain is underlain by lava-flow bedrock. Only two small road-related slides have occurred there since 1950. An unstable zone underlain by altered volcaniclastic rock has had 139 slides in the same period. Slide erosion has been 30 times greater along road rights-of-way than on forested sites in the unstable zone.

Swanson, F.J., and G.W. Lienkaemper. 1978. *Physical consequences of large organic debris in Pacific Northwest streams*. USDA Forest Service, Pacific Northwest Forest and Range Experiment Station. General Technical Report PNW-69.

This paper presents a general overview of the physical characteristics, history, and effects of natural organic debris in streams. A case study showing the characteristics of potential management impacts of the movement of stream debris is presented. Evidence of increased frequency of debris torrents after clearcutting and road construction was observed. In two western Oregon watersheds, increases in debris torrents of about 4 and 9 times for clearcut and 40 to 130 times for road rights- of-way relative to the frequency in forested areas were observed.

Swift, L.W., Jr. 1982. Duration of stream temperature increases following forest cutting in the southern Appalachian Mountains. *Water Resources Bulletin*. 18(6):273-275.

The effect of clearcutting riparian areas on water temperature was examined at the Coweeta Hydrologic Laboratory, North Carolina. During the first two summers of the study, stream temperatures at the downstream edge of clearcut was increased by an average of 3.3 °C. The increase declined the next three summers to 1.2 °C. In addition, the daily range of water temperatures (maximum minus minimum) increased for all 5 years after clearcut. The authors also used a method by Brown (1970) to estimate water temperature changes and found that the method significantly overestimated the actual increase.

Thedinga, J.F., M.L. Murphy, J. Heifetz, K.V. Koski, and S.W. Johnson. 1989. Effects of logging on size and age composition of juvenile coho salmon and density of pre-smolts in southeast Alaska streams. *Canadian Journal of Fisheries and Aquatic Science*. 46:1383-1391.

Short-term effects of logging on age composition and size of juvenile coho salmon (*Onchrhynchus kisutch*) were studied in 18 streams in southeast Alaska in 1982 and 1983. Studies were in old-growth forests where stream reaches had been clearcut with or without buffer strips. The number of fry in summer and winter was proportionately higher in clearcut and buffered reaches than in undisturbed reaches. A higher percentage of large (≥75 mm) fry remained in buffered reaches than in clearcut and undisturbed

reaches. Therefore, the density of fry that were potentially large enough to become smolts the next spring was greater in buffered reaches. The larger fry in the buffered and clearcut reaches compared with undisturbed reaches were probably the result of earlier fry emergence resulting from increased water temperature. This paper presents partial results of a larger study. The companion paper is Murphy, Heifetz, Johnson, Koski and Thedinga, 1986.

Trettin, C.C., and P.J. Sheets. *Impacts of forest drainage on water quality*. Center for Intensive Forestry in Northern Regions. pp. 231-239.

The effects of a prescription-type forest drainage system on water quality in the upper peninsula of Michigan were evaluated. No significant differences in calcium, total nitrogen, pH, suspended sediment, or water temperature were observed between drainage water and river samples. Iron and magnesium concentrations were slightly higher in the drainage water. The drainage system appeared to serve its purpose by draining the high water table and not causing appreciable water quality impacts. The authors suggest following some basic best management practices, such as not driving across ditches and properly installing ditches, to prevent water quality impacts.

Troendle, C.A., and R.M. King. 1985. The effect of timber harvest on the Fool Creek watershed, 30 years later. *Water Resources Research*. 21(12):1915-1922.

The Fool Creek watershed at the Fraser Experimental Forest, Colorado, was harvested using a pattern of alternating clearcut and forested strips in 1956. After 30 years of postharvest record, subtle impacts on the hydrology of the watershed were detected that had not been significant in the past.

Tschaplinski, P.J., and G.F. Hartman. 1983. Winter distribution of juvenile coho salmon (Oncorhynchus kisutch) before and after logging in Carnation Creek, British Columbia, and some implications for overwinter survival. *Canadian Journal of Fisheries and Aquatic Sciences*. 40:452-461.

Carnation Creek on the west coast of Vancouver Island was studied for the movement of coho fry prior to and after logging activities. In the areas of streambank damage, the coho fry moved to more sheltered settings during the winter season. Management practices, such as leaving streambank vegetation, were confirmed to prevent the influx of undesirable silvicultural materials from entering the spawning areas of salmon and cutthroat trout. Tables and figures presented demonstrate that logging the SMZ neither reduces the number of coho wintering in Carnation Creek nor reduces the number leaving in the spring.

Ursic, S.J. 1976. Water quality and southern forests...Where we presently stand. *Forest Farmer*. 36:17-35.

This short paper presents general information on the impacts of forestry on water yield, sedimentation, mechanical soil disturbance, and the status of water quality research.

Ursic, S.J. 1977. Water quality impacts of harvesting and regeneration practices. In: *Proceedings of the "208" Symposium, Nonpoint Sources of Pollution from Forested Land*. Southern Illinois University, Carbondale, Illinois. pp. 223-232.

A synopsis of water quality impacts from forest management activities such as harvesting, regeneration activities, and sediment contributions from channels is presented. A region- specific approach is utilized, and data from selected case studies are used. The figures cited in the paper are slightly dated and rely heavily on averaging. This paper provides a good summary of the impacts of forestry on water quality.

Van Lear, D.H., J.E. Douglass, S.K. Cox, and M.K. Augspurger. 1985. Sediment and nutrient export in runoff from burned and harvested pine watersheds in the South Carolina piedmont. *Journal of Environmental Quality*. 14(2):169-174.

Soil and nutrient export in ephemeral flow was studied over a three year period after clearcut logging. Two pre-harvest prescribed fires had no significant effect on water quality or flow. Harvesting occurred after the third prescribed burn and resulted in increased sediment concentrations, although the losses were less than values typical of mechanical site preparation. Nutrient concentrations were variable among watersheds, although no effect of timber harvest was observed.

Verry, E.S. 1972. Effect of an aspen clearcutting on water yield and quality in northern Minnesota. In: *Watersheds in Transition Symposium Proceedings*. Urbana, Illinois. American Water Resources Association. pp. 276-284.

A study was initiated to determine the effects of clearcutting an aspen stand on water quality and water yield. This paper presents the results of the first year of sampling. The data from the clearcut watershed indicated no change in the water quality. However, total streamflow during the period of snowmelt was several days earlier and had nearly twice the peak. For the year, the streamflow increased by 31%. Only general conclusions can be made based on the single year of data presented in this paper.

Verry, E.S. 1986. Forest harvesting and water: The Lake states experience. *Water Resources Bulletin*. 22(6):1039-1047.

This a summary of forest harvest and water quality in the Lakes states is separated into wetlands and uplands. Harvesting of timber from natural peatlands will not adversely affect streamflow and water quality if conducted on frozen ground; however, increased water table fluctuations will result. In uplands, streamflow increases upon clearcut and returns to preharvest levels within 15 years. Water quality impairment and habitat destruction can be minimized if stream channels are avoided. More than 30 references to studies conducted in the Lake states are included.

Whitman R. 1989. Clean water of multiple use? Best management practices for water quality control on the national forests. *Ecology Law Quarterly*. 16(4):909.

This article summarizes the nature and extent of the environmental problems around which conflicts revolve, and shows how state and federal laws, including NEPA, CWA and the National Forest Management Act, interact to protect water quality through forest planning. The paper also assesses the success of BMPs in protecting water quality, explains why BMPs are not always implemented even when legally prescribed, and identifies those settings where, even if fully implemented, BMPs fail. Finally, the author proposes some administrative and institutional reforms designed to correct these shortcomings. The article contains a review of the water quality problems associated with timber harvesting; the various statutes relating to forest practices; the roles of EPA, the states, and the Forest Service in water quality protection; and the effectiveness of BMPs. The suggested reforms include restructuring incentives to protect environmentally sensitive areas and restructuring state water quality standards for forestry-related NPS pollution.

Wood, J.C., W.H. Blackburn, H.A. Pearson, and T. Hunter. 1989. Infiltration and runoff water quality response to silvicultural and grazing treatments on a longleaf pine forest. *Journal of Range Management*. 42(5):378.

This study was conducted to assess the impact of intensive and extensive silvicultural practices and livestock grazing on runoff water quality in the Kisatchie National Forest in Louisiana. Infiltration was greater and interrill erosion, total soluble nitrogen, and phosphorus were less under extensive management with no livestock grazing than under intensive management with grazing. The paper presents significant data comparing various levels of forestry management and

provides evidence of how impacts can be reduced by improved management practices.

Wright, K.A., K.H. Sendek, R.M. Rice, and R.B. Thomas. 1990. Logging effects on streamflow: Storm runoff at Casper Creek on Northwestern California. *Water Resources Research*. 26(7):1657-1667.

The effects of road building and selective tractor harvesting on storm runoff were assessed for a small (424-ha) coastal watershed in northern California. Lag time (the time required for 50% of the input into the watershed to produce 50% of the output) and peak flows were analyzed. After road building and logging, lag time was decreased approximately 1.5 hours, and very small storm volumes and peak flows increased 132% and 111%, respectively. Storm volumes and peaks of large storms were not significantly increased by roads or logging. The authors conclude that in a rain-dominated hydrologic environment logging and forest road construction are not likely to change the flow regime of a stream adversely. These results conflict with others reported (Harr et al., 1975). The authors of this study compared the results of the two studies and speculated that the lack of large storm flows in the Harr study may account for the conflicting results.

Wu, A.Y.K., M.P. Papworth, and D.W. Flynn. 1984. The effects of some forest practices on water quality and yield in the Reefton Experimental Area, Victoria. In: *Reefton Experimental Area Pretreatment Compilation Report, Volume I.*

The aim of this study was to assess the effects on both water yield and water quality of some forest practices commonly used in the management of mixed species eucalypt forest in Victoria, Australia. This initial part of the report describes the area and preparations for collecting the data. The experimental area contains 6 catchments ranging in size from 70.4 to 521.2 ha. The larger catchments have perennial streams, whereas streamflow tends to be ephemeral in two of the catchments. Soils, topography, vegetation, rainfall patterns, and annual temperature ranges for the area are described, followed by a description of instrumentation used in the catchments to measure meteorological conditions, streamflow, and water quality and bedload. Catchment hydrology and calibration are also discussed, as well as the treatments to be used in the experiment. It was proposed that one catchment would receive a fuel reduction burn, a second would receive a rehabilitation treatment, and a third would be roaded at an intensity similar to that of the second, allowing the effects of roading and logging on water yield to be separated. A fourth catchment would serve as a control.

Yoho, N.S. 1980. Forest management and sediment production in the south-A review. *Southern Journal of Applied Forestry*. 4(1):27-36.

The author reviews sediment yields from various forestry activities, finding that forest practices commonly result in small short-term increases and that significant increases are limited to practices conducted with heavy machinery. Yields from similar sites receiving the same type of disturbance vary by several hundred percent, and sediment yields are reduced when channel disturbance is avoided. Careful planning, design, construction, use, and maintenance of forest roads and skid trails achieve the greatest reductions. The author provides comparative soil loss data for a variety of land uses: less than 0.1 ton/acre/yr (undisturbed mixed forest, forest thinning); 0.1 - 1.0 ton/acre/yr (carefully clearcut forest, abandoned fields); 1.0 - 10.0 tons/acre/yr (annually burned forest, mechanical site preparation); 10 - 100 tons/acre/yr (carelessly cultivated or steep sloped fields); and 100 or more tons/acre/yr (active construction, gullies).

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Swanston, D.N. 1974. *Slope stability problems associated with timber harvesting in mountainous regions of the western United States*. USDA Forest Service, Pacific Northwest Forest and Range Experiment Station. General Technical Report PNW-21. 14 pages.

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Swindel, B.F., C.J. Lassiter, and H. Riekerk. 1983. Effects of different harvesting and site preparation operations on the peak flows of streams in Pinus elliotii flatwoods forests. *Forest Ecology and Management*. 5:77-86.

Swindel, B.F., C.J. Lassiter, and H. Riekerk. 1983. Effects of clearcutting and site preparation on stormflow volumes of streams in Pinus elliotii flatwoods forests. *Forest Ecology and Management*. 5:245-253.

Switzer, G.L., D.M. Moehring, and T.A. Terry. 1978. Clearcutting vs. alternative harvesting-stand regeneration systems: Effects on soils and environment of the south. In: *Forest Soils and Land Use, Proceedings of the Fifth North American Forest Soils Conference*. Colorado State University. C.T. Youngberg, (ed.) pp. 477-515.

Tripp, D.B., and V.A. Poulin. 1986. *The effects of logging and mass wasting on salmonid spawning habitat in stream on the Queen Charlotte Islands*. British Columbia Ministry of Forests and Lands, Research Branch. 29 pages.

Troendle, C.A., and R.M. King. 1987. The effect of partial and clearcutting on streamflow at

Deadhorse Creek, Colorado. *Journal of Hydrology*. 90:145-157.

Ursic, S.J. 1991. Hydrologic effects of two methods of harvesting mature southern pine. *Water Resources Bulletin*. 27(2):303-315.

Ursic, S.J., and F.E. Dendy. 1963. Sediment yields from small watersheds under various land uses and forest covers. In: *Proceedings of the Federal Inter-Agency Sedimentation Conference*. USDA Miscellaneous Publication 970. pp. 47-52.

Vitousek, P.M., and J.M. Melillo. 1979. Nutrient losses from disturbed forests: Patterns and mechanisms. *Forest Science*. 25(4):605-619.

Wallis, J.R. 1963. *Logging for water quality in northern California*. USDA Forest Service, Pacific Southwest Forest and Range Experiment Station. Research Note PSW-N23. 7 pages.

Wooldridge, D.D. 1960. Watershed disturbance from tractor and skyline crane logging. *Journal of Forestry*. 58(5):369-372.

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BMPs AND SPECIFICATIONS

Binkley, V. 1963. Factors to consider when selecting skyline yarding systems for site protection. In: *Symposium on Forest Watershed Management*. March 25-28, 1963. Society of American Foresters and Oregon State University. pp. 259-270.

Different types of skyline systems (Skagit, Wyssen) are described. The physical requirements, rigging requirements, supports, cutting unit layout, and economic requirements of skyline systems, and factors affecting cost and soil disturbances are discussed. A brief summary of the advantages and disadvantages of skyline logging systems is presented. This is a general paper intended to introduce skyline systems.

Bradshaw, G. 1979. *Preplanned skid trails and winching versus conventional harvesting on a partial cut*. Research Note 62. Oregon State University, School of Forestry, Forest Research Lab, 4 pages.

A study was conducted to compare the economic and soil disturbance performance of two partial cut units, one with preplanned skid trails and winching and the other with conventional skidding. The conventional harvest produced 11% more and cost per volume harvested was 29% less than the preplanned. However, the preplanned treatment resulted in only 4% of its area in skid trails, compared to 22% for the conventional harvest. Tables of data for cost and soil disturbance are provided.

Bramhall, J.W. 1989. Riparian systems and forest management- changes in harvesting techniques and their effects on decomposed granitic soils. In: *Proceedings of the California Riparian Systems Conference*. Davis, California, September 22-24, 1988. USDA Forest Service, Pacific Southwest Forest and Range Experiment Station. General Technical Report PSW-110. pp. 176-179.

In the 1950s, timber on steep granitic terrain in Trinity County, California, was harvested by using the logging techniques of the time. After Trinity Dam was built in the 1960s, it became evident these techniques were not suited to quality riparian habitat and healthy anadromous fisheries. Since adoption of the Z'berg-Nejedly Forest Practice Act in 1973, efforts have been expended to repair damages to riparian vegetation and to find forest practices compatible with granitic soils. This article lists BMPs developed for timber harvesting on granitic soils in 1986, focusing on protection of the riparian zone. No effectiveness information is given.

Burton, T.M., and G.E. Likens. 1973. The effect of strip-cutting on stream temperatures in the Hubbard Brook Experimental Forest, New Hampshire. *BioScience*. 23:433-435.

A small watershed in the Hubbard Brook Experimental Forest, a northern hardwood forested ecosystem, was divided into horizontal strips each 25 m wide, and every third strip was logged commercially to determine the effects of strip-cutting on stream temperature. Stream temperature rose rapidly by 4-5 °C in the cut strips and subsequently cooled in the uncut strips. Stream temperature was fairly constant prior to cutting. Algal blooms were a result of increased solar radiation in cut strips. The role of temperature as a water quality factor is discussed, and other papers on stream temperature studies are briefly reviewed. Buffer strips are suggested as a means to mitigate the effect of cutting on stream temperature fluctuations.

Campbell, R.G., J.R. Willis, and J.T. May. 1973. Soil disturbance by logging with rubber-tired skidders. *Journal of Soil and Water Conservation*. 29(5):218-220.

This study was conducted to determine the effects of rubber-tired harvesting on Piedmont soils in Georgia. In the Piedmont region, rolling uplands have deep, well-drained soils with sandy loam to clay loam surface horizons and clay subsoils. A survey of logging damage by rubber-tired skidders indicated that 23% of Piedmont logging chances are disturbed. Soil physical conditions (bulk density, moisture retention, soil strength, chemical properties) indicated that 5-10% of an area has changes that could restrict tree growth. Survival and height growth of pine seedlings on noneroded skid trails were not affected by harvesting practices.

Carvell, K.L. 1984. A silvicultural evaluation of cable yarding for partial cuts. In: *Mountain Logging Symposium Proceedings*. West Virginia University, June 5-7. P.A. Peters and J. Luchok (eds.). pp. 133-141.

A literature survey related to cable yarding in partially-cut stands indicates that damage to residual trees, understory reproduction, soil and water quality from well-planned cable operations is comparable to, or less than that from rubber-tired skidder or tractor logging. In even-aged management, damage to small trees and the understory is not as critical as in uneven-aged management. Even in uneven-aged management, however, the younger trees (growing stock) can be adequately protected if damage is minimized through careful planning of the yarding operation and proper training of loggers.

Chatwin, S.C., D.E. Howes, J.W. Schwab, and D.N. Swanston. 1991. *A guide for management of landslide-prone terrain in the Pacific Northwest*. British Columbia Ministry of Forests. Land Management Handbook No. 18. 212 pages.

This guide was prepared for personnel operating in areas with existing or potential land stability problems. The document was developed for use in the Pacific Northwest; however, the principles presented may be applicable to other areas. Four topics are addressed: slope movement processes, recognition of landslide-prone areas, measures to manage unstable terrain during forestry activities (especially road construction and timber harvest), and road deactivation and revegetation on unstable terrain. Detailed definitions and techniques for determining potential instability and methods for preventing landslides from forestry roads are included.

Clayton, J.L. 1981. *Soil disturbance caused by clearcutting and helicopter yarding in the Idaho batholith*. USDA Forest Service Research Note INT-305. 7 pages.

Disturbance to soil from helicopter logging and broadcast burning of slash from a large commercial clearcut in the Idaho batholith was evaluated in this study. Clayton reported only 2% soil disturbance associated with the helicopter yarding. Slash burning increased soil disturbance

by 14%. The disturbance from helicopter yarding was lower than values reported for other yarding techniques. Data from this study can be used to compare traditional skidding practices known to disturb soil surfaces to a progressive system of yarding.

Cordero, W.G. 1982. *The second generation of the mini-skidder DH4 used as a prebunching machine*. Master's Thesis, University of Idaho, 76 pages.

A synopsis of mini-skidder harvest performance and soil compaction compared to standard skidder performance and soil compaction at a logging site is described. The mini-skidder resulted in significantly less compaction of soil than the conventional skidder (7% and 44% increase, respectively). Information is also provided on skidder harvest performance and operation costs using both skidders. The author found that using the mini-skidder for time-consuming tasks (bunching) and using the conventional skidder for the skidding operation was the most cost-effective method in this study. The author also recommends experimentation with different configurations and options for the machinery to determine the optimal setup for specific sites.

Crumrine, J.P. 1977. Best management practices for the production of forest products and water quality. In: *Proceedings of the 208 Symposium on Non-Point Sources of Pollution from Forested Land*. Southern Illinois University, Carbondale, Illinois. G.M. Aubertin (ed.). pp. 267-274.

Written shortly after passage of the Clean Water Act (1972), this article discusses the concept and use of BMPs in forestry generally. The author stresses the important contribution of NPS pollution to water quality problems. A distinction between preventative and mitigative controls for the enhancement and protection of water quality is made and discussed, with reference to forestry BMPs that fall under each category. A general discussion of the concept of BMPs, this is a transcript of a talk that was originally accompanied by slides.

Cubbage, F.W., and C.E. DeForest. 1991. BMPs and harvesting regulations in the South. In: *Forestry and the Environment...Engineering Solutions*. New Orleans, Louisiana, June 4-6, 1991. American Society of Agricultural Engineers.

This paper provides an overview of best management practices that apply to forestry practices, including road construction, timber harvest, stream crossing, streamside management zones, and maintenance and retiring of structures. This paper presents basic information about the types of BMPs that may be used. The paper introduces regulatory trends in the states of Florida, North Carolina, West Virginia, and Maryland, as well as regulatory trends in forested wetlands.

DeHart, D.B. 1982. *The effects of timber harvesting on erosion and sedimentation in New Hampshire*. 36 pages. New Hampshire Division of Forests and Lands, Department of Resources and Economic Development.

The results of a survey of the impacts of forest harvest practices on soil loss and water quality are presented in this document. Overall, commercially clearcut sites had higher erosion rates and greater water quality impacts than sites harvested by other methods. A glossary of forestry terms and an explanation of various forestry best management practices are also included in the document.

Dunford, E.G. 1962. Logging methods in relation to stream flow and erosion. *5th World Forestry Congress, 1960 Proceedings*. 3: 1703-1708.

This paper provides a general description of logging operations and discusses the effects of logging on soil properties (compaction and erosion) and the importance of the area disturbed. The effects of logging on streams, including

temperature changes, increased sediment loads, and alteration of general hydraulic characteristics, are discussed. Remedial measures (prelogging plans, proper location and maintenance of logging roads, and providing proper dispersion of surface runoff) are seen as essential to proper environmental forest protection.

Eschner, A.R., and J. Larmoyeaux. 1963. Logging and trout: Four experimental forest practices and their effect on water quality. *Progress in Fish Culture*. 25:59-67.

Studies were done to determine how four different timber harvesting practices affect water quality and streamflow. The four practices investigated were a commercial clearcut, a diameter limit (all trees over 17 in dbh), extensive selection (selected trees over 11 in dbh), and intensive selection (selected trees over 5 in dbh). Five contiguous, forested watersheds in the Fernow Experimental Forest west of the Allegheny Front in West Virginia served as study sites. Streamflow, precipitation, and water quality were studied on the watersheds for 6 years prior to four of the five watersheds being logged. Prediction equations were formulated from the data obtained. Stream discharge was increased by the treatments, low flow was significantly augmented, and water quality was damaged. Growth on remaining trees and new cover appeared immediately following the treatments, and improvements in water quality and a return to normal flow occurred. Tables detailing the treatments and their effects on the four logged watersheds, corresponding to the four practices studied, are included.

Froehlich, H.A. 1973. Natural and man-caused slash in headwater streams. *Loggers Handbook*. Vol. XXXIII. Pacific Logging Congress.

Froehlich observed the amount of debris in Oregon headwater streams. He found that debris occurs there naturally as well as being placed there by logging activities. After following 17 logging projects, he discovered that (1) conventional freefalling techniques cause large increases in stream debris; (2) in sharp contrast, cable-assisted directional falling causes small increases in stream debris; and (3) stream buffer strips decrease the amount of debris reaching the stream with increasing size (range was 20 to 130 feet wide). The author recommends using directional felling to prevent debris from entering the stream over clearing the streams or using buffer strips.

Graham, R.T. 1989. Importance of integrating harvesting, site preparation, and regeneration: The silvicultural system. In: *Forestry on the Frontier, Proceedings of the 1989 Society of American Foresters National Convention*. Spokane, Washington. pp. 217-218.

The author describes a silvicultural system as a planned program of silvicultural treatment during the whole life of a stand. The successful implementation of silvicultural systems is essential to good forestry practice. A prescription, or a successfully coordinated plan that integrates a sequence of treatments, is important to the implementation of a silvicultural system. The prescription should include the desired future condition of the stand, timber harvesting schedules and methods, site preparation after harvesting, and maintenance activities to ensure seedling survival. The integration of harvesting, site preparation, and regeneration is essential to productivity but is often not accomplished because forestry activities are split among divisions of industry or government. Lack of communication among the divisions undermines the implementation of good silvicultural systems. This article contains no data or case studies and is limited to theoretical discussion.

Hartman, G., J.C. Scrivener, L.B. Holtby, and L. Powell. 1987. Some effects of different streamside treatments on physical conditions and fish population processes in Carnation Creek, a coastal rain forest stream in British Columbia. In: *Streamside Management: Forestry and Fishery Interactions*. E.O. Salo and T.W. Cundy (eds). University of Washington, College of Forest Resources, Seattle, Washington. pp. 330-372.

Carnation Creek has been studied continuously since 1971. During this time 41% of the watershed was logged. Three different streamside treatments conducted in the alluvial floodplain portion were evaluated: (1) an intensive treatment of clearcutting, felling of streambank alder, and yarding of felled trees and merchantable timber; (2) a careful treatment of clearcutting to the margin of the stream and felling of streambank alder, with no in-channel activity; and (3) a leave strip treatment in which a variable width strip of vegetation was left along the stream. Stream temperature increased due to logging. The decrease in volume and stability of large debris was accompanied by streambank erosion and straightening of the channel. This in turn caused a change in gravel quality in the lower sections of the stream. Coho and chum salmon egg-to-fry survival was lower following the first major storm following logging. Trout smolt numbers decreased, but coho smolts increased by 76% between 1976 and 1983. Afterward they decreased to prelogging levels.

Hartung, R.E., and J.M. Kress. 1977. *Woodlands of the Northeast: Erosion and sediment control guides*. USDA Soil Conservation Service, Northeast Technical Service Center and Forest Service, Northeast Area S and PF. 26 pages.

This is a guidance manual for forestry activities in the northeastern United States. Extensive measures for erosion and sediment control are described, and structural design criteria are provided. Water control on roads, seeding of roadbanks, building of logging road bridges, and the need for adequate filter strips are described.

Hornbeck, J.W. 1968. Protecting water quality during and after clearcutting. *Journal of Soil and Water Conservation*. 23(1):19- 20.

This paper provides a follow-up study to Hornbeck and Reinhart (1964). In this study two watersheds were harvested using selection cutting and carefully planned logging operations that exposed less than 1% of the watershed's mineral soil. Turbidity levels from this study were lower than those reported in 1964. As with the 1964 study, skid roads were considered the primary source of the turbidity from the watershed. The author concludes that water quality impacts associated with timber harvest activities can be reduced if sound practices are used.

Hornbeck, J.W., G.E. Likens, R.S. Pierce, and F.H. Bormann. 1975. Strip cutting as a means of protecting site and streamflow quality when clearcutting northern hardwoods. In: *Forest Soils and Forest Land Management, Proceeding of the Fourth North American Forest Soils Conference*. B. Bernier and C.H. Winget (eds.). pp. 209-224.

The results of a progressive strip cutting (a form of clearcutting) experiment in northern hardwoods at the Hubbard Brook Experimental Forest are presented in this paper. Various changes to the ecosystem, including vegetation response, and changes in water yield and water quality are discussed. The following conclusions are made: (1) small increases in water yield were observed during two succeeding growing seasons; (2) stream temperature, pH, and turbidity showed minor changes after strip cutting; and (3) large increases in nitrate and calcium were observed although the losses were smaller than those typical of conventional clearcutting. The paper also presents data on other nutrients monitored during the experiment.

Hornbeck, J.W., C.W. Martin, and C.T. Smith. 1986. Protecting forest streams during whole-tree harvesting. *Northern Journal of Applied Forestry*. 3(3):97-100.

The effects of whole-tree harvests in the Northeast on stream turbidity, temperature, and chemistry in three watersheds are presented in this paper. The data indicate that the use of BMPs during whole-tree harvest can limit water quality impacts to levels typical of bole-only harvest. The paper lists eight BMPs that the authors suggest to minimize stream damage from all forms of tree harvesting: use streamside buffer strips of 15 to 30 m; select logging methods that minimize road construction; maximum grade on roads of 10% (except for short stretches); install cross drains and dips to move water from roads and trails; minimize rutting by skidders by avoiding repeat trips over the same route; exhibit flexibility in planning operations (e.g., build roads and trails during dry weather); finish the operation as soon as possible; and remove temporary bridges and culverts, and revegetate problem areas.

Huff, J.L., and E.L. Deal. 1982. *Forestry and water quality in North Carolina: A voluntary program for the control of nonpoint sources of pollution from logging and silvicultural activities*. North Carolina Agricultural Extension Service and North Carolina State University. 8 pages.

This extension service publication discusses BMPs for forest road construction to control erosion. General headings include planning logging roads, constructing logging roads, harvesting, maintenance of logging roads, maintenance of logging roads after logging, and regenerating a new stand. BMPs are listed and briefly discussed under each heading.

Jones, R.C., and B.H. Holmes. 1985. *Effects of land use practices on water resources in Virginia*. Virginia Polytechnic Institute and State University, Water Resources Research Center. VPI-VWRRC- BULL-144.

This report presents a review of forestry, agriculture, and urban land uses in Virginia and how they affect water resources. A review of hydrologic changes and water quality impacts from forestry operations is included. In addition, a review of forestry water quality management programs in the state is presented. This report presents generalized information on how a specific state manages water resources that may be affected by forestry activities.

Kochenderfer, J.N., and G.W. Wendel. 1978. *Skyline harvesting in Appalachia*. USDA Forest Service, Northeastern Forest Experiment Station. Forest Research Paper NE-400.

A skyline logging system called the URUS was tested during a partial cutting of forest in West Virginia. The document describes the advantages and disadvantages of skyline harvesting and provides recommendations for the equipment as well as for topographical sitings. The article concludes by stating that the more sophisticated yarding systems used in the West are not economically feasible or implementable for eastern forests.

Lantz, R.L. 1971. *Guidelines for stream protection in logging operations*. Oregon State Game Commission, Portland, Oregon. 29 pages.

This report reviews why certain logging practices in the West Coast Douglas fir region are more desirable than others for protecting fish habitat and water quality. Streams can be protected to a large extent by (1) keeping streamside vegetation intact and (2) taking precautions to eliminate or minimize soil disturbance and erosion, particularly that resulting from roads. The report emphasizes the need to change or eliminate some traditional logging practices due to the resource conflicts between and interdependence of fisheries and timber production. The report addresses the freshwater requirements of salmon and trout, the importance of protecting stream habitat, and

forestry practices that can be used to protect fish habitat. The author discusses streamside management areas and road location, construction, and maintenance practices.

Lynch, J.A., E.S. Corbett, and K. Mussallem. 1985. Best management practices for controlling nonpoint-source pollution on forested watersheds. *Journal of Soil and Water Conservation*. 41(1):164-167.

The Pennsylvania Department of Environmental Resources, Bureau of Forestry, developed a set of best management practices (BMPs) to limit and/or control nonpoint source pollution from silvicultural activities. Nonpoint source pollution in a forested watershed is characterized by changes in stream temperature, turbidity/ sediment levels, and nutrient concentrations and export. A watershed study conducted on the Leading Ridge Experimental Watersheds in central Pennsylvania suggested that the BMPs were effective in controlling nonpoint source pollution from a 44.5- hectare commercial clearcut. Slight increases in stream temperature, turbidity, and nitrate and potassium concentrations were observed, but these increases did not exceed drinking water standards.

Lysons, H.H., and R.H. Twito. 1973. Skyline logging: An economical means of reducing environmental impact of logging. *Journal of Forestry*. 71(9):580-583.

The basic tight, slack, and running skyline yarding systems are reviewed, and the desired characteristics of a logging system are identified to help select the most suitable means of yarding. Figures of the systems are provided. The physical, economic, and environmental characteristics of each of the systems are listed and discussed. Several misconceptions concerning skyline logging are clarified. One is that skyline logging is more costly than high-lead logging; skyline logging is economically feasible and is less sensitive to yarding distance than are other logging systems. Another is that the span length greatly decreases the load-carrying ability; for any given deflection, the load- carrying ability decreases only by the added weight of the line for the longer span. Also, a highly mobile cable system is probably the best way to harvest partial cuts and thinnings, contrary to popular beliefs.

McClimans, R.J. 1980. Best management practices for forestry activities. In: *Watershed Management*. Boise, Idaho, July 21-23, 1980. C.W. Johnson (ed.). American Society of Civil Engineers, Irrigation and Drainage Division, Committee on Watershed Management. pp. 694-705.

This paper defines critical combinations of site conditions for which BMPs are needed to minimize adverse impacts on soil and water resources. The document also includes assessment methodologies, as well as charts and graphs for the selection and application of appropriate BMPs. Forest practices are grouped according to their capacity to cause water pollution, the nature of the more commonly applied BMPs to control pollution, and site considerations. Guides, based on slope of land and distance from water, are provided to determine whether a particular BMP is necessary for the particular group of activities. Graphs developed to determine BMP applicability are presented, and the selected BMPs are discussed for each group of forest activities. Specifications for some BMPs are also presented.

Miller, J.H., and D.L. Sirois. 1986. Soil disturbance by skyline yarding vs. skidding in a loamy hill forest. *Soil Science Society of America Journal*. 50(6):1579-1583.

Soil disturbance was assessed on harvested units of mature southern pines (Pinus spp.), where a part of each unit was logged with a cable skyline system and a part with rubber-tired ground skidders. The effects of the two methods of harvesting were studied by aerial and ground surveys. Cable yarding required 2% less acreage in landing than skidding, and yarding corridors occupied 12% less area than did skid trails. Physical and chemical analyses of surface soils

(upper 15 cm) showed that loam soils with clay subsoils were most severely affected by the displacement of topsoil after both methods of logging. On 8% to 14% of both logged areas, harvesting activities resulted in significant reductions in organic matter; available moisture holding capacity; and available P, Ca, and K. Silt loam soils were severely compacted by cable yarding in the corridors that consistently ran upslope, creating the greatest erosion potential. The authors conclude that the carefully planned use of skyline cable systems would minimize the area affected by severe soil disturbance and should be considered for future harvesting in this locale.

Mumma, J.W., and J.S. Tixier. 1988. *Soil and water conservation practices handbook*. USDA Forest Service R-1 Missoula, Montana and R-4, Ogden, Utah. Handbook 2509.22.

The primary purpose of this document is to present BMPs for use in minimizing adverse impacts from forestry practices. It describes the application, monitoring, evaluation, and adjustment of these practices. Examples of BMPs that have been field-tested and are known to provide protection under specific circumstances are also presented. This general forestry BMP document includes definitions and the purposes for each practice.

Murphy, M.L., J. Heifetz, S.W. Johnson, K.V. Koski, and J.F. Thedinga. 1986. Effects of clear-cut logging with and without buffer strips on juvenile salmonids in Alaskan streams. *Canadian Journal of Fisheries and Aquatic Sciences*. 43(8):1521-1533.

To assess short-term effects of logging on juvenile Oncorhynchus kisutch, Salvelins malma, Salmo gairdneri, and Salmo clarki in southeastern Alaska, the fish density and habitat in summer and winter were compared in 18 streams in old-growth forest and in clearcuts with and without buffer strips. The study concludes that clearcutting may increase fry abundance in summer in some streams by increasing primary production, but may reduce abundance of parr in winter if debris is removed. Use of buffer strips maintains or increases debris, protects habitat, allows increased primary production, and can increase abundance of fry or parr. The report also contains references to more than 50 other papers.

Neuman, L. 1987. Silviculture and best management practices. In: *Erosion Control: You're Gambling Without it*. International Erosion Control Association. pp. 145-155.

This report presents information on the types of impairments typical of forestry activities and provides information on management techniques that may be used to minimize the impacts. The practices presented in this paper include timber harvesting, site preparation, and road construction and drainage. Erodibility factors, assigned to Florida soils by the SCS, and slope determine a site's sensitivity to erosion, and the paper presents site sensitivity classes for Florida soils. This classification is related to suggested BMP usage and implementation. Many useful tables of specifications for when and how to construct the practices are presented.

Patric, J.H., and G. Aubertin. Long-term effects of repeated logging on an Appalachian stream. *Journal of Forestry*. 75(8): 492-494.

The effect of BMPs on the turbidity of streams running off the Elk Lick Run Logging site was examined. After two well-planned loggings in 1910 and the 1930s, a 1957 logging with poorly planned and managed roads caused significant amounts of turbidity. A 1972 logging that followed BMPs did not affect turbidity.

Ponce, S.L. 1986. Controlling diffuse-source pollution associated with forest practices in North America. In: *Effects of land use on fresh waters: agriculture, forestry, mineral exploitation, urbanization*. L.G. Solbe (ed.). Water Research Centre, Chichester, England. pp. 432-443.

This paper provides an overview of strategies used within the United States to control the degradation of water quality from forest practices. The document includes information on regulations, source impacts, and control opportunities. Several excellent tables are presented with information on silvicultural activities and their associated impacts and control practices.

Pope, P.E. 1978. Forestry and water quality: Pollution control practices. *Forestry and Natural Resources*. Purdue University Cooperative Extension Services. FNR 88. 6 pages.

Best management practices (BMPs) for forestry activities are presented, stressing that feasible BMPs must depend on site- specific, case-by-case information such as management objectives and natural conditions. Information on the effectiveness of BMPs is not provided. The principal types of erosion control practices and qualitative positive and negative features, based on EPA Technical Report 37 (1977) are included.

Riekerk, H., D.G. Neary, and W.J. Swank. 1989. The magnitude of upland silviculture nonpoint source pollution in the south. In: *Proceedings of the Symposium on the Forested Wetlands of the Southern United States*. Orlando, Florida, July 12-14, 1988. USDA Forest Service, Southeast Forest Experiment Station. General Technical Report SE-50. pp. 8-18.

Streamflow water quality data from intensive silvicultural practices in the southern United States are summarized and discussed with respect to regional differences of nonpoint source pollution, and BMPs. Suspended sediment production by silviculture was low in the mountains and lower coastal plain, but high in the Piedmont and upper coastal plain regions. This was due to a combination of site preparation intensity and topographic relief. Nutrient exports in the Piedmont and upper coastal plain regions were controlled by the degree of soil disturbance and by the recovery rate of vegetation. Nutrient exports in the lower coastal plain were not much affected by intensive silviculture. Research is needed on the effects of silvicultural practices in wetlands and on the actual effectiveness of BMPs. Research and analyses of cumulative effects are also needed to determine the impacts of multiple silvicultural practices on downstream wetlands.

Rothwell, R.L. 1971. *Watershed management guidelines for logging and road construction*. Canadian Forestry Service, Department of Fisheries and Forestry, Forest Research Laboratory, Edmonton, Alberta, Canada. Information Report A-X-42. 78 pages.

This guidance document was prepared to minimize the impacts to water quality resulting from silviculture in North America. The document covers virtually all activities from start to finish of a logging event. These activities include road construction and maintenance. Appropriate best management practices are graphically described.

Rothwell, R.L. 1978. *Watershed management guidelines for logging and road construction in Alberta*. Canadian Forest Service, Northern Forest Research Center. Information Report NOR-X-208. 43 pages.

This document presents information on general guidelines to follow when constructing and maintaining a forest road. Information provided in the document includes the following: road gradient, road width, aspect, stream protection, stream crossings, cuts and fills, drainage, and retirement. This paper presents specifications for many of the best management practices suggested.

Triansoky, P. 1991. BMPs: A must if we are to survive. *Forest Farmer*. 28:13-15.

This general article discusses the concept of using BMPs in forestry, the benefits of employing BMPs, and the disadvantages for the forest farmer of not using them. Economic incentives for using BMPs are also discussed from the point of view that not using them will eventually cost the forest farmer as much or more than the original cost of the BMP.

USDA Forest Service. 1992. *Investigating Water Quality in the Pacific Southwest Region, Best Management Practices Evaluation Program (BMPEP): A User's Guide*. USDA Forest Service, Region 5, San Francisco, California.

This document is the result of a continuous loop of on-site evaluations, BMP prescription development, implementation, monitoring, and feedback. The monitoring/evaluation program described in this user's guide provides the feedback loop to obtain and document observations of how well BMPs protect water quality and also helps to identify deficiencies and their causes and necessary corrective actions. On-site evaluations were made on the following activities: streamside management zones, skid trails, suspended yarding, landings, meadow protection, special erosion control and revegetation, timber administration, road surface, drainage, slopes protection, stream crossings, servicing and refueling, in-channel construction practices, temporary roads, rip-rap, snow removal, protection of roads during wet periods, pioneer road construction, prescribed fire, revegetation of surface disturbed areas, and location of stock facilities in wilderness. In addition, assistance in accessing the Best Management Practices Evaluation Program database (BMP- DB) is provided.

Yoho, N.S. 1980. Forest management and sediment production in the south-A review. *Southern Journal of Applied Forestry*. 4(1):27-36.

The author reviews sediment yields from various forestry activities, finding that forest practices commonly result in small short-term increases and that significant increases are limited to practices conducted with heavy machinery. Yields from similar sites receiving the same type of disturbance vary by several hundred percent, and sediment yields are reduced when channel disturbance is avoided. Careful planning, design, construction, use, and maintenance of forest roads and skid trails achieve the greatest reductions. The author provides comparative soil loss data for a variety of land uses: less than 0.1 ton/acre/yr (undisturbed mixed forest, forest thinning); 0.1 - 1.0 ton/acre/yr (carefully clearcut forest, abandoned fields); 1.0 - 10.0 tons/acre/yr (annually burned forest, mechanical site preparation); 10 - 100 tons/acre/yr (carelessly cultivated or steep sloped fields); and 100 or more tons/acre/yr (active construction, gullies).

Adams, P.W., and H.A. Froehlich. 1981. *Compaction of forest soils*. USDA Forest Service, Pacific Northwest Range and Experiment Station. PNW-216. 13 pages.

Anderson, H.W., M.D. Hoover, and K.G. Reinhart. 1976. *Forests and water: Effects of forest management on floods, sedimentation, and water supply*. USDA Forest Service. General Technical Report PSW-18. 115 pages.

Baumgartner, D.M. (ed). 1981. *Interior west watershed management: Proceedings of a symposium*. Spokane, Washington, April 8-10, 1980. Washington State University, Cooperative Extension Service. 288 pages.

Binkley, V.W. 1965. *Economics and design of a radio-controlled skyline yarding system*. USDA Forest Service, Pacific Northwest Forest and Range Experiment Station. Research Paper PNW-25. 30 pages.

Blinn, C.R., and P.C. Bates. 1989. Integration of harvesting methods and silvicultural practices: An eastern perspective. In: *Forestry on the Frontier: Proceedings of the 1989 Society of American*

Foresters National Convention. Spokane, Washington. pp. 203-207.

Burke, D. 1975. Running skylines reduce access road needs, minimize harvest site impact. *Forest Industries*. pp. 46-48.

Cromack, K., Jr., F.J. Swanson, and C.C. Grier. 1978. A comparison of harvesting methods and their impact on soils and environment in the Pacific Northwest. In: *Forest Soils and Land Use, Proceedings of the Fifth North American Forest Soils Conference*. Colorado State University, Fort Collins, Colorado. C.T. Youngberg (ed.). pp. 449-478.

Cullen, J.B. 1991. *Best management practices for erosion control on timber harvesting operations in New Hampshire resource manual*. New Hampshire Department of Resources and Economic Development, Division of Forests and Lands.

Dissmeyer, G.E., and G.R. Foster. 1980. *A guide for predicting sheet and rill erosion on forest land*. USDA Forest Service. Technical Publication R8-P6. 40 pages.

Everest, F.H., and W.R. Meehan. 1981. Forest management and anadromous fish habitat productivity. In: *Transactions of the 46th North American Wildlife and Natural Resources Conference*. Wildlife Management Institute, Washington, DC. pp. 521-530.

Golden, M.S., C.L. Tuttle, J.S. Kush, and J.M. Bradley. 1984. *Forestry activities and water quality in Alabama: Effects, recommended practices, and an erosion-classified system*. Auburn University, Agricultural Experiment Station. Bulletin 555.

Helvey, J.D., and W.B. Fowler. 1979. *Grass seeding and soil erosion in a steep logged area in northeastern Oregon*. USDA Forest Service, Pacific Northwest Forest and Range Experiment Station. Research Note PNW-343. 11 pages.

Leaf, C.F. 1975. *Watershed management in the central and southern Rocky Mountains: A summary of status of our knowledge by vegetation type*. USDA Forest Service, Rocky Mountain Forest and Range Experiment Station. Research Paper RM-142. 28 pages.

Leaf, C.F. 1975. *Watershed management in the Rocky Mountain subalpine zone: The status of our knowledge*. USDA Forest Service, Rocky Mountain Forest and Range Experiment Station. Research Paper RM-137. 31 pages.

McEvoy, T.J. 1989. Private forests: Common sense erosion control. *American Forests*. 95:32-34,66-67.

Megahan, W.F. 1983. Appendix C: Guidelines for reducing negative impacts of logging. In: *Tropical watersheds: Hydrologic and soils response to major uses or conversions*. L.S. Hamilton and P.N. King (eds.). Westview Press, Boulder, Colorado. pp. 143-154.

Minnesota Department of Natural Resources, Division of Forestry. 1989. *Water quality in forest management: Best management practices in Minnesota*. 104 pages.

NCASI. 1984. *Forestry management practices and cumulative effects on water quality and utility*. National Council of the Paper Industry for Air and Stream Improvement. Technical Review Bulletin No. 435.

O'Leary, J. 1963. The high-lead system. In: *Symposium on Forest Watershed Management*. March 25-28, 1963. Society of American Foresters and Oregon State University. pp. 271-276.

Peters, P.A., and J. Luchok (eds). 1984. *Mountain Logging Symposium Proceedings*. West Virginia University, June 5-7, 1984. 372 pages.

Roby, K., J. Rector, and M. Furniss. 1991. *PSW region of the Forest Service about to launch BMP*

evaluation process. USDA Forest Service, Pacific Southwest Region. White paper. 2 pages.

Sopper, W.E. 1975. Effects of timber harvesting and related management practices on water quality in forested watersheds. *Journal of Environmental Quality*. 4(1):24-29.

Svinth, J.F. 1963. Revegetation of cut and fill Slopes. In: *Symposium on Forest Watershed Management*. March 25-28, 1963. Society of American Foresters and Oregon State University. pp. 253-258.

Thomas, J.W., D.A. Leckenby, L.J. Lyon, L.L. Hicks, and C.L. Marcum. 1988. *Integrated management of timber-elk-cattle: Interior forests of western North America*. USDA Forest Service, Pacific Northwest Research Station. General Technical Report PNW- GTR-225. 12 pages.

USDA Forest Service. 1989. *Annotated bibliography on soil erosion and erosion control in subarctic and high-latitude regions of North America*. USDA Forest Service, Pacific Northwest Forest and Range Experiment Station. General Technical Report PNW-GTR-253.

Whitman R. 1989. Clean water of multiple use? Best management practices for water quality control on the national forests. *Ecology Law Quarterly*. 16(4):909.

COSTS AND EFFECTIVENESS OF BMPs

Benson, R.E., and M.J. Niccolucci. 1986. What does it cost to protect nontimber resources during logging? *American Forests*. 92(6):26-28 and 53-54.

This paper presents an analysis of the major cost components associated with managing and protecting nontimber resources in National Forests. Data from 187 timber sales in the northern Rocky Mountains between 1975 and 1981 were used to test different ways of assigning costs to nontimber resources. The average cost of protecting nontimber resources was $26/1000 board-feet of timber sold. Broken down, costs were $12.69 for road construction and maintenance, $8.77 for log hauling, and $4.46 in other activities such as felling trees, log skidding, and slash disposal. These costs cover soil, water, habitat, and other resources. The opportunity costs and administrative costs associated with protection on nontimber resources are not included. The authors conclude that determining exact costs associated with protection of natural resources will not be possible until methods of estimating opportunity and administrative costs are developed.

Binkley, V. 1963. Factors to consider when selecting skyline yarding systems for site protection. In: *Symposium on Forest Watershed Management*. March 25-28, 1963. Society of American Foresters and Oregon State University. pp. 259-270.

Different types of skyline systems (Skagit, Wyssen) are described. The physical requirements, rigging requirements, supports, cutting unit layout, and economic requirements of skyline systems, and factors affecting cost and soil disturbances are discussed. A brief summary of the advantages and disadvantages of skyline logging systems is presented. This is a general paper intended to introduce skyline systems.

Bradshaw, G. 1979. *Preplanned skid trails and winching versus conventional harvesting on a partial cut*. Research Note 62. Oregon State University, School of Forestry, Forest Research Lab, 4 pages.

A study was conducted to compare the economic and soil disturbance performance of two partial cut units, one with preplanned skid trails and winching and the other with conventional skidding. The conventional harvest produced 11% more and cost per volume harvested was 29% less than the preplanned. However, the preplanned treatment resulted in only 4% of its area in skid trails, compared to 22% for the

conventional harvest. Tables of data for cost and soil disturbance are provided.

Cordero, W.G. 1982. *The second generation of the mini-skidder DH4 used as a prebunching machine*. Master's Thesis, University of Idaho, 76 pages.

A synopsis of mini-skidder harvest performance and soil compaction compared to standard skidder performance and soil compaction at a logging site is described. The mini-skidder resulted in significantly less compaction of soil than the conventional skidder (7% and 44% increase, respectively). Information is also provided on skidder harvest performance and operation costs using both skidders. The author found that using the mini-skidder for time-consuming tasks (bunching) and using the conventional skidder for the skidding operation was the most cost-effective method in this study. The author also recommends experimentation with different configurations and options for the machinery to determine the optimal setup for specific sites.

Cubbage, F.W. 1987. Costs of forest water quality protection. In: *Forestry and Water Quality: A Policy Workshop for State Foresters*. Oklahoma City, Oklahoma, July 6-9, 1987.

This paper presents a review of the costs of forestry NPS controls, including agency administrative costs, direct costs to landowners or timber operators (e.g., plan preparation), and indirect costs on timber supplies. Forest practice costs are reviewed for California, Massachusetts, Nevada, Alaska, Idaho, Oregon, and Washington. The various approaches used by these states and their effect on implementation cost are analyzed as well. The approach used by forestry and other agencies for implementing the voluntary or required practice rules greatly affects the various costs of program implementation, as well as who bears the costs. Criteria used to select the means of controlling NPS pollution must include BMP effectiveness, political and social acceptability, and economic efficiency.

Cubbage, F.W., and P. Lickwar. 1990. *Estimating the costs of water quality protection on private forest lands in Georgia*. Georgia Forestry Commission, Research Division.

The purpose of the information presented in this paper is to quantify the operational costs of implementing various forestry best management practices, with emphasis placed on practices associated with road construction. This paper presents very good cost information on the following: road construction, stream crossings, broad-based dips, water bars, seed, fertilizer, mulch. The information is useful because the costs are based on various physiographic classifications (i.e., coastal plain, piedmont, or mountain).

Curtis, J.G., D.W. Pelren, D.B. George, V.D. Adams, and J.B. Layzer. 1990. *Effectiveness of best management practices in preventing degradation of streams caused by silvicultural activities in Pickett State Forest, Tennessee*. Center for the Management, Utilization and Protection of Water Resources, Tennessee Technological University for the Tennessee Department of Conservation, Division of Forestry and the Tennessee Wildlife Resources Agency. 197 pages.

This study was undertaken to evaluate the effectiveness of BMPs applied to timber harvest operations in Pickett Forest. The effects on water quality, fish production, and macroinvertebrates, and the presence of herbicides in streams were studied. The BMPs employed were SMZs, road placement on ridgetops and high elevations, skid trails kept at least 14 m from streams, harvest during the driest season and maximum soil stability, logging of small, dispersed stands, seeding and mulching of disturbed areas, broad-based dips on the haul road, and a period of 10 years before the area would be logged again. Herbicides were applied to two stands. Hardwoods 75 mm dbh or less were thin line sprayed with a mixture of Garlon (active ingredients triclopyr and 2,4-D), Sidekick, and diesel fuel. Picloram was injected into all

hardwoods 255 mm dbh or greater. Concentrations of herbicides in streams following the treatments was low: 2,4-D @ <0.02-0.08l. Based on available toxicity data, the levels detected were not biologically harmful. However, care is needed during application to minimize transport to surface waters. Extensive data relating to all of the BMPs employed during the study are presented in the paper .

Dissmeyer, G.E. 1986. Economic impacts of erosion control in forests. In: *Proceedings of the Southern Forestry Symposium*. Atlanta, Georgia, November 19-21, 1985. S. Carpenter (ed.). Oklahoma State University, Agricultural Conference Series. pp. 262-287.

A review of the literature is coupled with data to provide the reader with information on the potential economic returns to the landowner from erosion control practices. The paper references over 30 citations. Information on soil compaction, nutrient cycling, soil productivity, and growth and yields is included.

Dissmeyer, G.E., and B.B. Foster. 1990. Economics of forest soil resource management. In: *Sustained Productivity of Forest Soils, Proceedings of the 7th National North American Forest Soils Conference*. pp. 515-525.

This paper summarizes a national effort by the USDA Forest Service to develop methods to quantify the economic benefits of soil and water resource management and to demonstrate these methods through example. The costs of soil resource management are accounted for and compared with benefits to compute benefit/ cost ratios, net present values, and internal rates of return.

Dissmeyer, G.E., and B.B. Foster. 1987. Some economic benefits of protecting water quality. In: *Managing Southern Forests for Wildlife and Fish: A Proceedings*. USDA Forest Service, Southern Forest Experiment Station. General Technical Report SO-65. pp. 6-11.

Many of the practices used to protect water quality are the same ones used to improve soil productivity. Protecting soil productivity has economic benefits for the landowner in terms of timber produced per acre, and lowered road construction and maintenance costs. Increased fisheries production in forest streams is another economic benefit of protecting forest soils. The effects of sediment on fish habitats, and the principles and economic benefits of soil productivity, are reviewed. Tables present the economic returns of implementing various forest BMPs. For instance, skid trail rehabilitation yielded a real return of from 2.4% to 4.8%. The benefit/cost ratio of rehabilitating cut-and-fill slopes ranged from 2.4 to 4.4 in studies reviewed. Erosion control confers economic benefits on landowners and protects water quality and fisheries.

Duerr, W.A., and J.C. Jones. 1976. Forestry practices and water quality enhancement. In: *Proceedings of the Seventh Annual Forestry and Wildlife Forum*. Virginia Polytechnic Institute and State University, Blacksburg, Virginia. pp. 73-81.

This paper discusses the various economic aspects of forest practice controls. The benefits of forest practices are seen as potential in that they accrue only if regulatory programs work as intended. The benefits are enhanced quality of the watershed, increased aesthetic values, and improved growing and harvesting. The costs of the regulatory controls are fines that are real and immediate. A general cost of regulations is the loss of freedom to do as one wishes on one's own land. The authors investigate whether the costs justify the benefits. Few data were available to determine this although some costs were found to be reduced by the use of forest practices. However, the costs of forest practices vary greatly from site to site and from state to state due to the disparity among forest practice laws. The authors conclude that the costs of forest practices legislation are borne by the timber owner in the form of reduced stumpage prices.

Dykstra, D.P., and H.A. Froehlich. 1976. Costs of stream protection during timber harvest. *Journal of Forestry*. 74(10): 684-687.

This article analyzes the cost of three stream protection alternatives: conventional felling with channel cleanup; cable- assisted directional felling; and use of buffer strips. The study was conducted along 10 deeply incised headwater stream channels in western Oregon. None of the three alternatives was clearly preferable on a majority of the study areas. The least- cost alternative on four of the areas was a 55-foot-wide buffer strip ($20.02 to $27.77 per MBF). On three of the remaining areas, conventional felling was the least expensive ($20.83 to $23.97 per MBF), and on the other three, cable-assisted directional felling was the least expensive ($18.79 to $26.30 per MBF).

Dykstra, D.P., and H.A. Froehlich. 1976. Stream protection: What does it cost? *Loggers Handbook*. Pacific Logging Congress, Portland, Oregon.

A procedure for evaluating the costs of alternative stream protection measures is presented. The costs associated with various practices, including tree felling, stream cleaning, and yarding are compared. The paper includes many data tables that present the comparisons of the stream protection costs. The authors warn that the cost of stream cleaning is a function of the debris volume to be removed and that this procedure does not estimate debris loading.

Ellefson, P.V., and P.D. Miles. 1984. Economic implications of managing nonpoint forest source of water pollutants: A midwestern perspective. In: *Mountain Logging Symposium Proceedings*. West Virginia University, June 5-7, 1984. P.A. Peters and J. Luchok (eds.). pp. 107-119.

Economic evaluations of 6 forest practices designed to enhance water quality from 18 timber harvesting operations in the Midwest were carried out. Net revenue reductions ranged from 1.2% with redesign of landing and skid trail locations to 26.4% with buffer strip requirements. Nine operations were profitable with application of all six practices. Limited production function information hinders such analyses.

Ellefson, P.V., and R.E. Weible. 1980. Economic impact of prescribing forest practices to improve water quality: A Minnesota case study. *Minnesota Forestry Research Notes*.

A study in southeastern Minnesota was designed to determine the marginal cost of implementing management practices considered important to the reduction of nonpoint forest sources of water pollutants. In addition, the impact of requiring additional pollution-abating forest practices on a timber purchaser's net revenue was analyzed. The practices analyzed included filter strips, buffer strips, seeding landings and trails, and skid trail design. The analyses focused on a cost structure representative of state-owned forestland and considered costs only, not benefits. Overall, it appeared that pollution abatement costs may be very difficult to absorb by small-volume timber operations operating close to economic breakeven before controls. The authors recommended further research to determine economic benefits from many forestry BMPs.

Froehlich, H.A., D.E. Aulerich, and R. Curtis. 1981. *Designing skid trail systems to reduce soil impacts from tractive logging machines*. Oregon State University, School of Forestry, Forest Research Lab. Research Paper 44. 15 pages.

The results of a study conducted to determine the feasibility of two skidding systems, conventional and designated trails, are presented. The study was conducted to determine the differences in soil disturbance between the two systems. Skid trails covered 20% of the ground surface in the conventional harvest and 11%, 7%, and 4% in the designated trails 100, 150, and 250 feet apart, respectively. The paper presents several tables of data on skid trail specifications, regression equations for skid cycle times, and productivity of the two systems.

Gibson, H.C., and C.J. Biller. 1975. A second look at cable logging in the Appalachians. *Journal of Forestry*. 73(10):649- 653.

Cable logging, once used extensively in the Appalachians, is being reexamined to determine whether smaller, more mobile systems can help solve some of the timber management problems on steep slopes. A small Austrian skyline was tested in West Virginia to determine its feasibility for harvesting eastern hardwoods. The short-term test included both selection and clearcut harvesting. Costs were higher for the clearcut system although the authors believe costs for selective harvesting would normally be higher.

Hall, E. 1982. The benefits and costs of alternative logging systems. In: *Forest Access Symposium*. University of Idaho, College of Forestry, Wildlife and Range Sciences, November 12-13, 1982. Coeur d'Alene, Idaho. pp. 23-25.

The costs and benefits of aerial logging practices are presented. Several types of aerial logging techniques are described and equipment and operating costs are provided for each. This is a short but informative paper on alternative logging methods.

Hickman, C.A. 1980. Cost-effectiveness of forestry nonpoint source pollution control measures. In: *U.S. Forestry and Water Quality: What Course in the 80's?* Richmond, Virginia, June 19-20, 1980. Water Pollution Control Federation and Virginia Water Pollution Control Association. pp. 162-182.

This paper addresses two analytical techniques, benefit-cost analysis and cost-effectiveness analysis, for determining the feasibility of pollution control measures. These two methods are described in detail, and the strengths and limitations of each are presented. No recommendations for use are made.

Hickman, C.A., and B.D. Jackson. 1978. *Economic impacts of controlling soil loss from silviculture activities: A case study of Cherokee County, Texas*. Texas A&M University, Texas Water Resources Institute. Technical Report No. 91. 116 pages.

The economic impacts of restricting soil loss from timber harvest activities were evaluated in this study. The following four control possibilities were considered: a countywide limit on allowable soil loss, a per-acre limit on allowable soil loss, a tax on excess soil loss, and a subsidy for reduced soil loss. The authors conclude that the four possible controls would probably not be economically justified based on the assumption used in this analysis.

Kemper, R.E., and L.S. Davis. 1976. Costs of environmental constraints on timber harvesting and regeneration. *Journal of Forestry*. 74(1):754-761.

This paper presents a methodology for measuring the cost of aesthetic and environmental constraints on timber harvesting and regeneration. The methodology was empirically quantified for two western national forests. The authors concluded from these case studies that the costs of increasing environmental care are substantial enough to warrant detailed quantification and consideration in public timber policy deliberation.

Kochenderfer, J.N., and G.W. Wendel. 1978. *Skyline harvesting in Appalachia*. USDA Forest Service, Northeastern Forest Experiment Station. Forest Research Paper NE-400.

A skyline logging system called the URUS was tested during a partial cutting of forest in West Virginia. The document describes the advantages and disadvantages of skyline harvesting and provides recommendations for the equipment as well as for topographical sitings. The article concludes by stating that the more sophisticated yarding systems used in the West are not economically feasible or implementable for eastern forests.

LeDoux, C.B. 1987. *Estimating yarding costs for the Clearwater cable yarder.* USDA Forest Service, Northeastern Forest Experiment Station. Research Paper NE-RP-609. 4 pages.

Six cable yarding systems were compared to the Clearwater yarder developed by the USDA. For this study, detailed time and motion data from field studies, labor and fuel costs, and the THIN yarding simulation model were used to develop a general equation for estimating yarding costs in eastern hardwoods. The authors report that the limited capacity of the Clearwater yarding system prevented reducing the cost per unit produced. Tables with costs of yarding and stand data are presented.

LeDoux, C.B. 1985. When is hardwood cable logging economical? *Journal of Forestry.* 83(5):285-298.

The effect on total production costs and revenues of alternate cable yarders, average slope yarding distances, size of material, tree species and market price, and silvicultural treatment is evaluated using a simple simulation model. This information is intended to aid forest managers in determining the feasibility of cable logging. The article contains several tables of cost data for different yarding systems.

Lickwar, P.M., C.A. Hickman, and F.W. Cubbage. 1991. Costs of protecting water quality during harvesting on private forestlands in the Southeast. *Southern Journal of Applied Forestry.*

Data on harvest volumes, topography, and other site and area characteristics were obtained from 22 private forest timber harvests in Alabama, Florida, and Georgia. An economic analysis was then used to estimate the marginal costs of implementing each state's recommended BMPs and a set of "enhanced" BMPs that offered increased water quality protection. Collectively, the costs of using the recommended BMPs averaged 2.9% of gross timber sale revenue, $2.34 per 1000 board feet (MBF) of timber harvested, or $12.45 per acre. The cost of implementing enhanced BMPs averaged 5.1% of gross stumpage value, $4.13 per MBF, or $21.94 per acre. Seed, fertilizer, and mulch; broad-based dips; and water bars were the most expensive practices on a total cost basis. Culvert installation, SMZs, and road relocation were less expensive for most tracts. A literature review of related studies is provided. Site location maps, site characteristics (physiographic, size, harvest method) are also given, and the economic analysis breaks the sites down by topography and BMPs implemented. This is one of the few studies available on forestry BMP implementation costs.

Lynch, J.A., and E.S. Corbett. 1981. Effectiveness of best management practices in controlling nonpoint pollution from commercial clearcuts. In: *Nonpoint Pollution Control - Tools and Techniques for the Future, Proceedings of a Technical Symposium.* pp. 213-224.

This paper reports an evaluation of the effectiveness of Pennsylvania's BMPs for controlling NPS pollution on public and private forestlands. This study was done following a commercial clearcut in central Pennsylvania. The paired watershed method was used to evaluate changes in water quality and quantity. The commercial clearcut produced a water yield increase of 5.39 area- inches the first year following cutting. Stream turbidity on the clearcut watershed was generally higher than that on the control watershed prior to cutting, and no major increase in turbidity occurred as a result of cutting. No serious channel erosion was found on the clearcut watershed. Increases in stream temperature were generally slight. The authors conclude that the BMPs required in Pennsylvania are sufficient to control NPS pollution during and following logging.

Lynch, J.A., and E.S. Corbett. 1989. Effectiveness of BMP's in controlling nonpoint pollution from silvicultural operations. In: *Proceedings of the Symposium on Headwaters Hydrology*. American Water Resources Association, Bethesda, Maryland. pp. 149-157.

Streamflow and water quality data were evaluated to determine the effectiveness of best management practices used to control nonpoint source pollution from a commercial clearcut. Tables of data on water quality constituent concentrations over a 10-year period are included in the paper.

Lynch, J.A., and E.S. Corbett. 1990. Evaluation of best management practices for controlling nonpoint pollution from silvicultural operations. *Water Resources Bulletin*. 26(1):41-52.

Fifteen years of streamflow and water quality data were evaluated to determine the effectiveness of BMPs in controlling nonpoint source pollution from a 110-acre commercial clearcut located in the Ridge and Valley Province of central Pennsylvania. In general, the BMPs analyzed effectively reduced water quality impacts associated with timber harvest. Although some increases in water quality constituents were observed, most were well below the drinking water standards although they may violate EPAs antidegradation policy. The authors suggest that buffer strips of unharvested timber provided the most protection to the streams and that improved performance may be possible through annual inspections and increasing the width of buffer strips if necessary. The information presented in this report demonstrates the potential for reductions in nonpoint source pollution possible with various BMPs.

Lysons, H.H., and R.H. Twito. 1973. Skyline logging: An economical means of reducing environmental impact of logging. *Journal of Forestry*. 71(9):580-583.

The basic tight, slack, and running skyline yarding systems are reviewed, and the desired characteristics of a logging system are identified to help select the most suitable means of yarding. Figures of the systems are provided. The physical, economic, and environmental characteristics of each of the systems are listed and discussed. Several misconceptions concerning skyline logging are clarified. One is that skyline logging is more costly than high-lead logging; skyline logging is economically feasible and is less sensitive to yarding distance than are other logging systems. Another is that the span length greatly decreases the load-carrying ability; for any given deflection, the load- carrying ability decreases only by the added weight of the line for the longer span. Also, a highly mobile cable system is probably the best way to harvest partial cuts and thinnings, contrary to popular beliefs.

Mussallem, K.E., and J.A. Lynch. 1980. Controlling nonpoint source pollution from commercial clearcuts. In: *Watershed Management 1980*. C.W. Johnson (ed.). American Society of Civil Engineers, Irrigation and Drainage Division, Committee on Watershed Management. pp. 669-681.

This study was designed to evaluate the effectiveness of Pennsylvania's BMPs. It compared measurements of stream quality at a control site that was not logged, a site logged using BMPs, and a site logged without BMPs that was treated with herbicides to eliminate the effect of regrowth. The use of BMPs reduced the impact of logging activities on stream quality.

Olsen, E.D., D.S. Keough, and D.K. LaCourse. 1987. *Economic impact of proposed Oregon Forest Practices Rules on industrial forest lands in the Oregon Coast Range: A case study*. Oregon State University, College of Forestry, Forest Research Laboratory. Research Bulletin 61. 15 pages.

A case study was performed to determine the harvesting and transportation requirements of three alternative prescriptions for riparian management areas. The three prescribed scenarios included buffer strips of 35, 50 and 70

feet, with various timber harvest percentages from the strips allowed. Timber-related practices were modeled, and the associated costs were estimated for each scenario to demonstrate the economic impact of changing the buffer width and length and increasing harvesting constraints. The results indicate that landowner costs would be significantly higher than present if more restrictive scenarios are used. Cost increases ranged from $75 to $653 per acre in this study. Numerous tables of harvest information and data are presented.

USDA Forest Service. 1992. *Investigating Water Quality in the Pacific Southwest Region, Best Management Practices Evaluation Program (BMPEP): A User's Guide*. USDA Forest Service, Region 5, San Francisco, California.

This document is the result of a continuous loop of on-site evaluations, BMP prescription development, implementation, monitoring, and feedback. The monitoring/evaluation program described in this user's guide provides the feedback loop to obtain and document observations of how well BMPs protect water quality and also helps to identify deficiencies and their causes and necessary corrective actions. On-site evaluations were made on the following activities: streamside management zones, skid trails, suspended yarding, landings, meadow protection, special erosion control and revegetation, timber administration, road surface, drainage, slopes protection, stream crossings, servicing and refueling, in-channel construction practices, temporary roads, rip-rap, snow removal, protection of roads during wet periods, pioneer road construction, prescribed fire, revegetation of surface disturbed areas, and location of stock facilities in wilderness. In addition, assistance in accessing the Best Management Practices Evaluation Program database (BMP- DB) is provided.

USDA Forest Service. 1987. *Soil and water resource management: A cost or a benefit? Approaches to watershed economics through example*. 99 pages.

Analysis procedures for estimating the economic benefits of soil and water resource management have been developed. This report discusses the procedures and the data and information required to employ them. The analysis procedures focus on the following management areas: timber, forage, fish, enhanced water quality, and road construction and maintenance. The procedures and economics of soil and water management are demonstrated in this document with 16 examples.

Binkley, V.W. 1965. *Economics and design of a radio-controlled skyline yarding system*. USDA Forest Service, Pacific Northwest Forest and Range Experiment Station. Research Paper PNW-25. 30 pages.

Brooks, K.N., H.M. Gregersen, E.R. Berglund, and M. Tayaa. 1982. Economic evaluation of watershed projects-an overview methodology and application. *Water Resources Bulletin*. 18(2):245-250.

Ellefson, P.V., and P.D. Miles. 1985. Protecting water quality in the Midwest: Impact on timber harvesting costs. *Northern Journal of Applied Forestry*. 2:57-61.

Fight, R.D. 1989. Western forests in transition: National forests. In: *Forestry on the Frontier, Proceedings of the 1989 Society of American Foresters National Convention*. Spokane, Washington. pp. 257-259.

Hickman, C.A., and B.D. Jackson. 1979. Economic impacts of controlling soil loss from silvicultural activities in east Texas. *Forest Science*. 25(4):627-640.

Klock, G.O. 1976. *Estimating two indirect logging costs caused by accelerated erosion*. USDA Forest Service, Pacific Northwest Forest and Range Experiment Station. General Technical Report PNW-44. 9 pages.

Kochenderfer, J.N., and G.W. Wendel. 1980. *Costs and environmental impacts of harvesting*

timber in Appalachia with a truck-mounted crane. USDA Forest Service, Northeastern Forest Experiment Station. Research Paper NE-456. 9 pages.

Lickwar, P.M. 1984. *Estimating the costs of water quality protection on private forest lands in the south*. Master's Thesis, University of Georgia.

Lynch, J.A., W.E. Sopper, E.S. Corbett, and D.W. Aurand. 1975. Effects of management practices on water quality and quantity: The Penn State Experimental Watersheds. In: *Municipal Watershed Management Symposium Proceedings*. USDA Forest Service. General Technical Report NE-13. pp. 32-46.

NCASI. 1988. *Procedures for assessing the effectiveness of Best Managements Practices in protecting water and stream quality associated with managed forests*. National Council of the Paper Industry for Air and Stream Improvement. Technical Bulletin No. 538. 23 pages.

Peters, P.A., and J. Luchok (eds). 1984. *Mountain Logging Symposium Proceedings*. West Virginia University, June 5-7, 1984. 372 pages.

USEPA. 1977. *Silvicultural activities and non-point pollution abatement: A cost-effectiveness analysis procedure*. U.S. Environmental Protection Agency. EPA 600/8-77-018. 121 pages.

6. SITE PREPARATION AND REGENERATION

IMPACTS ON WATER QUALITY

Askew, G.R., and T.M. Williams. 1984. Sediment concentrations from intensively prepared wetland sites. *Southern Journal of Applied Forestry*. 8(3):152-157.

This study was designed to evaluate the drainage and conversion process used by a major forest industry and to determine which aspect of the conversion process, if any, was a primary source of sediment. Suspended sediment concentrations were measured in water draining from a 5,900-acre Carolina bay undergoing conversion to loblolly pine plantations. Samples were collected during the first stormflow event of each month between January 1981 and December 1982 from subwatersheds involved in some of several phases of conversion. Suspended sediment concentration in water leaving the bay averaged only 16 mg/l for 13 storms. Road erosion and ditch installation produced the highest suspended sediment concentrations. Suspended sediment concentrations decreased substantially with increasing distance from the sediment source. Logging and site preparation activities did not cause an appreciable increase in suspended sediment when equipment did not operate in the drainage ditches. This study indicates that main haul roads and new drainage ditches are the sources of much of the increased suspended sediments found in drainage from managed forests in the lower coastal plain. The authors conclude that the impact of these activities can be minimized by using a drainage system that contains a length of main channel between sediment sources and sensitive areas.

Baker, M.B., Jr. 1990. *Hydrologic and water quality effects of fire*. USDA Forest Service, Rocky Mountain Forest and Range Experiment Station. General Technical Report RM-191. pp. 31-42.

This paper provides a review of studies conducted to determine the effects of prescribed burning on forest and rangelands of the Southwest. It provides a qualitative analysis on the types of water quality effects observed after prescribed burning; no substantial quantitative results are presented. The paper includes citations for nearly 70 articles related to water quality effects from prescribed burning.

Beasley, R.S. 1979. Intensive site preparation and sediment loss on steep watersheds in the Gulf Coastal plain. *Soil Science Society of America Journal*. 43(3):412-416.

The hydrologic effects of three methods of intensive site preparation (brush chopping, shearing and windrowing, and bedding on contour) were measured during the 1976 and 1977 water-years on three small watersheds on steep terrain in northern Mississippi. The first year sediment losses were 12.5, 12.8, 14.2, and 0.6 metric tons/ha for the chopped, sheared, bedded, and control treatments, respectively. These losses corresponded to the percent soil disturbance for each treatment. Soil losses were significantly lower during the second year for all treatments. This paper presents information on the erosion potential associated with forestry practices conducted on highly erodible sites.

Beasley, R.S., A.B. Granillo, and V. Zillmer. 1986. Sediment losses from forest management: Mechanical vs. chemical site preparation after clearcutting. *Journal of Environmental Quality*. 15(4):413-416.

The comparative effects of mechanical and chemical site preparation on water yields and sediment losses following forest clearcutting were evaluated over a 4-year period in the Athens Plateau area of southwestern Arkansas. Sediment loss from the mechanically prepared watersheds was significantly higher than that from chemically-prepared sites or the control. Chemical site preparation did not significantly change the sediment loss compared to the control. This paper provides valuable information comparing the differences in the sediment losses observed from two very different site preparation

methods used in Coastal Plain areas.

Beasley, R.S., and A.B. Granillo. 1985. Water yields and sediment losses from chemical and mechanical site preparation. *Forestry and Water Quality - A Mid-South Symposium*. Little Rock, Arkansas, May 8-9, 1985. B.G. Blackmon (ed.). Arkansas Cooperative Extension Service, University of Arkansas. pp. 106-116.

Sediment losses after clearcut and mechanical site preparation were compared to treatments of selective harvest and no harvest. Selectively cut and uncut treatments did not have significantly different sediment and water yields; clearcutting with mechanical site preparation resulted in significantly greater sediment and water yields. The study and results are displayed in several data tables and figures.

Blackburn, W.H., M.G. DeHaven, and R.W. Knight. 1982. Forest site preparation and water quality in Texas. In: *Proceedings of the Specialty Conference on Environmentally Sound Water and Soil Management*. Orlando, Florida, July 20-23, 1982. E.G. Kruse, C.R. Burdick, C.R. and Y.A. Yousef (eds.). American Society of Civil Engineers. pp. 57-66.

The effects of site preparation practices on water quality and yield in nine small watersheds in the Coastal Plain of Texas are presented. The treatments consisted of shearing and windrowing, roller chopping, and undisturbed. The shearing and windrowing treatment had significantly higher water yield and greater nutrient concentrations than did the other two treatments. This study provides a comparison of the water quality effects associated with two types of site preparation practices. The authors provide several tables of statistically analyzed data.

Blackburn, W.H., R.W. Knight, J.C. Wood, and H.A. Pearson. 1990. Stormflow and sediment loss from intensively managed forest watersheds in east Texas. *Water Resources Bulletin*. 26(3):465- 477.

Several small watersheds in East Texas were instrumented to determine the effect of forest harvesting, mechanical site preparation, and livestock grazing on stormflow, peak discharge rate, and sediment loss and the results were compared with pre- treatment levels. The treatments included clearcutting followed by roller chopping; clearcutting followed by shearing and windrowing; clearcutting followed by shearing, windrowing, and continuous grazing; and clearcutting followed by shearing, windrowing, and rotational grazing. The data indicated significantly greater stormflow, peak discharge rate, and sediment from clearcut harvesting and site preparation compared to undisturbed watersheds. Among the treatments, the sheared/ windrowed watersheds generally yielded the greatest stormflow and peak discharge rate, followed by the chopped watershed. This paper presents a significant amount of data on water quality impacts of timber harvest and site preparation activities.

Blackburn, W.H., and J.C. Wood. 1990. Nutrient export in stormflow following forest harvesting and site-preparation in east Texas. *Journal of Environmental Quality*. 19:402-408.

A watershed study was conducted to determine the effects on stormflow water quality from the following practices: (1) clearcutting, shearing, windrowing, and burning; (2) clearcutting, roller chopping, and burning; and (3) undisturbed control. The clearcut treatments had higher nutrient concentrations the first year following harvest and site preparation. During the second and third years, only the clearcut (shearing) treatment resulted in higher nutrient concentrations than the control. After 5 years, no significant difference in nutrient concentrations, except potassium, were observed among any treatment. Although the nutrient concentrations observed in this study were small, shearing and windrowing had the greatest impact on nutrient export. Roller chopping had a minimal impact on stormflow nutrient concentrations. The results of this study indicate the reduction in water quality impacts that can be derived from different management practices.

Brown, G.W., A.R. Gahler, and R.B. Marston. 1973. Nutrient losses after clear-cut logging and slash burning in the Oregon Coast Range. *Water Resources Research.* 9:1450-1452.

The impact of two patterns of clearcut logging on the nutrient losses from two Oregon watersheds was studied. With the exception of nitrate-nitrogen, no nutrient concentrations increased after clearcut. Nitrate-nitrogen concentrations significantly increased after clearcut logging and slash burning. No significant changes in nitrate concentrations were observed after patch-cut logging. Nitrate-nitrogen concentrations returned to prelogging levels within 6 years of harvest.

Brown, G.W., and J.T. Krygier. 1971. Clear-cut logging and sediment production in the Oregon coast range. *Water Resources Research.* 7(5):1189-1198.

The impact of road construction, two patterns of clear-cut logging, and controlled slash burning on the suspended sediment yield and concentration from three small watersheds was studied for 11 years. Sediment production was doubled after road construction but before logging in one watershed and was tripled after burning and clearcutting of another watershed. Felling and yarding did not produce statistically significant changes in sediment concentration. Variation in the relation between sediment concentration and water discharge on small undisturbed streams was large. Conclusions about the significance of all but very large changes in sediment concentrations are limited because of annual variation for a given watershed, variation between watersheds, and variation with stage at a given point. Tables present sediment concentrations in the two altered watersheds and one control watershed for the duration of the study.

Chamberlin, T.W., R.D. Harr, and F.H. Everest. 1991. Timber harvesting, silviculture, and watershed processes. In: *Influences of forest and rangeland management on salmonid fishes and their habitats.* W.R. Meehan (ed.). American Fisheries Special Publication 19:181-206.

This chapter examines the effects of timber management activities on stream ecosystems, particularly streams with anadromous salmonids. Timber management practices discussed include felling and yarding of trees, site preparation by burning or scarification, fire hazard reduction, forest regeneration by planting or seeding, reduction of competition by brush removal and tree thinning before commercial harvest, and some effects of road building on the hydrologic and sediment systems. Chapter contents: hydrologic effects; effects of harvests on erosion and sedimentation; effects of harvests on channel forms and geomorphic processes; cumulative effects of forest harvesting; and conclusions and management options.

DeHaven, M.G., W.H. Blackburn, R.W. Knight, and A.T. Weichert. 1984. *The impact of harvesting and site preparation on stormflow and water quality in east Texas.* Report TR-130. Texas Water Resources Institute, Texas A&M University. 147 pages.

Nine small watersheds in east Texas were used to determine the water quality effects of timber harvest and site preparation operations. The 3 treatments included clearcutting followed by shearing and windrowing, clearcutting followed by roller chopping, and undisturbed control. The roller chopped treatment exposed 16% of the soil and the shearing and windrowing exposed 57% of the soil. Higher stormflow and sediment loss was observed during the first three years post-treatment, although the differences decreased after the first year. During the second year, exposed decreased to 20 and 4% on sheared and chopped watersheds, respectively. Nutrient concentrations were also highest from the sheared treatment. The authors concluded that temporary increases in nutrient, sediment, and stormflow would occur on sheared and chopped watersheds, although greater losses would occur from sheared due to increased duration of soil exposure. Roller chopping appeared to cause minor changes compared to shearing and windrowing.

Douglass, J.E., and O.C. Goodwin. 1980. Runoff and soil erosion from forest site preparation practices. In: *U.S. Forestry and Water Quality: What Course in the 80's?* Richmond, Virginia, June 19-20, 1980. Water Pollution Control Federation and Virginia Water Pollution Control Association. pp. 50-73.

Soil losses and runoff were measured for 3 years after three types of mechanical site preparation treatments were applied on 16 small watersheds in the North Carolina Piedmont. The site preparation treatments included the following: (1) shearing, windrowing, and burning; (2) #1 plus disking; and (3) #2 plus fertilization and planting grass cover crop. The runoff and sediment data from these treatments were compared to data collected from a control watershed. The soil loss was greatest from the shearing, windrowing, burning, and disking site preparation method. This was due to greater soil disturbance in this treatment. This paper presents data on the value of ground cover for preventing soil loss from forested sites.

Douglass, J.E., and D.H. Van Lear. 1983. Prescribed burning and water quality of ephemeral streams in the piedmont of South Carolina. *Forest Science*. 29(1):181-189.

Two prescribed burns in Piedmont pine stands resulted in no significant increases in storm runoff, sediment export, or nutrient concentrations. The paper provides several tables of water quality data from preburn and postburn. These results are very site-specific and vary with the intensity of precipitation events.

Dyrness, C.T., and C.T. Youngberg. 1957. The effect of logging and slash burning on soil structure. *Soil Science Society of America Proceedings*. 21(4):444-447.

The effects of logging and slash burning on soil structure were investigated in soils in the Coast Range of western Oregon. Soil samples were collected from clearcut and undisturbed forested areas. The soil surface after logging and slash burning were as follows: lightly burned (45%), severely burned (8%), unburned (30%), and undisturbed (17%). Severe burning was the only treatment that had a significant effect on the soil structure. The authors concluded that because logging and slash burning resulted in only 8% severely burned area, high-lead logging and slash burning in the fall after rainfall would have no significant detrimental effect on soil structure.

Feller, M.C. 1981. Effects of clearcutting and slash burning on stream temperature in southwestern British Columbia. *Water Resources Bulletin*. 17(5):863-866.

Two watersheds were studied for the effect of logging practices on summer and winter water temperatures. One of the watersheds was clearcut and then planted, and the other was clearcut, slash burned, and then planted.Tables of watershed characteristics and duration of temperature effects are included. Both practices were found to increase stream temperature, but slash burning increased the temperature effect beyond that of clearcutting alone. This is attributed to burning the slash that remains at streamside after clearcutting. Clearcutting was found to increase minimum and maximum winter stream temperatures during the second winter following the cutting. Slash burning decreased minimum and maximum winter stream temperatures in the first winter following the burning. The effect on stream temperature of clearcutting and slash burning lasted longer (>7 years) than that of clearcutting alone.

Fredriksen, R.L. 1971. Comparative chemical water quality-Natural and disturbed streams following logging and slash burning. In: *Proceedings of a Symposium: Forest Land Uses and Stream Environment*. Oregon State University, October 19-21, 1970. J.T. Krygier and J.D. Hall (eds.). OSU, Corvallis, Oregon. pp. 125- 137.

The loss of nutrients from an old growth Douglas fir forest was measured in streams following timber harvest and slash burning. Nutrient cation losses increased 1.6 to 3.0 times the loss of the undisturbed watershed. The surge of nutrients following slash burning contained ammonia and manganese concentrations greater than federal

water quality standards for 12 days after burning. The authors conclude that nitrogen losses can be minimized by avoiding slash burning when possible. This paper presents many figures and tables with the data from the study.

Golden, M.S., C.L. Tuttle, J.S. Kush, and J.M. Bradley. 1984. *Forestry activities and water quality in Alabama: Effects, recommended practices, and an erosion-classified system.* Auburn University, Agricultural Experiment Station. Bulletin 555.

The report was prepared primarily as a source of information on the relationship between forestry practices and water quality, with orientation toward forestry practices prevalent in Alabama. Information on stream pollutants such as sediment, nutrients, pesticides, organic material, waste and litter, and temperature is provided. The review includes over 160 directly cited documents on these subjects. Also included in the report are recommendations of principles and practices designed to minimize the water quality impacts from Alabama forestry practices.

Gottfried, G.J., and L.F. DeBano. 1990. *Streamflow and water quality responses to preharvest prescribed burning in an undisturbed ponderosa pine watershed.* USDA Forest Service, Rocky Mountain Forest and Range Experiment Station. General Technical Report RM-191. pp. 222-228.

The impacts of prescribed burning on streamflow and water quality were evaluated following a prescribed burn. Prefire and postfire levels of nitrate-nitrogen, ammonium-nitrogen, phosphates, calcium, magnesium, sodium, and potassium were used as indicators of stream water quality. No significant changes in streamflow were observed after the burn; significant, but small, changes in nutrient levels were observed. Because only 43% of the watershed was burned, the water quality and stream flow values do not represent total loads of nutrients from the watershed or the total water yield. Also, data were presented only for water samples collected for 1 year after burning.

Harr, R.D., and R.L. Fredriksen. 1988. Water quality after logging small watersheds within the Bull Run Watershed, Oregon. *Water Resources Bulletin.* 24(5):1103-1111.

The water quality impacts from clearcut practices and slash burning are presented. Logging significantly increased nitrate- nitrogen levels for up to 7 years after harvest; smaller increases were observed after slash burning. Suspended sediment also had a small increase attributed to construction of a permanent road that crossed streams. Annual stream temperatures increased 2-3 °C after logging but returned to pretreatment levels after 3 years. This watershed study presents significant data on the effects of forest harvest and slash burning on water quality.

Hewlett, J.D. 1978. *Forest water quality: An experiment in harvesting and regenerating a Piedmont forest.* School of Forest Resources, University of Georgia. 22 pages.

Two streams in Putnam County, Georgia, were selected to determine the effects that harvesting and regeneration have on water quality and flow in order to determine appropriate BMPs. Periodic samples were taken and flow recorded. The study indicated that 90% of the undesirable mass export of sediment resulted from poor access roads and streamside management.

Krause, H.H. 1982. Effect of forest management practices on water quality - a review of Canadian studies. In: *Proceedings of the Canadian Hydrology Symposium - Associate Committee on Hydrology.* Fredericton, New Brunswick, June 14-15, 1982. National Research Council Canada, Canada. pp. 15-29.

The water quality effects of forest management practices are reviewed separately for the British Columbia Coastal Range, Rocky Mountains, Canadian shield, and Appalachian region. Sedimentation is a problem after road construction and occasionally after slash burning. Temperature increases are problematic at low altitudes in areas with warm summers. Changes in dissolved solids depend on the type of operation, forest cover, soils, and geologic substrate.

Maxwell, J.R., and D.G. Neary. 1991. Vegetation management effects on sediment yields. In: *Proceedings of the Fifth Interagency Sedimentation Conference, Vol. 2.* Las Vegas, Nevada, March 18-21, 1991. Interagency Committee on Water Data, Subcommittee on Sedimentation. pp 55-63, Section 12.

This paper presents the results of a regional analysis of the cumulative effects of vegetation management (fire, mechanical, herbicides, manual, biological) on sediment yield. Three Environmental Impact Statements (EIS) were prepared for three physiographic regions in the south and erosion was modeled for each region on a variety of landtypes and watersheds. In general, the results indicated greater sediment yields from road systems and cropland. In addition, greater sediment yields were typically observed from private lands. The data from the modeling indicated sediment yields could be reduced by favoring herbicide and low-intensity prescribed fire as a means of site preparation over mechanical and severe fire methods.

Megahan, W.F. 1987. Increased sedimentation following helicopter logging and prescribed burning on granitic soil. In: *Erosion and Sedimentation in the Pacific Rim, Proceedings of the Corvallis Symposium.* Oregon State University, August, 1987. R.L. Beschta (ed.). IAHS Publication No. 165, Corvallis, Oregon. pp. 259-260.

The effects of helicopter clearcut logging and prescribed burning on sediment yields in central Idaho are presented. Streamflow and sediment yield data were collected for 10 years prior to clearcut and for 10 years after clearcut and prescribed burning. Significant increases in annual sediment yields were observed. No data from the study are presented in this short paper.

Miller, E.L., R.S. Beasley, and E.R. Lawson. 1988. Forest harvest and site preparation effects on streamflow and peakflow of ephemeral streams in the Ouachita Mountains. *Journal of Environmental Quality.* 17(2): 212-218.

Soil erosion and sedimentation effects of three treatments- clearcutting, selective cutting, and no disturbance (control)- were measured and compared in watersheds in the Ouachita Mountains of Arkansas. After clearcut harvest, a drum chopper crushed the residual vegetation prior to burning; stream channels were not buffered from chopping or burning. The harvest and site preparation activities had no specific BMPs; however, "reasonable care" was used while conducting the activities. Sediment yield during the first year of the study was significantly higher in the clearcut treatment, but the differences between the treatments decreased the next 2 years. Even though the annual sediment yield was greater from the clearcut treatment, the yields were relatively low and appeared to have little impact on water quality. The document provides concise methodology for the experimental design and presents significant amounts of data collected during the experiment.

Neary, D.G., P.B. Bush, and M.A. Grant. 1986. Water quality of ephemeral forest streams after site preparation with the herbicide hexazinone. *Forest Ecology and Management.* 14(1):23- 40.

Four small watersheds (1 ha) in the upper Piedmont of north Georgia were treated with 1.68 kg/ha active ingredient of hexazinone pellets. Residues in stormflow peaked in the first storm at 442 mg/m3, declined rapidly thereafter, and disappeared within 7 months. Loss of hexazinone in stormflow averaged 0.53% of the applied herbicide. Total sediment yields were increased by a factor of 2.5 due to increased runoff associated with site preparation using herbicide and salvage logging. Hexazinone treatment produced a large increase in NO_3-N concentrations (peak = 5328 mg/m3), but NO_3-N levels returned to normal within 2 years. Hexazinone may have produced some stimulation of nitrifying bacteria. Overall, water quality changes were small and short-lived.

Neary, D.G., and J.B. Currier. 1982. Impact of wildfire and watershed restoration on water quality on South Carolina's Blue Ridge Mountains. *Southern Journal of Applied Forestry*. 6(2):81-90.

Neary and Currier studied the change in water quality caused by a large wildfire in South Carolina's Blue Ridge Mountains. Five watersheds contained five different conditions, including undisturbed; burned only; burned and fertilized; and burned, fertilized and covered with fire retardant. Concentrations of NO3-N increased the most (peak of 0.394 mg/l) as a result of fertilizer applications during restoration operations. Nitrate-N, NH_4-N, PO_4-P levels were elevated on the burned and fertilized watersheds mainly during storm events. Sodium, K, Ca, and Mg concentrations were 12-82% above background levels during most of the monitoring period. Suspended solid concentrations showed no relationship to watershed condition. Changes in water quality were of no biological significance to aquatic ecosystems and did not affect use of the watersheds as sources of drinking water. Based on the results of this intensive study, the authors concluded that the wildfire did not adversely affect the water quality for ecosystems or drinking.

Neary, D.G., and J.L. Michael. 1989. Effect of sulfometuron methyl on ground water and stream quality in coastal plain forest watersheds. *Water Resources Bulletin*. 25(3):617-623.

The stream concentration of sulfometuron methyl was determined after spraying for site preparation in a Coastal plain flatwood. Sulfometuron methyl was applied at a maximum labeled rate of 0.42 kg/ha a.i. to a 4-ha coastal plain flatwoods watershed as site preparation for tree planting. Herbicide residues were detected in stream flow for only 7 days after treatment and did not exceed 7 mg/m3. Sulfometuron methyl was not detected in any storm flow and was not found in any sediment (both bedload and suspended). Sampling of a shallow ground water aquifer, < 1.5 m below ground surface, did not detect any sulfometuron methyl residues for 203 days after herbicide application. Lack of herbicide residue movement was attributed to low application rates, rapid hydrolysis in acidic soils and water, and dilution in stream flow. This paper presents very important information on the potential for water contamination when spraying herbicides in forested areas. The information presented is useful for comparison of similarly applied ground-based pesticide applications under conditions similar to those found during the study.

Nutter, W.L. 1982. Water quality and yield from the intensively managed forest. In: *Proceedings of the Society of American Foresters*. pp. 89-93.

A review of the impacts of intensive forest management, including timber harvest, site preparation, road construction, and forest fertilization, on water yield and water quality is presented. This short review presents an overview of the impacts of intensive forestry operations.

Richter, D.D., C.W. Ralston, and W.R. Harms. 1982. Prescribed fire: Effects on water quality and forest nutrient cycling. *Science*. 215:661-663.

This paper describes the possible effects of prescribed fires on hydrologic fluxes of nitrogen, phosphorus, sulfur, and other basic cations. The authors conclude, based on literature data, that periodic prescribed fires would not have an appreciable effect on water quality. This paper provides a conclusion that should be used with caution because it was based on a limited literature review.

Riekerk, H. 1983. Impacts of silviculture on flatwoods runoff, water quality, and nutrient budgets. *Water Resources Bulletin*. 19(1)73-80.

Runoff and water quality from two different timber harvest practices, minimum and maximum disturbance, were compared to an undisturbed flatwood watershed. The maximum disturbance consisted of machine harvesting, slash burning, windrowing, bedding, and machine planting and the minimum disturbance treatment included

manual harvesting, slash chopping, bedding, and machine planting. Significantly greater water yield was observed for both treatments, with the greatest increase in the maximum disturbance treatment. Water yield increases lasted for a single year. As with water yield, the greatest degradation in water quality was observed from the maximum disturbance treatment although the impact was also of short duration. The author concludes that silvicultural activities in flatwoods would not result in any long-term degradation of water quality.

Riekerk, H. 1989. Influence of silvicultural practices on the hydrology of pine flatwoods in Florida. *Water Resources Research.* 25(4):713-710.

A study was conducted in a pine flatwoods to determine the effect of minimum and maximum disturbance timber harvest on the hydrology of the forest. The maximum disturbance was machine harvesting, slash burning, windrowing, bedding, and machine planting and the minimum disturbance treatment was manual harvesting, slash chopping, bedding, and machine planting. The results indicated that the maximum disturbance harvest had a significant impact on the hydrology. An increase in the water table and runoff after timber harvest was observed. The increases were due to decreased evapotranspiration after harvest. The changes in hydrology could lead to future problems in already poorly drained flatwoods.

Skille, J. 1990. *Stream and lake nutrient loading from burning logging slash.* Idaho Department of Health and Welfare, Division of Environmental Quality, Water Quality Bureau. Water Quality Summary Report No. 26.

The nutrient concentration changes in surface water caused by slash pile burning in riparian areas of Idaho were measured. Total phosphorus, nitrogen, flow, and other water quality parameters were recorded prior to and following runoff events, including rain and snowmelt. Background conditions were not established, but the author concludes that slash burning near streams has serious negative impacts on water quality and adds to the already serious NPS pollution concerns. Proposed regulations to prevent further impacts are addressed.

Snyder, G.G., H.F. Haupt, and G.H. Belt, Jr. 1975. *Clearcutting and burning slash alter quality of stream water in northern Idaho.* USDA Forest Service. Research Paper INT-168. 34 pages.

The effect of logging on water quality in three watersheds in Idaho was determined. Water samples were collected upstream, on- site, and downstream from clearcut and slash-burned sites. Buffer strips were left along the streams upstream and downstream of the harvest site. Increases in cation concentrations were observed, with larger increases observed at the on-site stations. The authors suggest the use of stream buffer strips as a management tool to reduce water quality impacts.

Stednick, J.D., L.N. Tripp, and R.J. McDonald. 1982. Slash burning effects on soil and water chemistry in southeastern Alaska. *Journal of Soil and Water Conservation.* 37(2):126-128.

This paper presents information on the short-term effects of slash burning after timber harvesting on the soil and water resources of an Alaskan coastal forest. Slash burning resulted in higher total phosphorus and potassium concentrations in streamflow. Suspended sediment concentrations were significantly higher below the burn area although no sample exceeded the water quality standard. The authors conclude that the small changes observed after slash burning would not result in significant impacts on water quality.

Stone, E.L., W.T. Swank, and J.W. Hornbeck. 1978. Impacts of timber harvest and regeneration systems on stream flow and soils in the eastern deciduous region. In: *Forest Soils and Land Use, Proceedings of the Fifth North American Forest Soils Conference.* C.T. Youngberg (ed.). Colorado State University. pp. 516-535.

A review of the impacts of forest harvest

activities on soil and water resources is presented. The review concentrates on the principles associated with impacts and therefore presents generalized conclusions from a sampling of the research efforts. Topics covered include water yield, water table changes, low and peak flow, soil moisture, stream temperature, sedimentation, and nutrients.

Van Lear, D.H., J.E. Douglass, S.K. Cox, and M.K. Augspurger. 1985. Sediment and nutrient export in runoff from burned and harvested pine watersheds in the South Carolina piedmont. *Journal of Environmental Quality*. 14(2):169-174.

Soil and nutrient export in ephemeral flow was studied over a three year period after clearcut logging. Two pre-harvest prescribed fires had no significant effect on water quality or flow. Harvesting occurred after the third prescribed burn and resulted in increased sediment concentrations, although the losses were less than values typical of mechanical site preparation. Nutrient concentrations were variable among watersheds, although no effect of timber harvest was observed. .

Williams, T.M. 1989. Site preparation on forested wetlands of the southeastern coastal plain. In: *Proceedings of the Symposium on the Forested Wetlands of the Southern United States*. Orlando, Florida, July 12-14, 1988. USDA Forest Service, Southeast Forest Experiment Station. General Technical Report SE-50. pp. 67-71.

A general discussion of site preparation objectives and site preparation techniques for pine and hardwood forests in the Southeastern United States is presented. Only a qualitative review of some of the impacts from different treatments is provided.

Wu, A.Y.K., M.P. Papworth, and D.W. Flynn. 1984. The effects of some forest practices on water quality and yield in the Reefton Experimental Area, Victoria. In: *Reefton Experimental Area Pretreatment Compilation Report, Volume I*.

The aim of this study was to assess the effects on both water yield and water quality of some forest practices commonly used in the management of mixed species eucalypt forest in Victoria, Australia. This initial part of the report describes the area and preparations for collecting the data. The experimental area contains 6 catchments ranging in size from 70.4 to 521.2 ha. The larger catchments have perennial streams, whereas streamflow tends to be ephemeral in two of the catchments. Soils, topography, vegetation, rainfall patterns, and annual temperature ranges for the area are described, followed by a description of instrumentation used in the catchments to measure meteorological conditions, streamflow, and water quality and bedload. Catchment hydrology and calibration are also discussed, as well as the treatments to be used in the experiment. It was proposed that one catchment would receive a fuel reduction burn, a second would receive a rehabilitation treatment, and a third would be roaded at an intensity similar to that of the second, allowing the effects of roading and logging on water yield to be separated. A fourth catchment would serve as a control.

Adams, T.E., and R.M. Rice. 1989. Erosion and sedimentation concerns related to hardwood management in California. *Western Journal of Applied Forestry*. 4(1):31-33.

Askew, G.R., and T.M. Williams. 1986. Water quality changes due to site conversion in coastal South Carolina. *Southern Journal of Applied Forestry*. 10(3):134-136.

Biswell, H.H., and A.M. Schultz. 1957. Surface runoff and erosion as related to prescribed burning. *Journal of Forestry*. 55:372- 374.
Blackburn, W.H., J.C. Wood, and M.G. DeHaven. 1986. Storm flow and sediment losses from site-prepared forestland in east Texas. *Water Resources Research*. 22(5):776-784.

Blackmon, B.G. (ed). 1985. *Forestry and water quality: A mid- south symposium*. Little Rock, Arkansas, May 8-9, 1985. Arkansas Cooperative Extension Service, University of Arkansas.

Clinnick, P.F. 1985. Buffer strip management in forest operations: a review. *Australian Forestry*. 48(1):34-45.

Cole, D.W., W.J.B. Crane, and C.C. Grier. 1973. The effect of forest management practices on water chemistry in a second growth Douglas fir ecosystem. In: *Forest Soils and Forest Land Management, Proceedings of the Fourth North American Forest Soils Conference*. Laval University, Quebec. pp. 195-207.

Cushwa, C.T., M. Hopkins, and B.S. McGinnis. 1971. *Soil movement in established gullies after a single prescribed burn in the South Carolina Piedmont*. USDA Forest Service, Southeast Forest Experiment Station. Research Note SE-153. 4 pages.

Dyrness, C.T. 1963. Effects of Burning on Soil. In: *Symposium on Forest Watershed Management*. March 25-28, 1963. Society of American Foresters and Oregon State University. pp. 291-304.

Hicks, B.J., R.L. Beschta, and R.D. Harr. 1991. Long-term changes in streamflow following logging in western Oregon and associated fisheries implications. *Water Resources Bulletin*. 27(2):217-226.

Hollis, C.A., R.F. Fisher, and W.L. Pritchett. 1978. Effects of some silvicultural practices on soil site properties in the lower coastal plain. In: *Forest Soils and Land Use, Proceedings of the Fifth North American Forest Soils Conference*. Colorado State University, Fort Collins, Colorado. C.T. Youngberg (ed.). pp. 585-606.

Larson, A.G., and D.D. Wooldridge. 1980. Effects of slash burial on stream water quality. *Journal of Environmental Quality*. 9(1): 18-20.

Levno, A., and J. Rothacher. 1969. *Increases in maximum stream temperatures after slash and burning in a small experimental watershed*. USDA Forest Service, Pacific Northwest Forest and Range Experiment Station. Research Note PNW-110. 7 pages.

Megahan, W.F. 1986. *Recent studies on erosion and its control on forest lands in the United States*.

Mersereau, R.C., and C.T. Dyrness. 1972. Accelerated mass wasting after logging and slash burning in western Oregon. *Journal of Soil and Water Conservation*. 27:112-114.

Miller, E.L. 1984. Sediment yield and storm flow response to clear-cut harvest and site preparation in the Ouachita Mountains. *Water Resources Research*. 20(4):471-475.

Morris, L.A., W.L. Pritchett, and B.F. Swindel. 1983. Displacement of nutrients into windrows during site preparation of a flatwood forest. *Soil Science Society of America Journal*. 47(3):591-594.

NCASI. 1984. *Forestry management practices and cumulative effects on water quality and utility*. National Council of the Paper Industry for Air and Stream Improvement. Technical Review Bulletin No. 435.

Pase, C.P., and A.W. Lindenmuth, Jr. 1971. Effects of prescribed fire - on vegetation and sediment in oak-mountain mahogany chaparral. *Journal of Forestry*. 69:800-805.

Red, J.T., and W.L. Nutter. 1986. Wastewater renovation in a slash pine plantation subjected to prescribed burning. *Journal of Environmental Quality*. 15(4):351-356.

Riekerk, J., A.C. Mace, D.G. Neary, and B.F. Swindel. 1986. Hydrologic responses to forest management in pine flatwoods and Florida's water. In: *Proceedings-Soil and Crop Science Society of Florida*. 45:163-169.

Sidle, R.C. 1980. *Impacts of forest practices on surface erosion*. Pacific Northwest Extension

Publication PNW 195. 15 pages.

Swindel, B.F., C.J. Lassiter, and H. Riekerk. 1983. Effects of different harvesting and site preparation operations on the peak flows of streams in Pinus elliotii flatwoods forests. *Forest Ecology and Management*. 5:77-86.

Swindel, B.F., C.J. Lassiter, and H. Riekerk. 1983. Effects of clearcutting and site preparation on stormflow volumes of streams in Pinus elliotii flatwoods forests. *Forest Ecology and Management*. 5:245-253.

Switzer, G.L., D.M. Moehring, and T.A. Terry. 1978. Clearcutting vs. alternative harvesting-stand regeneration systems: Effects on soils and environment of the south. In: *Forest Soils and Land Use, Proceedings of the Fifth North American Forest Soils Conference*. Colorado State University. C.T. Youngberg, (ed.) pp. 477-515.

Trimble, S.W., and F.H. Weirich. 1987. Reforestation reduces streamflow in the southeastern United States. *Journal of Soil and Water Conservation*. 42(4):274-276.

Wright, H.A., F.M. Churchill, and W.C. Stevens. 1982. Soil loss, runoff, and water quality of seeded and unseeded steep watersheds following prescribed burning. *Journal of Range Management*. 35(3):382-385.

BMPs AND SPECIFICATIONS

Bacon, C.G. 1989. Riparian silviculture: Active riparian management for multiple resources. In: *Forestry on the Frontier, Proceedings of the 1989 Society of American Foresters National Convention*. Spokane, Washington. pp. 99-102.

This paper presents an overview of riparian silviculture and its potential impacts on water quality, fisheries, and wildlife. It provides a general review of national perspectives on riparian silviculture and give specific examples of regional management and research efforts.

Bramhall, J.W. 1989. Riparian systems and forest management- changes in harvesting techniques and their effects on decomposed granitic soils. In: *Proceedings of the California Riparian Systems Conference*. Davis, California, September 22-24, 1988. USDA Forest Service, Pacific Southwest Forest and Range Experiment Station. General Technical Report PSW-110. pp. 176- 179.

In the 1950s, timber on steep granitic terrain in Trinity County, California, was harvested by using the logging techniques of the time. After Trinity Dam was built in the 1960s, it became evident these techniques were not suited to quality riparian habitat and healthy anadromous fisheries. Since adoption of the Z'berg-Nejedly Forest Practice Act in 1973, efforts have been expended to repair damages to riparian vegetation and to find forest practices compatible with granitic soils. This article lists BMPs developed for timber harvesting on granitic soils in 1986, focusing on protection of the riparian zone. No effectiveness information is given.

Corbett, E.S., and J.A. Lynch. 1985. Management of streamside zones on municipal watersheds. In: *Conference on Riparian Ecosystems and their Management: Reconciling Conflicting Uses*. Tucson, Arizona, April 16-18. pp. 187-190.

This paper focuses on the management practices, such as maintenance of buffer zones on the edges of reservoirs, that may be used to maintain the quality of municipal watersheds. This generic paper on the role and impact of buffer zones as a best management practice includes references to over 20 articles.

Cubbage, F.W., and C.E. DeForest. 1991. BMPs and harvesting regulations in the South. In: *Forestry and the Environment...Engineering Solutions*. New Orleans, Louisiana, June 4-6, 1991. American Society of Agricultural Engineers.

This paper provides an overview of best management practices that apply to forestry practices, including road construction, timber harvest, stream crossing, streamside management zones, and maintenance and retiring of structures. This paper presents basic information about the types of BMPs that may be used. The paper introduces regulatory trends in the states of Florida, North Carolina, West Virginia, and Maryland, as well as regulatory trends in forested wetlands.

Garland, J.J. 1987. Aspects of practical management in the streamside zone. In: *Streamside Management: Forestry and Fishery Interactions*. University of Washington, College of Forest Resources, Seattle, Washington. E.O. Salo and T.W. Cundy (eds.). pp. 277-288.

Management decisions in the streamside zone may profoundly affect practices in adjacent areas (reaching to the ridge top and beyond). Issues of technical, economic, and institutional (administrative) feasibility are associated with all management practices. Harvesting systems and site conditions (terrain, timber type, etc.) must be matched to be feasible. Decision arenas for resolution of conflicts involving facts and values are identified.

Heede, B.H. 1985. Interactions between streamside vegetation and stream dynamics. In: *Conference on Riparian Ecosystems and their Management: Reconciling Conflicting Uses*. Tuscon, Arizona, April 16-18, 1985. pp. 54-58.

This paper investigates the interrelationship between vegetation and stream system hydraulics in a broad sense that considers water, sediment, geomorphology, riparian vegetation, and streamside ecosystems. A 5-year study was conducted to test a hypothesis that log steps formed by downed trees replace gravel bars to reduce bedload movement. Log steps were removed from the stream to see whether they would be replaced by gravel bars. Seventy-four percent were replaced by gravel bars. Fallen logs were found to dissipate flow energy, maintain channel stability, decrease bedload movement, and increase water quality. The study stream was located in a mixed conifer forest of the Arizona White Mountains at a 2700-m elevation.

Heede, B.H. 1990. *Vegetation strips control erosion in watersheds*. Research Note RM-499. USDA Forest Service, Rocky Mountain Forest and Range Experiment Station.

An analysis was conducted on data collected to determine the effects of vegetation strips on erosion control. The data was collected from southwestern ponderosa pine forests, pinyon-juniper, and chaparral. In the ponderosa pine, 61 times more sediment was delivered when buffer strips were missing. This factor was 18 and 277 for pinyon-juniper and chaparral, respectively. Overland flow was also diminished from areas with buffer strips. No statistical analysis was conducted on the data.

Lantz, R.L. 1971. *Guidelines for stream protection in logging operations*. Oregon State Game Commission, Portland, Oregon. 29 pages.

This report reviews why certain logging practices in the West Coast Douglas fir region are more desirable than others for protecting fish habitat and water quality. Streams can be protected to a large extent by (1) keeping streamside vegetation intact and (2) taking precautions to eliminate or minimize soil disturbance and erosion, particularly that resulting from roads. The report emphasizes the need to change or eliminate some traditional logging practices due to the resource conflicts between and interdependence of fisheries and timber production. The report addresses the freshwater requirements of salmon and trout, the

importance of protecting stream habitat, and forestry practices that can be used to protect fish habitat. The author discusses streamside management areas and road location, construction, and maintenance practices.

Lowrance, R., R. Leonard, and J. Sheridan. 1985. Managing riparian ecosystems to control nonpoint pollution. *Journal of Soil and Water Conservation*. 40(1):87-91.

This article provides a general discussion of riparian zones and factors affecting their ability to control NPS pollution. Hydrological and vegetative factors affecting pollutant removal are discussed, and a case study of an NPS control using a riparian zone buffer is presented. Riparian zone management is related to regional differences in land use and vegetative characteristics.

McClimans, R.J. 1980. Best management practices for forestry activities. In: *Watershed Management*. Boise, Idaho, July 21-23, 1980. C.W. Johnson (ed.). American Society of Civil Engineers, Irrigation and Drainage Division, Committee on Watershed Management. pp. 694-705.

This paper defines critical combinations of site conditions for which BMPs are needed to minimize adverse impacts on soil and water resources. The document also includes assessment methodologies, as well as charts and graphs for the selection and application of appropriate BMPs. Forest practices are grouped according to their capacity to cause water pollution, the nature of the more commonly applied BMPs to control pollution, and site considerations. Guides, based on slope of land and distance from water, are provided to determine whether a particular BMP is necessary for the particular group of activities. Graphs developed to determine BMP applicability are presented, and the selected BMPs are discussed for each group of forest activities. Specifications for some BMPs are also presented.

Miller, E. 1987. *Effects of forest practices on relationships between riparian area and aquatic ecosystems*, In: Managing Southern Forest for Wildlife and Fish: A Proceedings. General Technical Report SO-65. USDA Forest Service, Southern Forest Experiment Station. pp. 40-47.

This paper presents an outline of the relationship between riparian and stream communities to help foresters better understand the objectives underlying streamside management designs. Topics reviewed in this paper include food energy, large organic debris, stream temperature, streambank and bed stability, terrestrial/aquatic buffer, and streamflow. These topics are discussed both as they relate to management of the riparian forest and riparian vegetation and the stream environment. Over 40 references are cited in this paper.

Neuman, L. 1987. Silviculture and best management practices. In: *Erosion Control: You're Gambling Without it*. International Erosion Control Association. pp. 145-155.

This report presents information on the types of impairments typical of forestry activities and provides information on management techniques that may be used to minimize the impacts. The practices presented in this paper include timber harvesting, site preparation, and road construction and drainage. Erodibility factors, assigned to Florida soils by the SCS, and slope determine a site's sensitivity to erosion, and the paper presents site sensitivity classes for Florida soils. This classification is related to suggested BMP usage and implementation. Many useful tables of specifications for when and how to construct the practices are presented.

New York State Department of Environmental Conservation, Division of Water. 1986. *Stream corridor management: A basic reference manual.*

Chapter 6 (Best Management Practices) provides an in depth discussion of BMPs relating to stream corridor management. This document discusses

numerous BMPs not directly related to forestry, but the information is generally useful for forestry applications. Many standard forestry stream BMPs, such as crossings and culverts, are discussed also. Contents include: Stream Problems, Techniques for Assessing Land Use Impacts on Water Quantity and Quality, Steps for Solving the Problem (A Planning and Problem-solving Framework), Stream Conservation Options and Choices for Local Government, Best Management Practices, and Implementing a Program in Your Community.

Nieswand G.H., R.M. Hordon, T.B. Shelton, and B. Chavooshian. 1990. Buffer strips to protect water supply reservoirs: A model and recommendations. *Water Resources Bulletin*. 26(6):959-966.

This paper discusses the development of a parameter-based model for buffer strip width determination for use in New Jersey, as part of a comprehensive watershed management project. The model is primarily intended for application to all watersheds above water supply intakes or reservoirs. Input requirements for the model include a combination of slope, width, and time of travel. Development of the model and its application to a watershed in New Jersey are discussed. The application results in a recommended buffer strip width that ranges from 50 to 300 feet, depending on a number of assumptions, and from 6-13% of the watershed area above the protected waterbody (reservoir) being occupied by the buffer.

Steinblums, I., H.A. Froehlich, and J.K. Lyons. 1984. Designing stable buffer strips for stream protection. *Journal of Forestry*. 82(1):49-52.

Failure of buffer strips due to blowdowns, disease, and logging is a recurring problem and can cause stream channels to load with debris, leading to sediment storage or erosion. This article reports a study of environmental factors that affect buffer strip stability and stream shading. On 40 streamside buffer strips in the Cascade Mountains of western Oregon, buffer strip stability was found to be a function of one vegetation and six topographic equation variables, and shading was related to three characteristics of buffer strips and one of adjacent clearcuts. Topographic maps and aerial photographs were used to supplement field observations. Stability and shading effectiveness of proposed buffer strips can be evaluated using the equations presented in the paper and data collected through site reconnaissance and topographic maps.

Trimble, G.R., and R.S. Sartz. 1957. How far from a stream should a logging road be located? *Journal of Forestry*. 55(5):339-341.

Observations were made along a forest road that traverses a well- stocked northern hardwood forest of somewhat uneven age in the Hubbard Brook Experimental Forest in the White Mountains of New Hampshire. Data are plotted as a relationship between degree of slope and distance sediment is carried by storm runoff, yielding recommended widths of filter strips for various conditions. A rule of thumb is a filter strip 25 feet wide on level ground with a 2-foot increase in width for each 1% increase in slope of the land between road and stream.

Whitman R. 1989. Clean water of multiple use? Best management practices for water quality control on the national forests. *Ecology Law Quarterly*. 16(4):909.

This article summarizes the nature and extent of the environmental problems around which conflicts revolve, and shows how state and federal laws, including NEPA, CWA and the National Forest Management Act, interact to protect water quality through forest planning. The paper also assesses the success of BMPs in protecting water quality, explains why BMPs are not always implemented even when legally prescribed, and identifies those settings where, even if fully implemented, BMPs fail. Finally, the author proposes some administrative and institutional reforms designed to correct these shortcomings. The article contains a review of the water quality

problems associated with timber harvesting; the various statutes relating to forest practices; the roles of EPA, the states, and the Forest Service in water quality protection; and the effectiveness of BMPs. The suggested reforms include restructuring incentives to protect environmentally sensitive areas and restructuring state water quality standards for forestry-related NPS pollution.

Anderson, H.W., M.D. Hoover, and K.G. Reinhart. 1976. *Forests and water: Effects of forest management on floods, sedimentation, and water supply*. USDA Forest Service. General Technical Report PSW-18. 115 pages.

Andrus, C., and H.A. Froehlich. 1988. Riparian forest development after logging or fire in the Oregon Coast Range: Wildlife habitat and timber value. In:: *Streamside Management: Riparian Wildlife and Forestry Interactions*. University of Washington. Institute of Forest Resources. No. 59. pp. 139-151.

Baumgartner, D.M. (ed). 1981. *Interior west watershed management: Proceedings of a symposium*. Spokane, Washington, April 8-10, 1980. Washington State University, Cooperative Extension Service. 288 pages.

Belt, G.H., J. O'Laughlin, and T. Merril. 1992. *Design of forest riparian buffer strips for the protection of water quality: Analysis of scientific literature*. University of Idaho, Wildlife and Range Policy Analysis Group Report No. 8. 35 pages.

Borg, H., A. Hordacre, and F. Batini. 1988. Effects of logging in stream and river buffers on watercourses and water quality in the southern forest of Western Australia. *Australian Forestry*. 51 (98-105).

Brazier, J.R., and G.W. Brown. 1973. *Buffer strips for stream temperature control*. Oregon State University, School of Forestry, Forest Research Laboratory. Research Paper 15.

Curtis, W.R. 1966. Forest zone helps minimize flooding in the Driftless Area. *Journal of Soil and Water Conservation*. 21:101- 102.

Ice, G.G. 1989. Guidelines and approaches for forest riparian management: State forest practice rules. In: *Forestry on the Frontier, Proceedings of the 1989 Society of American Foresters National Convention*. Spokane, Washington. pp. 94-98.

Megahan, W.F. 1983. Appendix C: Guidelines for reducing negative impacts of logging. In: *Tropical watersheds: Hydrologic and soils response to major uses or conversions*. L.S. Hamilton and P.N. King (eds.). Westview Press, Boulder, Colorado. pp. 143-154.

Mumper, D., D.R. Gibbons, L. Wilson, and M.J. Golde. 1987. Best management practices in the streamside zone. In: *Streamside Management: Forestry and Fishery Interactions*. University of Washington. E.O. Salo and T.W Cundy (eds.). Inst. of Forest Resources. No. 57. pp. 441-457.

NCASI. 1984. *Forestry management practices and cumulative effects on water quality and utility*. National Council of the Paper Industry for Air and Stream Improvement. Technical Review Bulletin No. 435.

NCASI. 1987. *Managing Oregon's riparian zone for timber, fish and wildlife*. National Council of the Paper Industry for Air and Stream Improvement. Technical Bulletin No. 514.

Payne, N.J., J.C. Feng, and P.E. Reynolds. 1990. Off-target deposits and buffer zones required around water for aerial glyphosate applications. *Pesticide Science*. 30(2):183-198.

Payne, N.J., B.V. Helson, K.M.S. Sundaram, and R.A. Fleming. 1988. Estimating buffer zone widths for pesticide applications. *Pesticide Science*. 24(2):147-161.

Robison, E.G., and R.L. Beschta. 1990. Identifying trees in riparian areas that can provide

coarse woody debris to streams. *Forest Science*. 36(3):790-801.

Salo, E.O., and T.W. Cundy (eds.). 1987. *Streamside management forestry and fishery interactions*. College of Forest Resources, University of Washington. 471 pages.

Swank, G.W. 1985. Streamside management units in the Pacific Northwest. In: *Conference on Riparian Ecosystems and Their Management: Reconciling Conflicting Uses*. USDA Forest Service, April 16-18. pp. 435-438.

USDA Forest Service. 1991. *Riparian forest buffers: Function and design for protection and enhancement of water resources*.

USDA Forest Service and USEPA. 1978. *Streamside management zone statutes and ordinances, criteria and institutional arrangements serving water quality objectives on state and private forest lands*. pp. 10-22.

Wong, S.L., and R.H. McCuen. 1981. *The design of vegetative buffer strips for runoff and sediment control*. University of Maryland, Department of Civil Engineering.

COSTS AND EFFECTIVENESS OF BMPs

Cubbage, F.W. 1987. Costs of forest water quality protection. In: *Forestry and Water Quality: A Policy Workshop for State Foresters*. Oklahoma City, Oklahoma, July 6-9, 1987.

This paper presents a review of the costs of forestry NPS controls, including agency administrative costs, direct costs to landowners or timber operators (e.g., plan preparation), and indirect costs on timber supplies. Forest practice costs are reviewed for California, Massachusetts, Nevada, Alaska, Idaho, Oregon, and Washington. The various approaches used by these states and their effect on implementation cost are analyzed as well. The approach used by forestry and other agencies for implementing the voluntary or required practice rules greatly affects the various costs of program implementation, as well as who bears the costs. Criteria used to select the means of controlling NPS pollution must include BMP effectiveness, political and social acceptability, and economic efficiency.

Cubbage, F.W., and P. Lickwar. 1990. *Estimating the costs of water quality protection on private forest lands in Georgia*. Georgia Forestry Commission, Research Division.

The purpose of the information presented in this paper is to quantify the operational costs of implementing various forestry best management practices, with emphasis placed on practices associated with road construction. This paper presents very good cost information on the following: road construction, stream crossings, broad-based dips, water bars, seed, fertilizer, mulch. The information is useful because the costs are based on various physiographic classifications (i.e., coastal plain, piedmont, or mountain).

Curtis, J.G., D.W. Pelren, D.B. George, V.D. Adams, and J.B. Layzer. 1990. *Effectiveness of best management practices in preventing degradation of streams caused by silvicultural activities in Pickett State Forest, Tennessee*. Center for the Management, Utilization and Protection of Water Resources, Tennessee Technological University for the Tennessee Department of Conservation, Division of Forestry and the Tennessee Wildlife Resources Agency. 197 pages.

This study was undertaken to evaluate the effectiveness of BMPs applied to timber harvest operations in Pickett Forest. The effects on water quality, fish production, and macroinvertebrates, and the presence of herbicides in streams were studied. The BMPs employed were SMZs, road placement on ridgetops and high elevations, skid trails kept at least 14 m from streams, harvest during the driest season and maximum soil stability, logging of small, dispersed stands,

seeding and mulching of disturbed areas, broad-based dips on the haul road, and a period of 10 years before the area would be logged again. Herbicides were applied to two stands. Hardwoods 75 mm dbh or less were thin line sprayed with a mixture of Garlon (active ingredients triclopyr and 2,4-D), Sidekick, and diesel fuel. Picloram was injected into all hardwoods 255 mm dbh or greater. Concentrations of herbicides in streams following the treatments was low: 2,4-D @ <0.02-0.08l. Based on available toxicity data, the levels detected were not biologically harmful. However, care is needed during application to minimize transport to surface waters. Extensive data relating to all of the BMPs employed during the study are presented in the paper .

Dykstra, D.P., and H.A. Froehlich. 1976. Costs of stream protection during timber harvest. *Journal of Forestry*. 74(10): 684-687.

This article analyzes the cost of three stream protection alternatives: conventional felling with channel cleanup; cable- assisted directional felling; and use of buffer strips. The study was conducted along 10 deeply incised headwater stream channels in western Oregon. None of the three alternatives was clearly preferable on a majority of the study areas. The least- cost alternative on four of the areas was a 55-foot-wide buffer strip ($20.02 to $27.77 per MBF). On three of the remaining areas, conventional felling was the least expensive ($20.83 to $23.97 per MBF), and on the other three, cable-assisted directional felling was the least expensive ($18.79 to $26.30 per MBF).

Ellefson, P.V., and P.D. Miles. 1984. Economic implications of managing nonpoint forest source of water pollutants: A midwestern perspective. In: *Mountain Logging Symposium Proceedings*. West Virginia University, June 5-7, 1984. P.A. Peters and J. Luchok (eds.). pp. 107-119.

Economic evaluations of 6 forest practices designed to enhance water quality from 18 timber harvesting operations in the Midwest were carried out. Net revenue reductions ranged from 1.2% with redesign of landing and skid trail locations to 26.4% with buffer strip requirements. Nine operations were profitable with application of all six practices. Limited production function information hinders such analyses.

Heede, B.H. 1990. *Vegetation strips control erosion in watersheds*. Research Note RM-499. USDA Forest Service, Rocky Mountain Forest and Range Experiment Station.

An analysis was conducted on data collected to determine the effects of vegetation strips on erosion control. The data was collected from southwestern ponderosa pine forests, pinyon-juniper, and chaparral. In the ponderosa pine, 61 times more sediment was delivered when buffer strips were missing. This factor was 18 and 277 for pinyon-juniper and chaparral, respectively. Overland flow was also diminished from areas with buffer strips. No statistical analysis was conducted on the data.

House, R., and V. Crispen. 1990. *Economic analyses of the value of large woody debris as salmonid habitat in coastal Oregon streams*. Technical Note OR-7:6512. USDI, Bureau of Land Management, Portland OR. 11 pages.

Three woody debris loading levels that result from different riparian management practices were analyzed in two stream reaches in the upper Nestucca River drainage, Oregon. The analysis included estimating summer juvenile populations of coho salmon, steelhead, and cutthroat trout and estimating the value of conifers in riparian zones for anadromous fish were compared to maximum timber harvest to determine the benefits of maintaining riparian vegetation to supply high levels of woody debris. The benefits of maintaining 2 km of stream at high levels (11.0 pieces per 100 m of stream) would be 11% higher within 20 years and 59% higher (an increase of over $100,000 in present value) after 94 years over conifer stumpage in the riparian zone. Long-term, economic benefits were found to be

substantially higher for streams managed with high levels of woody debris. .

Lickwar, P.M., C.A. Hickman, and F.W. Cubbage. 1991. Costs of protecting water quality during harvesting on private forestlands in the Southeast. ***Southern Journal of Applied Forestry.***

Data on harvest volumes, topography, and other site and area characteristics were obtained from 22 private forest timber harvests in Alabama, Florida, and Georgia. An economic analysis was then used to estimate the marginal costs of implementing each state's recommended BMPs and a set of "enhanced" BMPs that offered increased water quality protection. Collectively, the costs of using the recommended BMPs averaged 2.9% of gross timber sale revenue, $2.34 per 1000 board feet (MBF) of timber harvested, or $12.45 per acre. The cost of implementing enhanced BMPs averaged 5.1% of gross stumpage value, $4.13 per MBF, or $21.94 per acre. Seed, fertilizer, and mulch; broad-based dips; and water bars were the most expensive practices on a total cost basis. Culvert installation, SMZs, and road relocation were less expensive for most tracts. A literature review of related studies is provided. Site location maps, site characteristics (physiographic, size, harvest method) are also given, and the economic analysis breaks the sites down by topography and BMPs implemented. This is one of the few studies available on forestry BMP implementation costs.

Lynch, J.A., and E.S. Corbett. 1981. Effectiveness of best management practices in controlling nonpoint pollution from commercial clearcuts. In: ***Nonpoint Pollution Control - Tools and Techniques for the Future, Proceedings of a Technical Symposium.*** **pp. 213-224.**

This paper reports an evaluation of the effectiveness of Pennsylvania's BMPs for controlling NPS pollution on public and private forestlands. This study was done following a commercial clearcut in central Pennsylvania. The paired watershed method was used to evaluate changes in water quality and quantity. The commercial clearcut produced a water yield increase of 5.39 area- inches the first year following cutting. Stream turbidity on the clearcut watershed was generally higher than that on the control watershed prior to cutting, and no major increase in turbidity occurred as a result of cutting. No serious channel erosion was found on the clearcut watershed. Increases in stream temperature were generally slight. The authors conclude that the BMPs required in Pennsylvania are sufficient to control NPS pollution during and following logging.

Lynch, J.A., and E.S. Corbett. 1990. Evaluation of best management practices for controlling nonpoint pollution from silvicultural operations. ***Water Resources Bulletin.*** **26(1):41-52.**

Fifteen years of streamflow and water quality data were evaluated to determine the effectiveness of BMPs in controlling nonpoint source pollution from a 110-acre commercial clearcut located in the Ridge and Valley Province of central Pennsylvania. In general, the BMPs analyzed effectively reduced water quality impacts associated with timber harvest. Although some increases in water quality constituents were observed, most were well below the drinking water standards although they may violate EPAs antidegradation policy. The authors suggest that buffer strips of unharvested timber provided the most protection to the streams and that improved performance may be possible through annual inspections and increasing the width of buffer strips if necessary. The information presented in this report demonstrates the potential for reductions in nonpoint source pollution possible with various BMPs.

Mormon, D. 1993. ***Riparian rules effectiveness study.*** **Forest Practices Program, Oregon Department of Forestry. 198 pages + appendices.**

The purpose of this report is to present the Forest Practices Program's Riparian Rule effectiveness

study. The report describes the data collected for the study and provides an evaluation of the data. The study surveyed the pre- and post- operation stream and riparian conditions of Class I and II stream within or adjacent to 33 typical harvest units throughout Oregon. The primary focus of the data collection was to measure the resource protection provided on Class I streams through application of the rules, and to provide information on the costs and benefits of the program. The major conclusions presented in the report are as follows: 1) Class II streams experienced greater shade reduction as a result of harvesting than Class I streams; 2) existing quantities of aquatic coarse woody debris were not affected by harvesting, however, in western Oregon the future supply of woody debris was significantly reduced through the harvest of streamside trees; 3) harvesting resulted in minor reductions in snag density; 4) the projected net volume of timber retained annually on Oregons private and local government lands to meet Class I stream protection equals slightly more than 1% of annual harvest on those lands; 5) the application of riparian rules generally resulted in Class I stream protection that maintained pre-operation vegetative condition; and 6) timber retained after harvest in riparian management areas tends to be trees having lower volume and value.

Phillips, J. 1989. Nonpoint source pollution control effectiveness of riparian forests along a coastal plain river. *Journal of Hydrology*. 110:221-237.

The purpose of this research was to evaluate the NPS pollution control effectiveness of riparian environments in the lower Tar River basin, North Carolina. Soil map units, representing specific combinations of soil, topography, and vegetation characteristics, are compared in terms of their relative ability to filter nitrate in agricultural runoff. A typical riparian forest provides significant water quality protection, but there is wide variation in buffer effectiveness. A range of 15-80 m is appropriate for the soil-landform-vegetation complexes found in the study area riparian zones, and buffer widths of 60 m, and often much less, are generally adequate on the soils likely to be used for agricultural production. The author analyzes the effectiveness of buffer widths using a detention-time model and explains the model's development and application.

Clinnick, P.F. 1985. Buffer strip management in forest operations: a review. *Australian Forestry*. 48(1):34-45.

Dykstra, D.P., and H.A. Froehlich. 1976. Stream protection: What does it cost? *Loggers Handbook*. Pacific Logging Congress, Portland, Oregon.

Ellefson, P.V., and P.D. Miles. 1985. Protecting water quality in the Midwest: Impact on timber harvesting costs. *Northern Journal of Applied Forestry*. 2:57-61.

Erman, D.C., J.D. Newbold, and K.B. Roby. 1977. *Evaluation of streamside buffer strips for protecting aquatic organisms*. California Water Resources Center, University of California, Davis, California. 48 pages.

Irland, L.C. Streamside protective corridors: Techniques for weighing costs and benefits. *Paper presented at IUFRO World Forestry Research Congress: Draft*. Ljubljana, Yugoslavia, 1986. 28 pages.

Lickwar, P.M. 1984. *Estimating the costs of water quality protection on private forest lands in the south*. Master's Thesis, University of Georgia.

Lynch, J.A., and E.S. Corbett. 1989. Effectiveness of BMP's in controlling nonpoint pollution from silvicultural operations. In: *Proceedings of the Symposium on Headwaters Hydrology*. American Water Resources Association, Bethesda, Maryland. pp. 149-157.

NCASI. 1987. *Managing Oregon's riparian zone for timber, fish and wildlife*. National Council of the Paper Industry for Air and Stream

Improvement. Technical Bulletin No. 514.

NCASI. 1988. *Procedures for assessing the effectiveness of Best Managements Practices in protecting water and stream quality associated with managed forests*. National Council of the Paper Industry for Air and Stream Improvement. Technical Bulletin No. 538. 23 pages.

Olsen, E.D., D.S. Keough, and D.K. LaCourse. 1987. *Economic impact of proposed Oregon Forest Practices Rules on industrial forest lands in the Oregon Coast Range: A case study*. Oregon State University, College of Forestry, Forest Research Laboratory. Research Bulletin 61. 15 pages.

7. FORESTRY CHEMICALS

IMPACTS ON WATER QUALITY

Allen, H.L. 1987. Forest fertilizers: Nutrient amendment, stand productivity, and environmental impact. *Journal of Forestry*. 85: 37-46.

The benefits and impacts of forest fertilization practices are discussed. The discussion topics range from timber response to potential water quality alterations. This is a general information paper that uses literature data as the basis for its findings.

Aubertin, G.M., D.W. Smith, and J.H. Patric. 1973. Quantity and quality of streamflow after urea fertilization on a forested watershed: First year results. In: *Forest Fertilization Symposium Proceedings*. USDA Forest Service, Northeast Experiment Station, Upper Darby, Pennsylvania. General Technical Report NE-3. pp. 88- 100.

The quantity and quality of streamflow from a fertilized watershed were quantified in this paper. A 74-acre calibrated watershed was fertilize with an average of 500 pounds of urea per acre (range 400-600) in May. An initial period of no rain led to the loss of some N through ammonification. Light rains through the summer caused streamflow to decrease to a trickle. Ammonium-N and nitrate-N returned to prefertilization levels in 2 weeks and 6 weeks, respectively. Fall rains raised the ammonium-N concentration to 0.2 ppm and the nitrate-N concentration to 5.5 ppm. High streamflow during this period resulted in a substantial loss of N from the watershed in fall and winter. This study was conducted on a highly calibrated watershed with significant amounts of baseline data. However, the watershed is not typical of commercial forestry in that a dense stand of lush vegetation was present because the watershed had been clearcut 13 years earlier.

Burroughs, E.R., and H.A. Froehlich. 1972. Effects of forest fertilization on water quality in two small watersheds. *BLM Technical Note*. Bureau of Land Management, 17 pages.

A study was undertaken to determine nitrate and nitrite concentrations in streams following forest fertilization. Several thousand acres of Douglas fir forest in western Oregon were fertilized in 1970 and 1971. Dry urea pellets were applied at the rate of 440 pounds per acre (200 lb N per acre). Peak N levels in the two treated streams were 8.6 and 44.4 ppm, but the peaks were short-lived. Concentrations returned to pretreatment levels within 3-4 days. The fertilization did not cause levels of N to exceed those recommended for drinking water standards (10 ppm) near public water supply areas. Peak concentrations were probably caused by fertilizer that fell directly into streams, and such direct application should be avoided in future applications. Care should be taken not to apply fertilizers where sufficient dilution from downstream tributaries could contribute to contamination of municipal water supplies.

Chamberlin, T.W., R.D. Harr, and F.H. Everest. 1991. Timber harvesting, silviculture, and watershed processes. In: *Influences of forest and rangeland management on salmonid fishes and their habitats*. W.R. Meehan (ed.). American Fisheries Special Publication 19:181-206.

This chapter examines the effects of timber management activities on stream ecosystems, particularly streams with anadromous salmonids. Timber management practices discussed include felling and yarding of trees, site preparation by burning or scarification, fire hazard reduction, forest regeneration by planting or seeding, reduction of competition by brush removal and tree thinning before commercial harvest, and some effects of road building on the hydrologic and sediment systems. Chapter contents: hydrologic effects; effects on erosion and sedimentation; effects on channel forms and geomorphic processes; effects of forest harvesting; and conclusions/management options.

Corbett, E.S., and J.M. Heilman. 1975. Effect of management practices on water quality and quantity: The Newark, New Jersey municipal watersheds. In: *Municipal Watershed Management Symposium Proceedings*. USDA Forest Service, Northeastern Forest Experiment Station. General Technical Report NE-13. pp. 47-57.

The effects of best management practices on water quality in the Pequannock watershed basin of northern New Jersey is examined. The basin serves as the main source of drinking water for the inhabitants of Newark, NJ. A drought occurring in the mid 1960s reduced the available water to critical levels. This resulted in the treatment of vegetation with herbicides to increase forest water yields. Major water quality parameters studied to determine the effects of defoliation include flow, temperature, pH, and turbidity. A large amount of data is presented. The herbicide treatment resulted in augmentation of low flows. During the 5 years following the first treatment, the number of low-flow days was reduced from an average of 81 days per year to 35 days per year. Peak flow was increased by 17.3% during the growing season in watershed 3. Average summer maximum stream temperature increased 6°F over control in the watershed. Herbicide treatment of all trees 1 inch or larger within 20 ft of the stream channel watershed 1 did not statistically significantly increase water yield. The conclusions drawn from the study indicate that, under certain circumstances, water yield can be increased by decreasing the amount of vegetation in a watershed.

Curtis, J.G., D.W. Pelren, D.B. George, V.D. Adams, and J.B. Layzer. 1990. *Effectiveness of best management practices in preventing degradation of streams caused by silvicultural activities in Pickett State Forest, Tennessee.* Center for the Management, Utilization and Protection of Water Resources, Tennessee Technological University for the Tennessee Department of Conservation, Division of Forestry and the Tennessee Wildlife Resources Agency. 197 pages.

This study was undertaken to evaluate the effectiveness of BMPs applied to timber harvest operations in Pickett Forest. The effects on water quality, fish production, and macroinvertebrates, and the presence of herbicides in streams were studied. The BMPs employed were SMZs, road placement on ridgetops and high elevations, skid trails kept at least 14 m from streams, harvest during the driest season and maximum soil stability, logging of small, dispersed stands, seeding and mulching of disturbed areas, broad-based dips on the haul road, and a period of 10 years before the area would be logged again. Herbicides were applied to two stands. Hardwoods 75 mm dbh or less were thin line sprayed with a mixture of Garlon (active ingredients triclopyr and 2,4-D), Sidekick, and diesel fuel. Picloram was injected into all hardwoods 255 mm dbh or greater. Concentrations of herbicides in streams following the treatments was low: 2,4-D @ <0.02-0.08l. Based on available toxicity data, the levels detected were not biologically harmful. However, care is needed during application to minimize transport to surface waters. Extensive data relating to all of the BMPs employed during the study are presented in the paper.

Feller, M.C. 1989. Effects of forest herbicide applications on streamwater chemistry in southwestern British Columbia. *Water Resources Bulletin*. 25(3):607-616.

The herbicide glyphosate was applied to portions of two watersheds in southwestern British Columbia to kill vegetation that was competing with *Pseudotsuga menziesii* (Douglas fir) plantations. This application had little significant effect on streamwater chemistry (K^+, Na^{2+}, Mg^{2+}, Ca^{2+}, Cl^-, NO_3^-, NH_{4+}, PO_4^{3-}, SO_4^-, and SiO_2 concentrations, electrical conductivity, and pH) when vegetation cover in a watershed was reduced by 4%, but had significant effects, which lasted for at least 5 years, when cover was reduced by 43%. The greatest percentage increases were observed for NO_3^-, which increased from typical pretreatment levels of <0.5 mg/l to a maximum of 4.6 mg/l during the first posttreatment water year. Nitrate levels, usually the most impacted by forestry activities, stayed below those recommended for drinking

water (44 mg/l). This study presents the type of long-term data needed to analyze trends in water quality due to chemical applications.

Folmar, L.C., H.O. Sanders, and A.M. Julin. 1979. Toxicity of the herbicide glyphosate and several of its formulations to fish and aquatic invertebrates. *Archives of Environmental Contamination and Toxicology*. 8:269-278.

Studies were conducted of the herbicide's toxicity to aquatic invertebrates (scuds, midge larvae, mayfly nymphs, and daphnids) and fish (Rainbow trout, fathead minnows, channel catfish, and bluegills). Acute toxicities for Roundup ranged from 2.3 mg/L to 43 mg/L. Technical glyphosate was considerably less toxic than Roundup. Roundup was more toxic to rainbow trout and bluegills at higher temperatures and at pH 7.5 than pH 6.5. Eyed eggs were the least sensitive life stage, but toxicity increased markedly as the fish entered the sac fry and early swim-up stages. Application of Roundup at recommended rates along ditchbank areas of irrigation canals should not adversely affect resident populations of fish or invertebrates. However, spring applications in lentic situation, where dissolved oxygen levels are low or temperatures are elevated, could be hazardous to young-of-the-year fishes. Toxicity tables listing the LC50 or EC50 concentrations used and confidence limits are provided.

Fredriksen, R.L., D.G. Moore, and L.A. Norris. 1973. The impact of timber harvest, fertilization, and herbicide treatment on streamwater quality in western Oregon and Washington. In: *Forest Soils and Forest Land Management, Proceedings of the Fourth North American Forest Soils Conference*. B. Bernier and C.H. Winget (eds.). pp. 283-313.

This paper describes the impacts of forest management practices on stream water quality in the Douglas fir region. The conceptual base for understanding the processes of soil erosion and stream sedimentation and the outflow of native nutrients, fertilizers, and herbicides in streams is presented in this study. Research findings from studies in Cascade and Coast Range watersheds illustrate these concepts. The methodology commonly used in watershed studies is explained, and water quality effects of forestry activities are reviewed in detail. This is an excellent review of water quality effects, with data presented from numerous studies conducted in the region. The authors present five conclusions based on the review. Sedimentation of forest streams after timber harvest increases with increasing angle of slope, and forest roads that cross steeply inclined streams rather than roads on ridge tops. Clearcut forests and roads in steep country require more recovery time. Sedimentation can be decreased by careful planning. Nutrients are lost after clearcutting, but loss decreases rapidly with revegetation. Nitrogen concentrations in streams does not increase beyond accepted drinking water standards. The biological effects of forest fertilization on N transformations and movements in forest soils should be investigated. Long-term consequences of repeated forest fertilization on water quality must be determined. The drift or direct application of spray materials to surface waters is the principal route of herbicide entry into streams.

Gibbs, K.E., T.M. Mingo, and D.L. Courtemanch. 1984. Persistence of carbaryl (Sevin-4-oil) in woodland ponds and its effects on pond macroinvertebrates following forest spraying. *Canadian Entomologist*. 116:203-213.

The water quality impact of an aerial spraying of the insecticide carbaryl is presented. Carbaryl (Sevin-4-oil) was applied to woodland ponds in northern Maine at the rate of 840 g A.I./ha. Maximum residue levels found were 254 ug/l in the water and 53, 793 kg (dry wt) in the sediment. Residues of the carbaryl were detectable in the water samples for 14 months and in the sediment for 16 months after spraying. The study presents significant amounts of data on the levels of the carbaryl residues and on the number of aquatic organisms present prior to and after spraying. The amphipods *Hyallela azteca* and *Crangonyx richmondensis* were reduced to near zero levels after the applications and failed to recolonize ponds for 30 months after treatment. The concentrations observed may be somewhat higher than typical because the sprayed ponds had no vegetative buffer to intercept any of the spray.

Golden, M.S., C.L. Tuttle, J.S. Kush, and J.M. Bradley. 1984. *Forestry activities and water quality in Alabama: Effects, recommended practices, and an erosion-classified system.* Auburn University, Agricultural Experiment Station. Bulletin 555.

The report was prepared primarily as a source of information on the relationship between forestry practices and water quality, with orientation toward forestry practices prevalent in Alabama. Information on stream pollutants such as sediment, nutrients, pesticides, organic material, waste and litter, and temperature is provided. The review includes over 160 directly cited documents on these subjects. Also included in the report are recommendations of principles and practices designed to minimize the water quality impacts from Alabama forestry practices.

Groman, W.A. 1972. *Forest fertilization: A state-of-the-art review and description of environmental effects.* U.S. Environmental Protection Agency, Natural Environmental Research Center, Corvallis, Oregon. Environmental Protection Technical Series. EPA-R2-72-016.

Information on the concepts, scope, and methods of forest fertilization in various nations (European, New Zealand, Australia, Japan and Canada) and regions of the United States (Pacific Northwest, southern pine) is reported in this review. Results of completed forest fertilization water quality studies are summarized and evaluated, the status of current water quality studies is described, and the water quality effects of forest fertilization are discussed. The social, economic, and technological trends and developments affecting the practice of forest fertilization are discussed. Recommendations for further research are presented.

Helvey, J.D., J.N. Kochenderfer, and P.J. Edwards. 1989. Effects of forest fertilization on selected ion concentrations in central Appalachian streams. In: *Seventh Central Hardwood Forest Conference.* Carbondale, Illinois, March 5-8. USDA Forest Service. GTR NC-132. pp. 278-282.

Two small forest watersheds in West Virginia were fertilized with nitrogen and phosphorus to determine effects on streamflow chemistry. Fertilizer application rates were 336 kg/ha N as ammonium nitrate and 224 kg/ha P_2O_5 as triple superphosphate. Concentrations of nitrate-N increased on both watersheds 5 months after fertilization. Maximum monthly concentrations were 8.5 and 7.3 mg/l (background levels were a maximum 1-2 mg/l). Elevated levels of nitrate-N were observed for 3 years following treatment. Phosphate-phosphorus concentrations did not change appreciably.

Hetherington, E.D. 1976. *Dennis Creek: A look at water quality following logging in the Okanagan Basin.* Rac. For. Res. Cen., Canada Forest Service. Information Report BX-X-147. 33 pages.

Water quality was monitored in the Lens Creek watershed on southern Vancouver Island to determine nitrogen loss following fall application of 224 kg N/ha urea fertilizer on a second-growth Douglas fir forest. Peak N concentrations were 14 mg/l as urea, 1.9 mg/l as ammonia, and 9.3 mg/l as nitrate. For the first 14 months, estimated N outputs in excess of background amounts were 5.9% and 14.5% of the total applied N for the two subsidiary watersheds with 46% and 80% of their drainage areas fertilized. These losses were considerably higher than amounts of less than 1% previously reported for western North America. The results of this study were compared to other studies and found to differ significantly, indicating the extent to which site-specific conditions affect losses.

Hetherington, E.D. 1985. Streamflow nitrogen loss following forest fertilization in a southern Vancouver Island watershed. *Canadian Journal of Forestry Research.* 15(1):34-41.

Water quality was monitored in the Lens Creek watershed on southern Vancouver Island to determine nitrogen loss following fall application of 224 kg N/ha urea fertilizer on a second-growth Douglas fir forest. The results of this study were compared to other studies and found to differ significantly, indicating the extent to

which site-specific conditions affect losses.

Hildebrand, L.D., D.S. Sullivan, and T.P. Sullivan. 1980. Effects of Roundup herbicide on populations of Daphnia magna in a forest pond. *Bulletin of Environmental Contamination and Toxicology*. 25:353-357.

Roundup herbicide is a nonselective postemergence defoliant. Its effects were tested on Daphnia magna, an indiscriminate filter feeder. Treatment levels were control, field dose, 10x field dose, and 100x field dose. Populations were sampled 2, 4, and 8 days after treatment. Control and experimental treatment populations did not show any significant variation in survival. Food web and bioaccumulation studies were not a part of this study.

Hilmon, J.B., and J.E. Douglass. 1968. Potential impact of forest fertilization on range, wildlife, and watershed management. In: *Forest Fertilization: Practice and Theory*. Tennessee Valley Authority. pp. 197-202.

This is a review of the potential impacts of fertilization on forage, wildlife, and water resources. Results of studies carried out in Florida, Georgia, and North Carolina are presented. Plots received different rates of fertilization, and the nutrient quality of forage for livestock was measured. A similar study was carried out on plots managed for both timber and forage production. The authors briefly discuss the effects of fertilization on the nutrient value of wildlife forage, and, in greater detail, the water quality and yield effects of fertilization.

Hiltibran, R.C. 1967. Effects of some herbicides on fertilized fish eggs and fry. *Transactions of the American Fisheries Society*. 96:414-416.

The toxicity of amitrole, dalapon, endothall, dichlobenil, dimethylamine salt of 2,4-D, isooctyl ester of 2,4-DP, propionic acid, and potassium salt of silvex at various concentrations was examined in a laboratory study. At the concentrations used, no reduction in the survival period of any of the fry was observed. Other herbicides did reduce the survival period at some of the concentrations used. Endothall, because of its low toxicity to fish, low toxicity to eggs or fry, and rates of aquatic use, appears to be one of the safest herbicides to use during the spawning season. Fry were more susceptible to the toxicity of herbicides than were fertilized eggs. Granular formations of some herbicides proved to be less toxic than liquid formulations.

Lichy, C.T. 1980. Impact of forest chemicals on water pollution. In: *U.S. Forestry and Water Quality: What Course in the 80's?* Richmond, Virginia, June 19-20, 1980. Water Pollution Control Federation and Virginia Water Pollution Control Association. pp. 152-161.

This paper is a general discussion of herbicides used in forestry and their potential to cause adverse environmental impacts. Herbicides are used for various phases of forestry, including site preparation and tree release. Timing and mode of application are discussed with respect to the herbicide reaching the intended target. The persistence of herbicides in the environment and the potential impacts in streams are discussed. The author concludes that herbicides and other chemicals, if used properly, do not pose a threat to the forest environment.

Likens, G.E., F.H. Bormann, N.M. Johnson, D.W. Fisher, and R.S. Pierce. 1970. Effects of forest cutting and herbicide treatment on nutrient budgets in the Hubbard Brook watershed- ecosystem. *Ecological Monographs*. 40(1):23-47.

All vegetation on watershed 2 of the Hubbard Brook Experimental Forest in New Hampshire was cut in November and December 1965. Vegetation regrowth was inhibited by periodic herbicide applications. Annual stream flow was increased above normal values by 39% the first year and 28% the second year. Large increases in all major ions except NH_4^+, SO_4^{2-} and HCO_3^- were observed for 5 months after deforestation. Nitrate concentrations in stream water were 41- and 56-fold higher during the first and second years following deforestation, respectively. Stream temperatures following deforestation were

higher than normal and fluctuated 3-4 °C during the day during summer, in contrast to normally constant daytime temperatures. Turbidity increases were negligible, but particulate matter output increased 4-fold. Overall, the deforestation experiment resulted in significant pollution of the drainage stream from the ecosystem; this was largely due to the interruption of the nutrient cycle caused by the loss of vegetation.

Mayack, D.T., P.B. Bush, D.G. Neary, and J.E. Douglass. 1982. Impact of hexazinone on invertebrates after application to forested watersheds. ***Archives of Environmental Contamination and Toxicology.*** **11:209-217.**

The herbicide hexazinone was applied to a forested watershed in the Piedmont region of Georgia. Aquatic macrophytes and terrestrial invertebrates were monitored and sampled for residue levels of the chemical. Residue levels in terrestrial invertebrates were a maximum of two orders of magnitude greater than comparable levels (0.01 to 0.18 ppm) found in forest floor material. Hexazinone and its metabolites were generally not detected (<0.1 ppm) in aquatic invertebrates and macrophytes. No community changes, alteration in species, or population densities were recorded as a result of this application. No data on forestry activities and impacts are included.

McCall, M. 1970. ***The effects of aerial forest fertilization on water quality for two streams in the Capitol Forest.*** **Washington State DNR, Olympia, Washington.**

The studies of two streams in the fall and winter of 1969/1970 indicated that aerial application of a urea fertilizer to the forested areas in the watersheds resulted in a rapid increase in urea concentration in the water. This was likely due to the direct application to feeder streams. Further sampling showed that urea concentration fell to background levels within 1 month. After a month, the nitrogen lost was apparently in the nitrate form only. The overall effect on the water quality was to significantly change the nitrogen levels, although the change was of short duration.

Megahan, W.F. 1980. Nonpoint source pollution from forestry activities in the western United States: Results of recent research and research needs. In: ***U.S. Forestry and Water Quality: What Course in the 80s?*** **. Richmond, VA, June 19-20, 1980. Water Pollution Control Federation and Virginia Water Pollution Control Association. pp. 92-151.**

This paper reviews NPS pollution issues in forestry in general. A section on introduced forest chemicals reviews chemicals and their use in forestry, and their potential impacts. Comparison data from many studies on the presence of forest chemicals in streams are presented in tables. The information on the various types of chemicals used in forestry is helpful as a guide to chemical use and contains data on application rates, intended uses, and persistence.

Miller, J.H., and A.C. Bace, Jr. 1980. ***Streamwater contamination after aerial application of a pelletized herbicide.*** **USDA Forest Service, Southern Forest Experiment Station. Research Note SO- 255.**

Loblolly pine seed coated with arasan (a bird repellent), and endrin (an animal repellent) were applied at 0.8 kg/ha (3/4 lb/ acre) to a recently harvested Piedmont watershed, followed immediately by an application of 1.6 lb/acre of hexazinone. Concentrations of hexazinone and its metabolites were monitored for the 8 months following. Concentrations were highest (2.4 ppm) 30 minutes after application and declined to 1.1 ppm at 1 hour after application, then to half that (0.49 ppm) at 2 hours after application. Stream contamination was primarily the result of some chemical falling directly onto the water surface. However, in estimating the environmental hazard of the application, the authors note that sustained exposure is more harmful than peak exposures. The sustained concentration for the first 96 hours was about 0.1 ppm. Levels of hexazinone injurious to commonly occurring fish species and humans are not likely to be attained in normal forestry practice.

NCASI. 1979. *A review of current knowledge and research on the impact of alternative forest management practices on receiving water quality*. National Council of the Paper Industry for Air and Stream Improvement. Technical Bulletin No. 322. 141 pages.

This bulletin reviews research on the impact of forest management practices on water quality. Ninety-three projects are reviewed. Separate chapters briefly discuss forest practice effects on loadings of sediment, nutrient, and organic debris, and changes in temperature and water quality changes due to the use of forest chemicals. Current knowledge is assessed, and a reference list of 410 related papers is provided. Appendices provide information on the application of the universal soil loss equation for predicting sediment loading, erosion rates, and predictive equations for stream nutrient concentrations.

Neary, D.G. 1988. Chapter 24: Effects of pesticide applications on forested watersheds. In: *Forest Hydrology and Ecology at Coweeta*. W.T. Swank and D.A. Crossley, Jr. (eds.). Springer- Verlag, New York. pp. 325-337.

This is a review of literature on the effects of forest pesticides, including paraquat, atrazine, 2,4-D, picloram, and hexazinone. Data from many references are used to present conclusions about the potential for forestry chemicals to contaminate water and soil resources.

Neary, D.G. 1985. Fate of pesticides in Florida's forests: An overview of potential impacts in water quality. In: *Proceedings - Soil and Crop Science Society of Florida, Volume 44*. pp. 18-24.

The operational hazards of pesticide use on loblolly forests of northern Florida and the effects of pesticides on surface and ground water are examined. Data on the fate and movement of forest pesticides in other southern forests are used to assess the potential impact on the quality of Florida surface and ground water. The pesticides hexazinone, picloram, bromacil, and carbofuran are examined. The authors draw five conclusions: (1) the majority of pesticide use in intensive forestry involves low- toxicity herbicides applied infrequently over extensive land areas; (2) intensive (yearly) toxic pesticide use is concentrated on seed orchards and nurseries occupying small areas of the slash-loblolly ecosystem; (3) current pesticide technology and application methods minimize the movement of pesticides into sensitive surface waters; (4) at currently registered herbicide application rates, some short-duration, low-level pulses of residues could enter surface, unconfined aquifers, although water quality standards are not likely to be exceeded; and (5) the greatest hazard to surface and ground water quality arises from mishandling of concentrates during transportation, storage, mixing-loading, equipment cleaning, and container disposal. The authors found that the highest risk of ground water contamination arises from the possible mishandling and disposal of pesticides.

Neary, D.G., P.B. Bush, and J.L. Michael. 1986. Herbicides in southern forestry—Improving water quality. In: *39th Proceedings - Southern Weed Science Society*. pp. 335-341.

This paper provides a brief overview of the water quality implications associated with herbicide use in southern forestry. It provides data from other studies in an attempt to determine whether water quality is improved, maintained, or degraded by using herbicides, especially when compared to mechanical site preparation methods.

Neary, D.G., P.B. Bush, J.E. Douglass, and R.L. Todd. 1985. Picloram movement in an Appalachian hardwood forest watershed. *Journal of Environmental Quality*. 14(4):585-591.

The herbicide picloram was applied at a rate of 5.0 kg/ha to 4 ha of a 28-ha watershed in western North Carolina. The herbicide was broadcast manually as a pellet formulation in May, with the intention of removing a poor-quality mixed oak overstory and rhododendron-laurel understory prior to planting white pine. Picloram residues in soil samples peaked in concentration in the upper 0.07 m at 11.58 mg/kg, had a half life of about 4 weeks, and declined to near detection limits 28

weeks after application. Residues were detected in soil solution 1.2 m into the soil. Only sporadic, low-level residues were detected in stream flow during a 70-week period. Use of picloram did not affect the quality of stream flow from the watershed for domestic or agricultural purposes.

Neary, D.G., P.B. Bush, and M.A. Grant. 1986. Water quality of ephemeral forest streams after site preparation with the herbicide hexazinone. *Forest Ecology and Management*. 14(1):23- 40.

Four small watersheds (1 ha) in the upper Piedmont of north Georgia were treated with 1.68 kg/ha active ingredient of hexazinone pellets. Residues in stormflow peaked in the first storm at 442 mg/m^3, declined rapidly thereafter, and disappeared within 7 months. Loss of hexazinone in stormflow averaged 0.53% of the applied herbicide. Total sediment yields were increased by a factor of 2.5 due to increased runoff associated with site preparation using herbicide and salvage logging. Hexazinone treatment produced a large increase in NO_3-N concentrations (peak = 5328 mg/m^3), but NO_3-N levels returned to normal within 2 years. Hexazinone may have produced some stimulation of nitrifying bacteria. Overall, water quality changes were small and short-lived.

Neary, D.G., and J.B. Currier. 1982. Impact of wildfire and watershed restoration on water quality on South Carolina's Blue Ridge Mountains. *Southern Journal of Applied Forestry*. 6(2):81- 90.

Neary and Currier studied the change in water quality caused by a large wildfire in South Carolina's Blue Ridge Mountains. Five watersheds contained five different conditions, including undisturbed; burned only; burned and fertilized; and burned, fertilized and covered with fire retardant. Concentrations of NO_3-N increased the most (peak of 0.394 mg/l) as a result of fertilizer applications during restoration operations. Nitrate-N, NH_4-N, PO_4-P levels were elevated on the burned and fertilized watersheds mainly during storm events. Sodium, K, Ca, and Mg concentrations were 12-82% above background levels during most of the monitoring period. Suspended solid concentrations showed no relationship to watershed condition. Changes in water quality were of no biological significance to aquatic ecosystems and did not affect use of the watersheds as sources of drinking water. Based on the results of this intensive study, the authors concluded that the wildfire did not adversely affect the water quality for ecosystems or drinking.

Neary, D.G., and J.L. Michael. 1989. Effect of sulfometuron methyl on ground water and stream quality in coastal plain forest watersheds. *Water Resources Bulletin*. 25(3):617-623.

The stream concentration of sulfometuron methyl was determined after spraying for site preparation in a Coastal plain flatwood. Sulfometuron methyl was applied at a maximum labeled rate of 0.42 kg/ha a.i. to a 4-ha coastal plain flatwoods watershed as site preparation for tree planting. Herbicide residues were detected in stream flow for only 7 days after treatment and did not exceed 7 mg/m^3. Sulfometuron methyl was not detected in any storm flow and was not found in any sediment (both bedload and suspended). Sampling of a shallow ground water aquifer, <1.5 m below ground surface, did not detect any sulfometuron methyl residues for 203 days after herbicide application. Lack of herbicide residue movement was attributed to low application rates, rapid hydrolysis in acidic soils and water, and dilution in stream flow. This paper presents very important information on the potential for water contamination when spraying herbicides in forested areas. The information presented is useful for comparison of similarly applied ground-based pesticide applications under conditions similar to those found during the study.

Norris, L.A. 1970. Degradation of herbicides in the forest floor. In: *Tree Growth and Forest Soils*. Oregon State University Press, Corvallis, Oregon. C.T. Youngberg and C.B. Davey (eds.). pp. 397-411.

This paper is a review of research on the persistence, degradation, and impact of herbicides

in forests. Past research on the degradation of 2,4-D, amitrole, and picloram in forest soils is reviewed, with emphasis on the influence of factors such as litter type, the chemical formulation of the herbicide, and the presence of other chemicals. The methodologies and the results of more current research are then reviewed. The herbicides 2,4-D, 2,4,5-T, amitrole, and picloram are degraded but at different rates. The degradation of 2,4-D differs slightly in litter from different vegetation types. 2,4,5-T approaches 90% degradation after 4 months, making it somewhat more persistent than 2,4-D. Amitrole has an initial rate of degradation exceeding that of 2,4-D and is rapidly lost in the forest floor, but its degradation is not completely biological. Picloram is more resistent to degradation than the other herbicides, but it is biodegradable.

Norris, L.A., H.W. Lorz, and S.V. Gregory. 1991. Forest chemicals. In: *Influences of Forest and Rangeland Management on Salmonid Fishes and Their Habitats*. W.R. Meehan (ed.).

This paper contains a comprehensive discussion of forest chemicals. Tables provide information on application rates; toxicity; concentrations of chemicals in soils, lakes, and streams; and chemical compositions of numerous forest chemicals. Chapter contents: Use of Chemicals in the Forest; Relation of Chemical Use to Salmonid Habitats; Direct Chemical Effects; Behavior and Toxicity of Commonly Used Forest Chemicals (2,4-D, picloram, hexazinone, atrazine, triclopyr, MSMA, fosamine ammonium, glyphosate, dalapon, dinoseb, malathion, carbaryl, azinphos-methyl, carbofuran, acephate, Bacillus thuringiensis, nuclear polyhedrosis virus, fertilizers, fire retardants); Risk Assessment; Indirect Effects of Forest chemicals; Research Needs; and Conclusions.

Norris, L.A., and D.G. Moore. 1971. The entry and fate of forest chemicals in streams. In: *Proceedings of the Symposium: Forest Land Uses and Stream Environment*. Oregon State University, October 19-21, 1970. J.T. Krygier and J.D. Hall (eds.). OSU, Corvallis, Oregon. pp. 138-158.

This article reviews the initial distribution of aerially applied forest chemicals, as well as mechanisms of their entry into, and their fate in, the aquatic environment. The movement of pesticides from the air to vegetation and the forest floor and soil to streams-and directly from the air to streams-is explained. The movement of fertilizers is similarly tracked. The authors draw conclusions based on a review of available data and information. Concentrations of the herbicides 2,4-D, picloram, 2,4,5-T, and amitrole above 0.1 ppm will rarely be found in streams if applied properly. Similarly, the insecticides reviewed (carbamate, pyrethrum insecticides, malathion, and DDT and its metabolites) will rarely endanger aquatic life. There are limited data on fertilizers, but the concentrations encountered in streams are well below those of public water supplies.

Norris, L.A., and D.G. Moore. 1981. Introduced chemicals and water quality. In: *Proceedings of the Symposium: Interior West Watershed Management*. Spokane, WA, April 8-10, 1980. D.M. Baumgartner (ed.). Washington State University, Cooperative Extension Service. pp. 203-220.

The use of chemicals in forestry and their environmental effects are reviewed. Results from selected research are presented in tables and figures to demonstrate general principles of forest chemical use. The authors arrive at the following conclusions: (1) direct application or drift to surface water is the principal mechanism by which aerially applied chemicals enter forest streams; (2) with the exception of nitrate-N as a transformation product of urea fertilizer or ammonia-based fertilizers or fire retardants, the long-term entry of chemicals via leaching to streams does not seem to occur at measurable levels; (3) the concentrations and persistence of chemicals found in these streams does not appear to represent a substantive hazard to aquatic organisms or downstream water users; and (4) forest managers and chemical applicators can markedly influence the amount of chemical that enters streams by careful attention to the orientation of treated areas to streams and the conditions of application.

Nutter, W.L. 1982. Water quality and yield from the intensively managed forest. In: *Proceedings of the Society of American Foresters*. pp. 89-93.

A review of the impacts of intensive forest management, including timber harvest, site preparation, road construction, and forest fertilization, on water yield and water quality is presented. This short review presents an overview of the impacts of intensive forestry operations.

Oregon Department of Forestry. 1992. *Forest herbicide application: Water sampling study*. Oregon Department of Forestry, Forest Practices Program.

The purpose of this report is to present the results of a water monitoring study conducted by the Forest Practices Program to determine the effectiveness of forest chemical rules in preventing stream contamination from herbicide applications. The study was not conducted using the rigorous QA/QC protocols typical of field research studies but was conducted to provide general insight into forest chemical rule effectiveness.

Phillippi, M.A., and G.B. Coltharp. 1990. Post-treatment effects of forest fertilization on the predominant benthic community of a headwater stream in eastern Kentucky. *Transactions of the Kentucky Academy of Science*. 51(1/2):18-25.

Biological sampling was conducted from 1978 to 1981. Higher concentrations of nitrate-N were present in the affected stream compared to two unaffected streams. Standing-crop biomass of invertebrates and the number of individuals were not significantly different between the treated stream and one untreated stream. The number of taxa and the species diversity were significantly higher in the unaffected stream in the unfertilized watershed. The authors conclude that the benthic fauna is unaffected by the forest fertilization. Graphs of species abundance and number of individuals of different taxa accompany the text.

Riekerk, H. 1989. Forest fertilizer and runoff-water quality. In: *Proceedings - Soil and Crop Science Society of Florida*. Vol. 48, pp. 99-102.

Runoff water quality was monitored from three replications of annually fertilized and nonfertilized young slash pine (*Pinus elliotti*) plantations in north central Florida during 4 years. The results showed some increase in NH_4-N during the first year, but an increase in K did not occur until after the second year. Increases in NH_4-N, K and orthophosphate occurred during the last year, and they appeared to be associated with more rainfall. These findings support current recommendations for forest fertilization in the southeastern United States. These recommendations are not discussed in the paper. The research indicated the need for additional ground water monitoring to explain changes in runoff water quality.

Sopper, W.E. 1975. Effects of timber harvesting and related management practices on water quality in forested watersheds. *Journal of Environmental Quality*. 4(1):24-29.

The results of selected studies are presented to provide an overview of the types of water quality investigations undertaken on forested watersheds. Studies from timber harvesting activities, fertilization, and herbicide use are included. Many tables of data from the various studies, and very general conclusions based on the information, are provided.

Tiedemann, A.R., T.M. Quigley, and T.D. Anderson. 1988. Effects of timber harvest on stream chemistry and dissolved nutrient losses in northeast Oregon. *Forest Science*. 34(2):344-358.

An upper slope conifer forest in eastern Oregon and Washington was studied. Three harvested watersheds (41% clearcut and 17% selection harvest) were compared to a control watershed. Nitrate-N concentrations in stream flow increased in response to both clearcutting treatments. The maximum level observed (0.52 mg/l) was, however, far below maximum allowable levels for drinking water standards (10 mg/l). Small but

significant increases in cation concentrations were observed with both clearcutting treatments. Comparisons of chemical characteristics and constituents among the four watersheds under study revealed enormous variability. However, this study supported other studies from the Pacific Northwest that indicated that forest harvest activities have no adverse impact on water quality for drinking purposes. The dissolved nutrient concentrations and variations are provided and discussed in detail.

USDA Forest Service. 1987. *Soil and water resource management: A cost or a benefit? Approaches to watershed economics through example*. 99 pages.

Analysis procedures for estimating the economic benefits of soil and water resource management have been developed. This report discusses the procedures and the data and information required to employ them. The analysis procedures focus on the following management areas: timber, forage, fish, enhanced water quality, and road construction and maintenance. The procedures and economics of soil and water management are demonstrated in this document with 16 examples.

Walker, W.W. 1976. Chemical and microbiological degradation of malathion and parathion in an estuarine environment. *Journal of Environmental Quality*. 5(2):210-215.

Malathion was essentially completely degraded during 18 days of incubation in sterile and nonsterile water, while respective parathion losses ranged from 16% to 23% after 40 days. Malathion abatement was in direct proportion to increasing salinity, while parathion was quite persistent, even in high-salinity (25 ppt) water. Microorganisms capable of degrading malathion and parathion were isolated from insecticide-enriched sediment. Four bacteria isolated from malathion-enriched sediment readily degraded malathion, one to malathion half-ester and another to malathion dicarboxylic acid through the half-ester intermediate; three bacteria isolated from parathion-enriched sediment were efficient in parathion metabolism. One bacterium isolated from parathion-enriched sediment was capable of degrading malathion to the diacid through the half-ester intermediate.

Baumgartner, D.M. (ed). 1981. *Interior west watershed management: Proceedings of a symposium*. Spokane, Washington, April 8-10, 1980. Washington State University, Cooperative Extension Service. 288 pages.

Beasley, R.S., and A.B. Granillo. 1985. Water yields and sediment losses from chemical and mechanical site preparation. *Forestry and Water Quality - A Mid-South Symposium*. Little Rock, Arkansas, May 8-9, 1985. B.G. Blackmon (ed.). Arkansas Cooperative Extension Service, University of Arkansas. pp. 106-116.

Bengtson, G.W. 1972. Forest fertilization: Promises and problems. In: *Proceedings of the Society of American Foresters*. Hot Springs, Arkansas, October 1-5, 1972. pp. 231-261.

Bengtson, G.W. 1979. Forest fertilization in the United States: Progress and outlook. *Journal of Forestry*. 77:222-229.

Brown, G.W. 1985. Controlling nonpoint source pollution from silvicultural operations: What we know and don't know. In: *Perspectives on Nonpoint Source Pollution: Proceedings of a National Conference*. Kansas City, Missouri, May 19-22, 1985. U.S. Environmental Protection Agency.

Burdick, G.E., H.J. Dean, and E.J. Harris. 1960. The effect of Sevin upon the aquatic environment. *New York Fish and Game Journal*. 7:14-25.

Davis, E.A., and P.A. Ingebo. 1970. Fenuron contamination of stream water from a chaparral watershed in Arizona. In *Research Progress Report of the Western Society of Weed Science*. pp. 22- 23.

Gessel, S.P. 1969. Introduction to forest fertilization in North America. *Forest Industry*. 96(10):26-28.

Greene, C.S. 1988. Water quality, timber and herbicides. In: *Proceedings of the 9th Annual*

Forest Vegetation Management Conference. Redding, California, November 3-5, 1987. pp. 17-33.

Hornbeck, J.W., and R.S. Pierce. 1973. Potential impact of forest fertilization on streamflow. In: *Forest Fertilization Symposium Proceedings, Northeastern Forest Soils Conference.* SUNY College of Environmental Science and Forestry. USDA Forest Service. General Technical Report NE-3. pp. 79-87.

Hurlbert, S.H., M.S. Mulla, and H.R. Willson. 1972. Effects of an organophosphorus insecticide on the phytoplankton, zooplankton, and insect populations of fresh-water ponds. *Ecological Monographs.* 42(3):269-299.

Johnson, P.L., and W.T. Swank. 1973. Studies of cation budgets in the Southern Appalachians on four experimental watersheds with contrasting vegetation. *Ecology.* 54:70-80.

Malueg, K.W., C.F. Powers, and D.F. Krawczyk. 1972. Effects of aerial forest fertilization with urea pellets on nitrogen levels in a mountain stream. *Northwest Science.* 46:52-58.

McKellar, R.L., O.E. Schubert, B.C. Byrd, L.P. Stevens, and E.J. Norton. 1982. Aerial application of GARLON 3A herbicide to a West Virginia watershed. *Down to Earth.* 38(2):15-19.

Michael, J.L., D.G. Neary, and M.J.M. Wells. 1989. Picloram movement in soil solution and streamflow from a coastal plain forest. *Journal of Environmental Quality.* 18(1):89–95.

Moore, D.G. 1975. *Effects of forest fertilization with urea on stream water quality-Quilcene Ranger District, Washington.* USDA Forest Service, Pacific Northwest Forest and Range Experiment Station. Research Note PNW-241. 9 pages.

Moore, D.G. 1971. Fertilization and water quality. In: *Western Reforestation, Proceedings of the Annual Meeting of the Western Reforestation Coordination Committee.* Western Forest Conservation Association. pp. 28-31.

Moore, D.G. 1975. Impacts of forest fertilization on water quality in the Douglas fir region-A summary of monitoring studies. In: *Proceedings of the 1974 National Convention of the Society of American Foresters.* New York, September 22-26, 1974. pp. 209-219.

NCASI. 1984. *A guide to monitoring streamwater quality following forestry herbicide concentration.* National Council of the Paper Industry for Air and Stream Improvement. Technical Bulletin No. 430. 40 pages.

Neary, D.G. 1983. Monitoring herbicide residues in springflow after an operational application of hexazinone. *Southern Journal of Applied Forestry.* 17(4):217-223.

Norris, L.A. 1976. Forests and rangelands as sources of chemical pollutants. In: *Non-Point Sources of Water Pollution.* Oregon State University, Water Resources Research Center. pp. 17-36.

Norris, L.A. 1968. *Stream contamination by herbicides after fall rains on forest land.* Western Society of Weed Scientists. Research Progress Report. pp. 33-34.

Norris, L.A., M.L. Montgomery, L.E. Warren, and W.D. Mosher. 1982. Brush control with herbicides on hill pasture sites in southern Oregon. *Journal of Range Management.* 35:75-80.

Payne, N.J., J.C. Feng, and P.E. Reynolds. 1990. Off-target deposits and buffer zones required around water for aerial glyphosate applications. *Pesticide Science.* 30(2):183-198.

Payne, N.J., B.V. Helson, K.M.S. Sundaram, and R.A. Fleming. 1988. Estimating buffer zone widths for pesticide applications. *Pesticide*

Science. 24(2):147-161.

Pionke, H.B., and G. Chesters. 1973. Pesticide-sediment-water interactions. *Journal of Environmental Quality*. 2(1):29-45.

Rydelius, J.A. 1985. Forest chemicals and water quality. *Journal of Forestry*. 83(10):610.

Thut, R.N., and E.P. Haydu. 1971. Effects of forest chemicals on aquatic life. In: *Proceedings of the Symposium: Forest Land Uses and Stream Environment*. Oregon State University, October 19-21, 1970. J.T. Krygier and J.D. Hall (eds.). OSU, Corvallis, Oregon. pp. 159-171.

Tiedemann, A.R., J.D. Helvey, and T.D. Anderson. 1978. Stream chemistry and watershed nutrient economy following wildfire and fertilization in eastern Washington. *Journal of Environmental Quality*. 7(4):580-588.

BMPs AND SPECIFICATIONS

Collman, S.J. 1989. Integrated pest management: A Seattle street tree case study. In: *Forestry on the Frontier, Proceedings of the 1989 Society of American Foresters National Convention*. Spokane, Washington. pp. 416-420.

This is a case study of the application of integrated pest management (IPM) to an urban forestry problem. An infestation of oystershell scale (*Lepidosaphes ulmi*) was reportedly causing the decline of ash cultivars along Seattle's streets. Examination of the declining trees found that 59.7% had only light or no scale infestation. Many healthy trees had heavy infestations. Data on aspects of the life history of the scales during the infestation demonstrated that literature information on hatching times was incorrect, which would have had an effect on the timing of insecticide applications. The author concludes that there was a 70% chance that the declining in some trees was due to less-than- optimum site conditions rather than the scale insects. A thorough examination of the problem should precede any textbook treatment application.

McClimans, R.J. 1980. Best management practices for forestry activities. In: *Watershed Management*. Boise, Idaho, July 21-23, 1980. C.W. Johnson (ed.). American Society of Civil Engineers, Irrigation and Drainage Division, Committee on Watershed Management. pp. 694-705.

This paper defines critical combinations of site conditions for which BMPs are needed to minimize adverse impacts on soil and water resources. The document also includes assessment methodologies, as well as charts and graphs for the selection and application of appropriate BMPs. Forest practices are grouped according to their capacity to cause water pollution, the nature of the more commonly applied BMPs to control pollution, and site considerations. Guides, based on slope of land and distance from water, are provided to determine whether a particular BMP is necessary for the particular group of activities. Graphs developed to determine BMP applicability are presented, and the selected BMPs are discussed for each group of forest activities. Specifications for some BMPs are also presented.

Neuman, L. 1987. Silviculture and best management practices. In: *Erosion Control: You're Gambling Without it*. International Erosion Control Association. pp. 145-155.

This report presents information on the types of impairments typical of forestry activities and provides information on management techniques that may be used to minimize the impacts. The practices presented in this paper include timber harvesting, site preparation, and road construction and drainage. Erodibility factors, assigned to Florida soils by the SCS, and slope determine a site's sensitivity to erosion, and the paper presents site sensitivity classes for Florida soils. This classification is related to suggested BMP usage and implementation. Many useful tables of

specifications for when and how to construct the practices are presented.

Pope, P.E. 1978. Forestry and water quality: Pollution control practices. *Forestry and Natural Resources*. Purdue University Cooperative Extension Services. FNR 88. 6 pages.

Best management practices (BMPs) for forestry activities are presented, stressing that feasible BMPs must depend on site- specific, case-by-case information such as management objectives and natural conditions. Information on the effectiveness of BMPs is not provided. The principal types of erosion control practices and qualitative positive and negative features, based on EPA Technical Report 37 (1977) are included.

Bengtson, G.W. 1972. Forest fertilization: Promises and problems. In: *Proceedings of the Society of American Foresters*. Hot Springs, Arkansas, October 1-5, 1972. pp. 231-261.

Golden, M.S., C.L. Tuttle, J.S. Kush, and J.M. Bradley. 1984. *Forestry activities and water quality in Alabama: Effects, recommended practices, and an erosion-classified system*. Auburn University, Agricultural Experiment Station. Bulletin 555.

Greene, C.S. 1988. Water quality, timber and herbicides. In: *Proceedings of the 9th Annual Forest Vegetation Management Conference*. Redding, California, November 3-5, 1987. pp. 17-33.

Minnesota Department of Natural Resources, Division of Forestry. 1989. *Water quality in forest management: Best management practices in Minnesota*. 104 pages.

COSTS AND EFFECTIVENESS OF BMPs

Allen, H.L. *Economics of forest fertilization*. pp. 161-169.

Allen analyzes the costs and benefits of forest fertilization as an investment strategy for southeastern loblolly pine forests. A return on investment (the interest rate that results in a net present value of zero) is used for the analysis. The impact of taxes on the decision to fertilize is examined, as are four other factors important in determining the profitability of fertilization: product mix, stumpage prices, fertilizer application costs, and response. Based on these factors, the author examines preplant phosphorus and established stand examples. The analysis concludes that fertilization is an attractive investment, that will become even more attractive in the future with improved technology and methodologies.

Corbett, E.S., and J.M. Heilman. 1975. Effect of management practices on water quality and quantity: The Newark, New Jersey municipal watersheds. In: *Municipal Watershed Management Symposium Proceedings*. USDA Forest Service, Northeastern Forest Experiment Station. General Technical Report NE-13. pp. 47-57.

The effects of best management practices on water quality in the Pequannock watershed basin of northern New Jersey is examined. The basin serves as the main source of drinking water for the inhabitants of Newark, NJ. A drought occurring in the mid 1960s reduced the available water to critical levels. This resulted in the treatment of vegetation with herbicides to increase forest water yields. Major water quality parameters studied to determine the effects of defoliation include flow, temperature, pH, and turbidity. A large amount of data is presented. The herbicide treatment resulted in augmentation of low flows. During the 5 years following the first treatment, the number of low-flow days was reduced from an average of 81 days per year to 35 days per year. Peak flow was increased by 17.3% during the growing season in watershed 3. Average summer maximum stream temperature increased 6°F over control in the watershed. Herbicide treatment of all trees 1 inch or larger within 20 ft of the stream channel watershed 1 did

not statistically significantly increase water yield. The conclusions drawn from the study indicate that, under certain circumstances, water yield can be increased by decreasing the amount of vegetation in a watershed.

USDA Forest Service. 1987. *Soil and water resource management: A cost or a benefit? Approaches to watershed economics through example*. 99 pages.

Analysis procedures for estimating the economic benefits of soil and water resource management have been developed. This report discusses the procedures and the data and information required to employ them. The analysis procedures focus on the following management areas: timber, forage, fish, enhanced water quality, and road construction and maintenance. The procedures and economics of soil and water management are demonstrated in this document with 16 examples.

Bengtson, G.W. 1979. Forest fertilization in the United States: Progress and outlook. *Journal of Forestry*. 77:222-229.

8. STREAMSIDE MANAGEMENT AREAS

IMPACTS ON WATER QUALITY

Adams, M.B. Movement of sediment and nutrients through riparian areas. In: *Proceedings of Technical Workshop on Sediments*. Corvallis, Oregon, February 3-7, 1992. U.S. Environmental Protection Agency and USDA Forest Service.

A review of the literature examining the role of riparian vegetation in moderating the movement of sediment and nutrients in aquatic ecosystems in the eastern U.S. is presented. Data from several watershed studies that present the effect of riparian zones on sedimentation reduction are included. Future research, including a better understanding of the filtering capacity of buffer strips containing various tree species, is recommended.

Adams, P.W., R.L. Beschta, and H.A. Froehlich. Mountain logging near streams: Opportunities and challenges. In: *Proceedings of International Mountain Logging and Pacific Northwest Skyline Symposium*. Oregon State University, December, 1988. OSU, Corvallis, Oregon. pp. 153-162.

This is a review of the values of streamside areas for timber, wildlife, fish, water quality, forage, aesthetics, and recreation. Topics reviewed include the nature and function of streamside areas, the potential effects of logging near streams, and the opportunities and challenges in logging near streams. A brief conclusion of the reviewed information is also presented.

Andrus, C.W., B.A. Long, and H.A. Froehlich. 1988. Woody debris and its contribution to pool formation in a coastal stream 50 years after logging. *Canadian Journal of Fisheries and Aquatic Sciences*. 45:2080-2086.

The objective of this study was to determine how young stands of timber might be managed so that they supply adequate amounts of woody debris to fish-bearing streams. The amount of woody debris is, in part, a product of the surrounding forest. The amount of woody debris in coastal Oregon streams has been altered over the past 80 years as a result of logging, road building, and the conversion of forested land to other uses. In this study, a watershed that had not been logged since a wildfire swept through the area 50 years earlier was sampled for age of debris and pool depth and volume. Debris from the current stand of trees along the stream accounted for only 14% of debris volume in the stream and only 8% of the debris responsible for creating pools. Study results indicate that riparian trees must be left to grow longer than 50 years to ensure that an adequate, long-term supply of woody debris is available to stream channels. Debris from previous stands plays a crucial role in the interim and should not be removed from stream channels.

Bacon, C.G. 1989. Riparian silviculture: Active riparian management for multiple resources. In: *Forestry on the Frontier, Proceedings of the 1989 Society of American Foresters National Convention*. Spokane, Washington. pp. 99-102.

This paper presents an overview of riparian silviculture and its potential impacts on water quality, fisheries, and wildlife. It provides a general review of national perspectives on riparian silviculture and give specific examples of regional management and research efforts.

Bilby, R.E. 1984. Removal of woody debris may affect stream channel stability. *Journal of Forestry*. 82:609-613.

This paper reports on an investigation of the effect of removing large woody debris (LWD) from a small stream after logging, as is mandated by several western states. Large changes in channel structure were observed during the first high flow after cleaning. The location of debris left in the stream and stream sediment were substantially altered. The degree of channel rearrangement was greater than that in a comparable undisturbed stream. The loss in

channel stability due to indiscriminate removal of LWD may have adverse effects on fish populations. LWD influencing channel morphology should be left in place during cleaning. Post-logging cleaning guidelines are provided in the form of a dichotomous key, though the author stresses that these guidelines are applicable only to streams similar to Salmon Creek in the Coast Range of Washington, where the study was conducted. The author found that the degree to which the debris is buried, its length and diameter, and whether it is braced by boulders, bedrock outcrops, or other stable pieces of debris determine whether it should be removed or left in place.

Bilby, R.E., and G.E. Likens. 1980. Importance of organic debris dams in the structure and function of stream ecosystems. *Ecology*. 61(5):1107-1113.

Small headwater streams in forested areas are heavily dependent on the input of organic material from the surrounding terrestrial system as an energy source. Debris dams act as retention mechanisms that allow organic matter to be processed in the stream ecosystem rather than transported downstream in coarse particulate form. In this study, all organic debris was removed from a 175-m stretch of a second-order stream in New Hampshire. A dramatic increase in organic carbon export (dissolved = 18%; fine particulate = 632%; coarse particulate = 138%) from the system resulted. Organic debris dams are extremely important components of small stream ecosystems. In first-order streams, the dams contain nearly 75% of the standing stock of organic matter. In second-order streams, this proportion drops to 58%, and in third-order streams it is 20%.

Borg, H., A. Hordacre, and F. Batini. 1988. Effects of logging in stream and river buffers on watercourses and water quality in the southern forest of Western Australia. *Australian Forestry*. 51: 98-105.

A study was performed in Western Australia to determine the effects of river and stream buffer size on water quality. River buffers in Australia are normally 200 m wide, and stream buffers are 100 m wide. On five of the six test sites, buffers were reduced in size by half (to 100 m for rivers and to 50 m for streams), and on the sixth site the buffer was completely removed. Complete removal of the buffer led to logging debris entering the channel and minor changes in the stream channel profile and algal blooms. Suspended sediment concentrations at the sixth site did not increase. Stream and river buffers in the southern forest of Western Australia can be reduced to half their usual width without detrimental effects on watercourses as long as logging is confined to the dry season.

Brazier, J.R., and G.W. Brown. 1973. *Buffer strips for stream temperature control.* Oregon State University, School of Forestry, Forest Research Laboratory. Research Paper 15.

This experiment explored the different characteristics of buffer strips that may be important in regulating stream temperature. These characteristics included commercial timber volume, width of the buffer strips, and canopy density along the path of the sunlight. Commercial timber volume alone was found not to be an important criterion for temperature control; nor is the width of the buffer strip an important criterion. For the small streams studied, the maximum shading ability of the average buffer strip was reached within a width of 80 feet. Standard 100- to 200-foot buffer strips will generally include more timber than necessary. Angular canopy density is the only single criterion a forester can use that will ensure adequate stream temperature control without overdesigning the buffer strip.

Brown, G.W. 1969. Predicting temperatures of small streams. *Water Resources Research.* 5:68-75.

Sections of three small streams in western Oregon, typical of streams in the forested regions of the Oregon Cascade and Coast Ranges, were studied to determine whether stream temperature could be accurately predicted. One section was heavily shaded and had a graved bottom, and the other sections were exposed to direct sunlight.

One exposed section had a rock bottom and the other had a gravel bottom. The author found that hourly temperatures of small streams can be accurately predicted using an energy balance. On the three study streams, hourly temperature changes of 0-16°F were predicted to within 1°F more than 90% of the time. On unshaded stretches, net radiation is the predominant energy source, while evaporation and convection account for less than 10% of the total energy exchange. Conduction of heat into the stream bottom is an important energy balance component on shallow streams having a bedrock bottom, where up to 25% of the energy absorbed by the stream may be transferred into the bed. Using this technique, foresters can control water temperature through manipulation of streamside vegetation.

Brown, G.W. 1970. Predicting the effect of clearcutting on stream temperature. *Journal of Soil and Water Conservation*. 25:11-13.

This paper presents a methodology for predicting the effects of clearcutting on stream water temperature. The author states that predicting the effects could be done by estimating maximum daily changes, rather than hourly changes which would require experience in micrometeorology and additional equipment. This paper presents a simple model for estimating the daily maximum changes assuming the following: the stream surface is uniformly exposed to direct sunlight, direct solar radiation dominates the net heat gain in small streams, maximum temperature will occur during midday hours on a clear day, and predicted solar input can be used to estimate heat input. Model equations are also presented in this paper. Much of the background to this work was published in Brown 1969 and Brown and Kryger 1970.

Brown, G.W., and J.T. Krygier. 1970. Effects of clearcutting on stream temperature. *Water Resources Research*. 6(4):1133-1140.

This study examined the effects of three forest management practices: fully clearcut, patch-cut with buffer strips, and unlogged on stream temperatures. Significant increases in stream temperature were observed in the clearcut watershed. The patch- cut watershed, which had buffer strips along the stream, did not have significantly greater water temperatures than the unlogged watershed. The results presented in this paper have been duplicated by many studies conducted since. Evidence suggests that leaving streamside buffers strips alleviates much of the temperature increase associated with timber harvest. Stream production impacts were not assessed in this study.

Curtis, J.G., D.W. Pelren, D.B. George, V.D. Adams, and J.B. Layzer. 1990. *Effectiveness of best management practices in preventing degradation of streams caused by silvicultural activities in Pickett State Forest, Tennessee.* Center for the Management, Utilization and Protection of Water Resources, Tennessee Technological University for the Tennessee Department of Conservation, Division of Forestry and the Tennessee Wildlife Resources Agency. 197 pages.

This study was undertaken to evaluate the effectiveness of BMPs applied to timber harvest operations in Pickett Forest. The effects on water quality, fish production, and macroinvertebrates, and the presence of herbicides in streams were studied. The BMPs employed were SMZs, road placement on ridgetops and high elevations, skid trails kept at least 14 m from streams, harvest during the driest season and maximum soil stability, logging of small, dispersed stands, seeding and mulching of disturbed areas, broad-based dips on the haul road, and a period of 10 years before the area would be logged again. Herbicides were applied to two stands. Hardwoods 75 mm dbh or less were thin line sprayed with a mixture of Garlon (active ingredients triclopyr and 2,4-D), Sidekick, and diesel fuel. Picloram was injected into all hardwoods 255 mm dbh or greater. Concentrations of herbicides in streams following the treatments was low: 2,4-D @ <0.02-0.08l. Based on available toxicity data, the levels detected were not biologically harmful. However, care is needed during application to minimize transport to surface waters. Extensive data relating to all of the BMPs employed during the study are presented in the paper.

DeBano, L.F. 1977. Influences of forest practices on water yield, channel stability, erosion, and sedimentation in the Southwest. In: *Proceedings of the Society of American Foresters*. pp. 74-78.

This paper presents information on the climate and hydrologically important vegetation types in the Southwest, the basin hydrologic processes affecting water yield and erosion, and the effect of cover manipulations, such as timber harvesting. Results are presented suggesting that water yield is not significantly improved by tree harvest unless small clearings or strips are created. In addition, clearing of trees increases the amount of erosion if storms of high intensity occur. The authors also recommend leaving dead and dying trees along the stream channel to control erosion into streams.

Erman, D.C., J.D. Newbold, and K.B. Roby. 1977. *Evaluation of streamside buffer strips for protecting aquatic organisms*. California Water Resources Center, University of California, Davis, California. 48 pages.

Sixty-two northern California streams were studied to evaluate the impact on invertebrate communities of logging with and without streamside buffer strips. Logging without buffer strips causes a significant change in benthic invertebrates compared to unlogged streams. Populations of Chironomidae, Baetis, and Nemoura increase, but overall invertebrate diversity is reduced in logged streams. Streams with buffer strips at least 30 m wide have invertebrate populations and physical characteristics indistinguishable from those of unlogged streams. Streams with buffer strips less than 30 m wide generally show the same impacts as streams without protective measures. Streams logged without protective measures at least 10 years prior to 1975 still had invertebrate diversities significantly lower than unlogged streams. The indices of taxonomic diversity and ecological distance were used. Numerous data tables and a full discussion of methods are provided.

Everest, F.H., R.L. Beschta, J.C. Scrivener, K.V. Koski, J.R. Sedell, and C.J. Cedarholm. 1987. Fine sediment and salmonid production: A paradox. In: *Streamside Management: Forestry and Fishery Interactions*. University of Washington. E.O. Salo, and T.W. Cundy, (eds.) Institute of Forest Resources No. 57. Chapter 4, pp. 98-142.

The purpose of this chapter is to examine state-of-the-art knowledge of the effects of sediment on salmonids The topics reviewed include forest management and sediment production, sediment processing by forest streams, forest management and sedimentation, variability of fine sediments in streambeds, effects of sedimentation on salmonids, natural mitigation of the effects of fine sediment in streams, sediment as a factor limiting salmonid populations, cumulative effects of sedimentation and fishing, and streamside management guidelines and sediment. Over 120 references are cited in this review.

Golden, M.S., C.L. Tuttle, J.S. Kush, and J.M. Bradley. 1984. *Forestry activities and water quality in Alabama: Effects, recommended practices, and an erosion-classified system.* Auburn University, Agricultural Experiment Station. Bulletin 555.

The report was prepared primarily as a source of information on the relationship between forestry practices and water quality, with orientation toward forestry practices prevalent in Alabama. Information on stream pollutants such as sediment, nutrients, pesticides, organic material, waste and litter, and temperature is provided. The review includes over 160 directly cited documents on these subjects. Also included in the report are recommendations of principles and practices designed to minimize the water quality impacts from Alabama forestry practices.

Grant, G. 1988. *The RAPID technique: A new method for evaluating downstream effects of forest practices on riparian zones*. USDA Forest Service, Pacific Northwest Forest and Range Experiment Station. General Technical Report PNW-220.

The RAPID (riparian aerial photographic inventory of disturbance) technique is a method for using measurements made on aerial photographs of patterns of riparian canopy disturbance to evaluate changes in channel conditions through time and to link such changes with their possible upstream causes. The RAPID technique provides resource specialists and managers with a relatively quick way of identifying stream reaches that are chronically or recently disturbed by a variety of channel processes, including increased peak flows and sedimentation from point and nonpoint sources. With examples from western Oregon, this paper describes how to apply the RAPID technique and analyze the results to evaluate downstream or cumulative effects of forest practices.

Grant, G. 1988. *The RAPID technique: A new method for evaluating downstream effects of forest practices on riparian zones*. USDA Forest Service, Pacific Northwest Research Station. General Technical Report PNW-GTR-220. 36 pages.

The riparian aerial photographic inventory of disturbance (RAPID) techniques is a method for using measurements made on aerial photographs of patterns of riparian canopy disturbance to evaluate changes in channel conditions and relating them to their possible upstream causes. This document uses examples from western Oregon to describe an application of the technique to evaluate downstream or cumulative effects of forest practices. Information is provided on background and theory, collecting data, analyzing and interpreting results, and conclusions.

Grant, J.W., J. Englert, and B.F. Bietz. 1986. Application of a method for assessing the impact of watershed practices: Effects of logging on salmonid standing crops. *North American Journal of Fisheries Management*. 6:24-31.

Total salmonid biomass is used as an indicator of stream habitat quality for salmonids and to assess the impacts of logging disturbances, including stream crossings, clearcuts, and bank modification, on the salmonid populations of 10 streams in New Brunswick and Nova Scotia. Salmonid biomass decreased significantly downstream of two stream crossings, probably due to increased siltation, while seven clearcuts and one bank modification along the other eight streams had no significant effect on salmonid biomass. Removal of the canopy cover was associated with increases in the fork length or weight at age, or both, of juvenile Atlantic salmon but had no consistent effect on the size at age of brook trout. The authors discuss the negative (increased sediment load) and positive (increased productivity) consequences of canopy cover removal, and emphasize that site- specific circumstances should be taken into account when determining how to manage streams.

Gregory, S.V., F.J. Swanson, W.A. McKee, and K.W. Cummins. 1991. An ecosystem perspective of riparian zones. *Bioscience*. 41(8): 540-551.

This paper presents a conceptual model of riparian zones that integrates the physical processes that shape valley floor landscapes, the succession of terrestrial plant communities, the formation of habitat, and the production of nutritional resources for aquatic ecosystems. Topics reviewed include geomorphology, structure of valley-floor landforms, riparian vegetation, riparian interactions (link between forest and stream), and ecosystem perspectives of riparian zones. Over 70 references are cited in the review.

Hartman, G., J.C. Scrivener, L.B. Holtby, and L. Powell. 1987. Some effects of different streamside treatments on physical conditions and fish population processes in Carnation Creek, a coastal rain forest stream in British Columbia. In: *Streamside Management: Forestry and Fishery Interactions*. E.O. Salo and T.W. Cundy (eds). University of Washington, College of Forest Resources, Seattle, Washington. pp. 330-372.

Carnation Creek has been studied continuously since 1971. During this time 41% of the watershed was logged. Three different streamside treatments conducted in the alluvial floodplain portion were evaluated: (1) an intensive treatment of clearcutting, felling of streambank alder, and yarding of felled trees and merchantable timber; (2) a careful treatment of clearcutting to the margin of the stream and felling of streambank alder, with no in-channel activity; and (3) a leave strip treatment in which a variable width strip of vegetation was left along the stream. Stream temperature increased due to logging. The decrease in volume and stability of large debris was accompanied by streambank erosion and straightening of the channel. This in turn caused a change in gravel quality in the lower sections of the stream. Coho and chum salmon egg-to-fry survival was lower following the first major storm following logging. Trout smolt numbers decreased, but coho smolts increased by 76% between 1976 and 1983. Afterward they decreased to prelogging levels.

Hawkins, C.P., M.L. Murphy, and N.H. Anderson. 1982. Effects of canopy, substrate composition, and gradient on the structure of macroinvertebrate communities in Cascade Range streams of Oregon. *Ecology*. 63:1840-1856.

The relationship between stream community structure and abundance and the density and type of riparian vegetation present is examined. Six streams in the western Cascade Mountains were studied between 1978 and 1979, and it was determined that neither the canopy nor the substrate strongly influenced the number of taxa. This paper presents limited data addressing the complexity of streamside forests and focuses almost exclusively on community structure. Numerous tables on community structure for the Western Cascades are provided.

Heede, B.H. 1985. Interactions between streamside vegetation and stream dynamics. In: *Conference on Riparian Ecosystems and their Management: Reconciling Conflicting Uses*. Tuscon, Arizona, April 16-18, 1985. pp. 54-58.

This paper investigates the interrelationship between vegetation and stream system hydraulics in a broad sense that considers water, sediment, geomorphology, riparian vegetation, and streamside ecosystems. A 5-year study was conducted to test a hypothesis that log steps formed by downed trees replace gravel bars to reduce bedload movement. Log steps were removed from the stream to see whether they would be replaced by gravel bars. Seventy-four percent were replaced by gravel bars. Fallen logs were found to dissipate flow energy, maintain channel stability, decrease bedload movement, and increase water quality. The study stream was located in a mixed conifer forest of the Arizona White Mountains at a 2700-m elevation.

Holtby, L.B. 1988. Effects of logging on stream temperatures in Carnation Creek, B.C. *Canadian Journal of Fisheries and Aquatic Sciences*. 45:502-515.

The objectives of this study were to quantify the effects of clearcut logging on stream temperatures in Carnation Creek and to quantify the effects of the logging-related component of those temperature changes on the coho salmon population. Forty-one percent of the basin of the creek was clearcut, increasing stream temperatures in all months of the year. As a result, coho salmon emerged earlier and increased the length of their summer growing season by up to 6 weeks. Over-winter survival improved as a result of increased growth by the fall. Warmer spring temperatures were also associated with earlier seaward migration of smolts, probably resulting in decreased smolt-to-adult survivals. For this analysis, the author used a linked series of models to predict the effects of logging on

stream temperatures and then the effects of those temperatures on critical coho life history events. A life history model was used to quantify the effects of stream temperature changes related to logging on the population size of adult coho salmon. The author concludes: (1) habitat perturbations can have quantifiable effects on fish populations; (2) habitat alteration can affect more than one life stage simultaneously and in opposite directions; (3) the effects of perturbations at one life stage can persist throughout the remainder of the life cycle; and (4) for anadromous fish species, the effects of habitat perturbations during freshwater rearing can persist into the marine phase.

Koski, K.V. Riparian zone functions and interactions with sediment. In: *Proceedings of Technical Workshop on Sediments*. Corvallis, Oregon, February 3-7, 1992. U.S. Environmental Protection Agency and USDA Forest Service.

This paper presents information on how riparian zones can serve as a management measure to minimize sediment pollution and maintain high-quality aquatic habitat through the following functions: filter strip, woody debris, and streambank and stream channel stability. The focus of this paper is on Alaska and the Pacific Northwest. Information on the linkage between the riparian zone and the stream ecosystem is presented. A detailed review of nearly 70 references is included.

Kundt, J.F. 1988. *Streamside forests: The vital, beneficial resource*. U.S. Fish and Wildlife Service and University of Maryland, Cooperative Extension Service.

This cooperative Extension Service publication discusses the benefits of streamside forests, including improving water quality, maintaining wildlife and fish populations, and providing recreational and commercial uses. The paper briefly discusses how the public can become involved in the protection of streamside forests. Numerous photographs demonstrate the points raised, and simple graphics explain how streamside forests help to remove sediment, nitrogen, and phosphorus from runoff.

Lantz, R.L. 1971. *Guidelines for stream protection in logging operations*. Oregon State Game Commission, Portland, Oregon. 29 pages.

This report reviews why certain logging practices in the West Coast Douglas fir region are more desirable than others for protecting fish habitat and water quality. Streams can be protected to a large extent by (1) keeping streamside vegetation intact and (2) taking precautions to eliminate or minimize soil disturbance and erosion, particularly that resulting from roads. The report emphasizes the need to change or eliminate some traditional logging practices due to the resource conflicts between and interdependence of fisheries and timber production. The report addresses the freshwater requirements of salmon and trout, the importance of protecting stream habitat, and forestry practices that can be used to protect fish habitat. The author discusses streamside management areas and road location, construction, and maintenance practices.

Lowrance, R., R. Leonard, and J. Sheridan. 1985. Managing riparian ecosystems to control nonpoint pollution. *Journal of Soil and Water Conservation*. 40(1):87-91.

This article provides a general discussion of riparian zones and factors affecting their ability to control NPS pollution. Hydrological and vegetative factors affecting pollutant removal are discussed, and a case study of an NPS control using a riparian zone buffer is presented. Riparian zone management is related to regional differences in land use and vegetative characteristics.

Maser, C., R.F. Tarrant, J.M. Trappe, and J.F. Franklin (tech. eds.). 1988. *From the forest to the sea: A story of fallen trees*. General Technical Report PNW-GTR-229. USDA Forest Service and USDI Bureau of Land Management. 153 pages.

This document presents a synthesis of existing research information on the impact of fallen trees

in various stages on ecological diversity and offers some hypotheses and conclusions. The information presented is intended to help resource managers make decisions on the loss of woody debris on habitat diversity and ecological processes. The following chapters are included: coarse woody debris in forests and plantations of coastal Oregon; what is known about large trees that fall to the forest floor and into streams and rivers, estuaries, the sea, and coastal beaches; and options for public lands. Nearly 350 references are cited in this document.

McGurk, B.J. 1989. Predicting stream temperature after riparian vegetation removal. In: *Proceedings of the California Riparian Systems Conference*. Davis, California, September 22-24, 1988. USDA Forest Service, Pacific Southwest Forest and Range Station. pp. 157-164.

This paper reports on field work at two streams in California that evaluates Brown's stream temperature change prediction technique (Brown 1970) and an empirical equation developed in Oregon. One of the sites was a clearcut site and the other was a mature fir forest. Larger diurnal temperature fluctuations were observed in the water flowing through the clearcut site than in the undisturbed area above the clearcut site. The mature fir forest also had a large diurnal water temperature variation. A 5.6 °C temperature rise was observed through a 380-m clearcut that exposed the stream channel, and Brown's equation predicted a change of 6.1 °C. Brown's exposed surface area model may be a good choice for land managers because it requires a minimum of field data that are relatively simple to obtain. A technique that includes the effect of shade recovery after timber harvest is suggested for use during long-range harvest planning.

Meehan, W.R. 1970. *Some effects of shade cover on stream temperature in southeast Alaska*. Research Note PNW-113. USDA Forest Service, Pacific Northwest Forest and Range Experiment Station.

This study was done to determine the role of streamside vegetation under the cool, moist conditions of southeast Alaska. Study objectives were (1) to develop a practical method for measuring the effects of shade on stream temperature and (2) to conduct exploratory studies of the relationship between stream cover and water temperature. The study was conducted in small streams in the northern part of southeast Alaska. Measurements of stream temperature were taken on sunny and completely overcast days and along unshaded and shaded stretches of the streams. Weather information for sampling days and temperature data are tabulated. Temperature measurements demonstrated that streamside vegetation plays a definite role in maintaining cool stream temperatures. The author notes that temperature increases in streams after clearcutting in southeast Alaska do not approach levels lethal to fish. The precise role of streamside vegetation in the aquatic environment needs further research in order for fisheries and land managers to prescribe clearcutting for optimum timber and fisheries production.

Meehan, W.R., F.J. Swanson, and J.R. Sedell. 1977. *Influences of riparian vegetation on aquatic ecosystems with particular reference to salmonid fishes and their food supply*, In: Importance, Preservation and Management of Riparian Habitat: A Symposium. USDA Forest Service, Rocky Mountain Forest and Range Experiment Station. General Technical Report RM-43. pp. 137-145.

This paper presents a review of the role of riparian vegetation on streamwater quality and salmonid habitat. Topics included the benefits of riparian zones, such as stream shade, channel and bank stability, source of woody debris. Temporal and spatial changes in the riparian zone, the indirect influences of riparian vegetation on salmonids, and the effects of man's activities are also discussed.

Megahan, W.F., and P.N. King. 1985. Identification of critical areas of forest lands for control of nonpoint sources of pollution. *Environmental Management*. 9(1):7-18.

The authors present a critical areas approach to controlling NPS pollution from forestlands.

Critical areas include sites with high mass and surface erosion hazards, overland flow areas, and the riparian zone. Most NPS pollution problems on forestlands can be controlled by identifying these critical areas and carefully planning their management. The discussion of these three critical areas is accompanied by guidelines for identifying them and examples of land use constraints that might be applied; for instance, limiting activities causing severe soil disturbance and road construction requiring large cutslopes where surface erosion hazards are high.

Miller, E. 1987. *Effects of forest practices on relationships between riparian area and aquatic ecosystems*, In: Managing Southern Forest for Wildlife and Fish: A Proceedings. General Technical Report SO-65. USDA Forest Service, Southern Forest Experiment Station. pp. 40-47.

This paper presents an outline of the relationship between riparian and stream communities to help foresters better understand the objectives underlying streamside management designs. Topics reviewed in this paper include food energy, large organic debris, stream temperature, streambank and bed stability, terrestrial/aquatic buffer, and streamflow. These topics are discussed both as they relate to management of the riparian forest and riparian vegetation and the stream environment. Over 40 references are cited in this paper.

Murphy, M.L., J. Heifetz, S.W. Johnson, K.V. Koski, and J.F. Thedinga. 1986. Effects of clear-cut logging with and without buffer strips on juvenile salmonids in Alaskan streams. *Canadian Journal of Fisheries and Aquatic Sciences*. 43(8):1521-1533.

To assess short-term effects of logging on juvenile *Oncorhynchus kisutch*, *Salvelins malma*, *Salmo gairdneri*, and *Salmo clarki* in southeastern Alaska, the fish density and habitat in summer and winter were compared in 18 streams in old-growth forest and in clearcuts with and without buffer strips. The study concludes that clearcutting may increase fry abundance in summer in some streams by increasing primary production, but may reduce abundance of parr in winter if debris is removed. Use of buffer strips maintains or increases debris, protects habitat, allows increased primary production, and can increase abundance of fry or parr. The report also contains references to more than 50 other papers.

Murphy, M.L., and K.V. Koski. 1989. Input and depletion of woody debris in Alaska streams and implications for streamside management. *North American Journal of Fisheries Management*. 9(4):427-436.

Natural rates of input and depletion of large woody debris (LWD) in southeast Alaska streams were studied to provide a basis for managing streamside zones to maintain LWD for fish habitat after timber harvest. Input and depletion rates were inversely proportional to LWD diameter and ranged from 1%/year for large LWD in all stream types to 3%/year for small LWD in large, high-energy, bedrock-controlled streams. A model indicated that 90 years after clear-cut logging without a stream-side buffer strip large LWD would be reduced by 70% and recovery to prelogging levels would take more than 250 years. Because nearly all LWD is derived from within 30 m of the stream, the use of a 30-m wide, unlogged buffer strip along both sides of the stream during timber harvest should maintain LWD.

Murphy, M.L., K.V. Koski, J. Heifetz, S.W. Johnson, D. Kirchhofer, and J.F. Thedinga. 1984. Role of large organic debris as winter habitat for juvenile salmonids in Alaska streams. In: *Western Proceedings of the 64th Annual Conference of the Western Association of Fish and Wildlife Agencies*. Victoria, British Columbia, July 16-19, 1984. pp. 251-262.

To assess short-term effects of logging on juvenile Oncorhynchus kisutch, Salvelins malma, Salmo gairdneri, and Salmo clarki in southeastern Alaska, the fish density and habitat in summer and winter were compared in 18 streams in old-growth forest and in clearcuts with and without buffer strips. Buffered reaches did not consistently differ from old-growth reaches; clearcut reaches had more periphyton, lower

channel stability, and less canopy, pool volume, large woody debris, and undercut banks than old-growth reaches. Fry abundance was related to the amount of large woody debris. Clearcutting may increase fry abundance in summer in some streams by increasing primary production, but may reduce abundance of parr in winter if debris is removed. Use of buffer strips maintains or increases debris, protects habitat, allows increased primary production, and can increase abundance of fry and parr. This paper presents partial results of a larger study; the companion paper is Thedinga, Murphy, Heifetz, Koski, and Johnson, 1989. This report presents significant amounts of data and conclusions and contains references to more than 50 other papers.

Narver, D.W. 1971. Effects of logging debris on fish production. In: *Proceedings of the Symposium: Forest Land Uses and Stream Environment.* , 19-21 October, 1970. J.T. Krygier and J.D. Hall (eds.). Oregon State University, Corvallis, Oregon. pp. 100-111.

Stream salmonids (eight species of Pacific salmon, trout, and char) are discussed in relation to their environmental requirements and the possible impact of logging debris on their production. The emphasis is on small streams because of their great importance as nursery and spawning areas for certain species and because they may be more susceptible to damage than larger streams or rivers. Extensive use is made of pertinent literature. The author concludes that accumulations of logging debris in small streams can have serious effects on the production of salmonid fishes.

Neary, D.G., N.B. Comerford, and L.W. Swift. Land and riparian interactions with sediment in the southern United States. In: *Proceedings of Technical Workshop on Sediments.* Corvallis, Oregon, February 3-7, 1992. U.S. Environmental Protection Agency and USDA Forest Service.

This paper presents a review of the literature and includes the following: a synthesis of research results in current literature on buffer zones, determining the utility of buffer zones in protecting forested wetlands and surface waters from the sediment nonpoint source pollution impacts of silvicultural operations, and identifying information gaps and research needs. Some review information from studies on the protection afforded by buffer strips is presented.

New York State Department of Environmental Conservation, Division of Water. 1986. *Stream corridor management: A basic reference manual.*

Chapter 6 (Best Management Practices) provides an in depth discussion of BMPs relating to stream corridor management. This document discusses numerous BMPs not directly related to forestry, but the information is generally useful for forestry applications. Many standard forestry stream BMPs, such as crossings and culverts, are discussed also. Contents include: Stream Problems, Techniques for Assessing Land Use Impacts on Water Quantity and Quality, Steps for Solving the Problem (A Planning and Problem-solving Framework), Stream Conservation Options and Choices for Local Government, Best Management Practices, and Implementing a Program in Your Community.

Newbold, J.D., D.C. Erman, and K.B. Roby. 1980. Effects of logging on macroinvertebrates in streams with and without buffer strips. *Canadian Journal of Fisheries and Aquatic Sciences.* 37: 1076-1085.

The impact of logging with and without buffer strip protection on stream macroinvertebrates was examined through comparisons of community structure in commercially logged and control watersheds throughout northern California. A nonparametric test of community dissimilarities within matched blocks of two control and one or two treated stations showed significant logging effects on unprotected streams using certain indices but not using others. Shannon diversity in unprotected streams was lower than in control streams. Densities of total macroinvertebrate fauna were higher in unprotected streams than in controls. Diversity in wide-buffered streams was greater than in streams without buffers, indicating effective protection from logging effects. The data indicate a clear association between buffer

strip width and effectiveness and suggest that most or all of the impact on the benthos was prevented by buffer strips of 30 m or wider. These findings are compared to those of other studies on buffer strip width and effectiveness, with possible explanations of discrepancies.

Palfrey, R., and E. Bradley. *Natural buffer areas study*. Maryland Department of Natural Resources, Tidewater Administration, Coastal Resources Division. 30 pages.

This report reviews the potentially detrimental impacts of land uses adjacent to watercourses and describes how buffer areas can mitigate these impacts. Environmental factors (e.g., type of vegetation, width of buffer area, slope, and height of vegetation) that determine how effectively buffer areas function are discussed. Recommendations regarding the establishment of buffer areas in the State of Maryland are presented; for example, buffer strip widths of 100 feet. Subtopics covered in the report include the use of buffer areas for sediment control, storm water runoff control, nutrient filters, and temperature moderators, and their value as food sources and transition zones.

Patric, J.H. 1980. Effects of wood products harvest on forest soil and water relations. *Journal of Environmental Quality*. 9(1):73-80.

This report presents the results of nearly three decades of research on a watershed in the Fernow Experimental Forest in north-central West Virginia. Selection harvests between 1958 and 1968 had a negligible effect on water properties. A clearcut leaving a buffer strip in 1969-70 had no effect on stormflow or stream temperature, but increased water yield by 38% the first year after cutting. Concentrations of sediment, nitrate, Ca, Mg, K, and Na in streamflow increased slightly. The buffer strip was cut and the stream channel cleared in 1972, increasing water yield by 9% and raising stream temperature by as much as 7.8 °C. Regrowth over the entire watershed reduced all effects on water within 2 years after each treatment. Historical data from the studies reviewed are presented for parameters such as turbidity and precipitation.

Patton, D.R. 1973. *A literature review of timber harvesting effects on stream temperatures: Research needs for the Southwest*. USDA Forest Service, Rocky Mountain Forest and Range Experiment Station. Research Note RM-249. 4 pages.

The paper focuses on the effect of temperature on fisheries. Water temperature affects fish by changing their metabolic rate and the oxygen content of water, and influencing hatching and development time and migration. Creating a more open forest in the water-producing zone can change water temperature in shallow, low-volume streams. The author concludes that research is needed on how timber harvesting affects water temperature to produce guidelines to meet FWPCA standards for cold-water fish. Suggested research topics are identification of perennial streams with temperature marginally high; the effect of timber harvesting on water temperature; determination of temperature ranges of rare and endangered fish; and the importance of riparian vegetation in maintaining aquatic habitat.

Platts, W.S., and R.L. Nelson. 1989. Stream canopy and its relationship to salmonid biomass in the intermountain West. *North American Journal of Fisheries Management*. 9:446-457.

Several riparian habitat components, including canopy density, light intensity, unobstructed sun arc, and average potential daily thermal input in grazed and ungrazed portions of representative streams in the northern Rocky Mountains and the Great Basin of the western United States, were measured. The objectives were to assess prevailing stream canopy conditions and to determine to what extent these habitat components were correlated with salmonid biomass. Unobstructed sun arc was significantly correlated with thermal input and was the best overall predictor of salmonid biomass per unit volume. Thermal input was a better predictor of salmonid biomass per unit volume in the Great Basin than in the Rocky Mountains. Mean estimates of fish biomass per unit volume were better related to stream canopy attributes than to biomass estimates based on stream surface area.

Rishel, G.B., J.A. Lynch, and E.S. Corbett. 1982. Seasonal stream temperature changes following forest harvesting. *Journal of Environmental Quality*. 11(1):112-116.

The objectives of this study were to document changes in water temperature of small headwater streams following a clearcut- herbicide treatment and a commercial clearcut harvest. The study was designed to provide data on the maximum expected change in stream temperature following forest cover removal and to evaluate the effectiveness of a buffer zone on the commercial clearcut site in controlling stream temperature changes. The average monthly maximum temperature change in the clearcut-herbicide treatment stream was 4.4 °C, and the highest recorded temperature in the stream was 32 °C, compared to 22 °C on an adjacent forested watershed. On the clearcut watershed with a buffer strip, only slight changes in stream temperature were observed. The average monthly maximum temperature increase was < 1 °C, and the highest temperature recorded was 23 °C.

Robison, E.G., and R.L. Beschta. 1990. Identifying trees in riparian areas that can provide coarse woody debris to streams. *Forest Science*. 36(3):790-801.

This paper presents a method for determining the probability that a tree, upon falling, will provide coarse woody debris to a stream and relates this probability to the basal area factor (BAF) obtained by a wedge device or prism so that specific leave trees can be easily and consistently selected in the field. The prediction method developed assumes (1) a tree has an equal chance of falling in any direction; (2) there are equal numbers of trees both larger and smaller than a tree of "average" diameter; (3) the potential of a tree to provide debris is evaluated for the time it is evaluated, ignoring future growth; and (4) the entire tree, with rootwad and bole, will fall (breakage is not considered). Formulas and computations are fully explained, and Douglas fir is used to illustrate the application.

Salo, E.O., and T.W. Cundy (eds.). 1987. *Streamside management forestry and fishery interactions*. College of Forest Resources, University of Washington. 471 pages.

The results of a symposium held to synthesize technical information on forestry and fisheries interactions and to discuss regulatory changes governing forest management practices are presented. Contents include: Variables Related to Fish Habitat (e.g., sediment, woody debris, temperature); Forest Management of the Streamside Zone; Case Studies - Effects of Timber Harvest on Fishery Resources; and Panel Discussions. The presented papers focus for the most part on the Pacific Northwest. The panel discussions concern economics and social considerations, streamside management zone BMPs, and policy perspectives. This collection of papers provides complete discussion of the interdependence of forestry and fisheries resources.

Sedell, J.R., P.A. Bisson, F.J. Swanson, and S.V. Gregory. 1988. *What we know about large trees that fall into streams and rivers*, In: From the forest to the sea: A story of fallen trees. USDA Forest Service, Pacific Northwest Forest and Range Experiment Station. General Technical Report PNW-229. pp. 47-81.

The physical and biological characteristics of forested streams in the Northeast are discussed at length. The history of logging activities, riparian management, and ecosystem structure are compared; the effects of removed and downed timber on habitat are emphasized. Physical variables and stream debris frequency were studied for their effects on fish species and habitat development. The data indicate that complete removal of timber from any stream has an adverse impact on fish-dependent food chains and sediment capture. Overall, this article addresses stream debris dynamics and the effects on indigenous species. The document contains numerous figures and tables.

Steinblums, I., H.A. Froehlich, and J.K. Lyons. 1984. Designing stable buffer strips for stream protection. *Journal of Forestry*. 82(1):49-52.

Failure of buffer strips due to blowdowns, disease, and logging is a recurring problem and can cause stream channels to load with debris, leading to sediment storage or erosion. This article reports a study of environmental factors that affect buffer strip stability and stream shading. On 40 streamside buffer strips in the Cascade Mountains of western Oregon, buffer strip stability was found to be a function of one vegetation and six topographic equation variables, and shading was related to three characteristics of buffer strips and one of adjacent clearcuts. Topographic maps and aerial photographs were used to supplement field observations. Stability and shading effectiveness of proposed buffer strips can be evaluated using the equations presented in the paper and data collected through site reconnaissance and topographic maps.

Swanson, F.J., S.V. Gregory, J.R. Sedell, and A.G. Campbell. 1982. *Land-water interactions: The riparian zone*, In: Analysis of coniferous forest ecosystems in the western United States. Edmonds, R.L., (ed.) US/IBP Synthesis Series 14:267-291.

This chapter presents a general review and synthesis of concepts regarding the riparian zone, with emphasis placed on conditions observed in mountain streams and small rivers. Topics discussed include the structure and composition of riparian vegetation, functions of the riparian zone, spatial variation of terrestrial/ aquatic interfaces, temporal variation in the riparian zone, and a summary of these concepts.

Swift, L.W., Jr. 1982. Duration of stream temperature increases following forest cutting in the southern Appalachian Mountains. *Water Resources Bulletin*. 18(6):273-275.

The effect of clearcutting riparian areas on water temperature was examined at the Coweeta Hydrologic Laboratory, North Carolina. During the first two summers of the study, stream temperatures at the downstream edge of clearcut was increased by an average of 3.3 °C. The increase declined the next three summers to 1.2 °C. In addition, the daily range of water temperatures (maximum minus minimum) increased for all 5 years after clearcut. The authors also used a method by Brown (1970) to estimate water temperature changes and found that the method significantly overestimated the actual increase.

Thedinga, J.F., M.L. Murphy, J. Heifetz, K.V. Koski, and S.W. Johnson. 1989. Effects of logging on size and age composition of juvenile coho salmon and density of pre-smolts in southeast Alaska streams. *Canadian Journal of Fisheries and Aquatic Science*. 46:1383-1391.

Short-term effects of logging on age composition and size of juvenile coho salmon (*Onchrhynchus kisutch*) were studied in 18 streams in southeast Alaska in 1982 and 1983. Studies were in old-growth forests where stream reaches had been clearcut with or without buffer strips. The number of fry in summer and winter was proportionately higher in clearcut and buffered reaches than in undisturbed reaches. A higher percentage of large (≥75 mm) fry remained in buffered reaches than in clearcut and undisturbed reaches. Therefore, the density of fry that were potentially large enough to become smolts the next spring was greater in buffered reaches. The larger fry in the buffered and clearcut reaches compared with undisturbed reaches were probably the result of earlier fry emergence resulting from increased water temperature. This paper presents partial results of a larger study. The companion paper is Murphy, Heifetz, Johnson, Koski and Thedinga, 1986.

USDA Forest Service. 1987. *Soil and water resource management: A cost or a benefit? Approaches to watershed economics through example*. 99 pages.

Analysis procedures for estimating the economic benefits of soil and water resource management have been developed. This report discusses the procedures and the data and information required to employ them. The analysis procedures focus

on the following management areas: timber, forage, fish, enhanced water quality, and road construction and maintenance. The procedures and economics of soil and water management are demonstrated in this document with 16 examples.

Anderson, H.W., M.D. Hoover, and K.G. Reinhart. 1976. *Forests and water: Effects of forest management on floods, sedimentation, and water supply*. USDA Forest Service. General Technical Report PSW-18. 115 pages.

Andrus, C., and H.A. Froehlich. 1988. Riparian forest development after logging or fire in the Oregon Coast Range: Wildlife habitat and timber value. In:: *Streamside Management: Riparian Wildlife and Forestry Interactions*. University of Washington. Institute of Forest Resources. No. 59. pp. 139-151.

Berry, J.D. 1975. Modeling the impact of logging debris in streams. In: *Proceedings of the Watershed Management Symposium*. Logan, Utah, August 11-13, 1975. American Society of Civil Engineers, Division of Irrigation and Drainage. pp. 676-680.

Beschta, R.L. 1979. Debris removal and its effects on sedimentation in an Oregon Coast Range stream. *Northwest Science*. 53:71-77.

Beschta, R.L., and J. Weatherred. 1984. *TEMP-84: A computer model for predicting stream temperatures resulting from the management of streamside vegetation*. U.S. Department of Agriculture, Watershed Systems Development Group, Fort Collins, Colorado. WSDG-AD-00009.

Bilby, R.E. 1981. Role of organic debris dams in regulating the export of dissolved and particulate matter from a forested watershed. *Ecology*. 62(5):1234-1243.

Brown, G.W., and J.T. Krygier. 1967. Changing water temperatures in small mountain streams. *Journal of Soil and Water Conservation*. 22:242-244.

Burton, T.M., and G.E. Likens. 1973. The effect of strip-cutting on stream temperatures in the Hubbard Brook Experimental Forest, New Hampshire. *BioScience*. 23:433-435.

Corbett, E.S., J.A. Lynch, and W.E. Sopper. 1978. Timber harvesting practices and water quality in the eastern United States. *Journal of Forestry*. 76(8):484-488.

Curtis, W.R. 1966. Forest zone helps minimize flooding in the Driftless Area. *Journal of Soil and Water Conservation*. 21:101- 102.

Gregory, S.V., G.A. Lamberti, D.C. Erman, K.V. Koski, M.L. Murphy, and J.R. Sedell. 1987. Influence of forest practices on aquatic production. In: *Streamside Management: Forestry and Fishery Interactions*. University of Washington. E.O. Salo, and T.W. Cundy, (eds.) Institute of Forest Resources No. 57. Chapter 7, pp. 233-255.

Hewlett, J.D., and J.C. Fortson. 1982. Stream temperature under an inadequate buffer strip in the Southeast Piedmont. *Water Resources Bulletin*. 18(6):983-988.

Koski, K.V., and M.L. Murphy. 1989. *Summary of NMFS Auke Bay Laboratory research on streamside management issues*.

Megahan, W.F. 1983. Appendix C: Guidelines for reducing negative impacts of logging. In: *Tropical watersheds: Hydrologic and soils response to major uses or conversions*. L.S. Hamilton and P.N. King (eds.). Westview Press, Boulder, Colorado. pp. 143-154.

NCASI. 1987. *Managing Oregon's riparian zone for timber, fish and wildlife*. National Council of the Paper Industry for Air and Stream Improvement. Technical Bulletin No. 514.

Patton, D.R. 1980. *The effect of streamside forest harvesting on stream temperature in the Georgia mountains*. Master's Thesis, University of Georgia, School of Forest Resources, Athens, Georgia. 49 pages.

Payne, N.J., J.C. Feng, and P.E. Reynolds. 1990. Off-target deposits and buffer zones required around water for aerial glyphosate applications. *Pesticide Science*. 30(2):183-198.

Payne, N.J., B.V. Helson, K.M.S. Sundaram, and R.A. Fleming. 1988. Estimating buffer zone widths for pesticide applications. *Pesticide Science*. 24(2):147-161.

Potts, D.F., and B.K.M. Anderson. 1990. Organic debris and the management of small stream channels. *Western Journal of Applied Forestry*. 5(1):25-28.

Rood, S.B., and J.M. Mahoney. 1990. Collapse of riparian poplar forests downstream from dams in western prairies: Probable causes and prospects for mitigation. *Environmental Management*. 14(4): 451-464.

Salo, E.O., and T.W. Cundy (eds.). 1987. *Streamside management forestry and fishery interactions*. College of Forest Resources, University of Washington. 471 pages.

Sedell, J.R., et al. 1982. Importance of streamside forests to large rivers: The isolation of the Willamette River, Oregon, USA from its floodplain by snagging and streamside forest removal. *Internationle Vereingung fur theoretische und angewandte Limnolgia Verhanlungen*. 22:1828-1834.

Snyder, G.G., H.F. Haupt, and G.H. Belt, Jr. 1975. *Clearcutting and burning slash alter quality of stream water in northern Idaho*. USDA Forest Service. Research Paper INT-168. 34 pages.

Swank, G.W. 1985. Streamside management units in the Pacific Northwest. In: *Conference on Riparian Ecosystems and Their Management: Reconciling Conflicting Uses*. USDA Forest Service. April 16-18. pp. 435-438.

Swanson, F.J., and G.W. Lienkaemper. 1978. *Physical consequences of large organic debris in Pacific Northwest streams*. USDA Forest Service, Pacific Northwest Forest and Range Experiment Station. General Technical Report PNW-69.

Swift, L.W., Jr., and J.B. Messer. 1971. Forest cuttings raise temperatures of small streams in the southern Appalachians. *Journal of Soil and Water Conservation*. 26:111-116.

USDA Forest Service. 1991. *Riparian forest buffers: Function and design for protection and enhancement of water resources*.

USEPA and USDA Forest Service. *Proceedings of Technical Workshop on Sediments*. Corvallis, Oregon, February 3-7, 1992. U.S. Environmental Protection Agency and USDA Forest Service.

Wong, S.L., and R.H. McCuen. 1981. *The design of vegetative buffer strips for runoff and sediment control*. University of Maryland, Department of Civil Engineering.

BMPs AND SPECIFICATIONS

Bacon, C.G. 1989. Riparian silviculture: Active riparian management for multiple resources. In: *Forestry on the Frontier, Proceedings of the 1989 Society of American Foresters National Convention*. Spokane, Washington. pp. 99-102.

This paper presents an overview of riparian silviculture and its potential impacts on water quality, fisheries, and wildlife. It provides a general review of national perspectives on riparian silviculture and give specific examples of regional management and research efforts.

Bramhall, J.W. 1989. Riparian systems and forest management- changes in harvesting techniques and their effects on decomposed granitic soils. In: *Proceedings of the California Riparian Systems Conference*. Davis, California, September 22-24, 1988. USDA Forest Service, Pacific Southwest Forest and Range Experiment Station. General Technical Report PSW-110. pp. 176- 179.

In the 1950s, timber on steep granitic terrain in Trinity County, California, was harvested by using the logging techniques of the time. After Trinity Dam was built in the 1960s, it became evident these techniques were not suited to quality riparian habitat and healthy anadromous fisheries. Since adoption of the Z'berg-Nejedly Forest Practice Act in 1973, efforts have been expended to repair damages to riparian vegetation and to find forest practices compatible with granitic soils. This article lists BMPs developed for timber harvesting on granitic soils in 1986, focusing on protection of the riparian zone. No effectiveness information is given.

Corbett, E.S., and J.A. Lynch. 1985. Management of streamside zones on municipal watersheds. In: *Conference on Riparian Ecosystems and their Management: Reconciling Conflicting Uses*. Tucson, Arizona, April 16-18. pp. 187-190.

This paper focuses on the management practices, such as maintenance of buffer zones on the edges of reservoirs, that may be used to maintain the quality of municipal watersheds. This generic paper on the role and impact of buffer zones as a best management practice includes references to over 20 articles.

Cubbage, F.W., and C.E. DeForest. 1991. BMPs and harvesting regulations in the South. In: *Forestry and the Environment...Engineering Solutions*. New Orleans, Louisiana, June 4-6, 1991. American Society of Agricultural Engineers.

This paper provides an overview of best management practices that apply to forestry practices, including road construction, timber harvest, stream crossing, streamside management zones, and maintenance and retiring of structures. This paper presents basic information about the types of BMPs that may be used. The paper introduces regulatory trends in the states of Florida, North Carolina, West Virginia, and Maryland, as well as regulatory trends in forested wetlands.

Garland, J.J. 1987. Aspects of practical management in the streamside zone. In: *Streamside Management: Forestry and Fishery Interactions*. University of Washington, College of Forest Resources, Seattle, Washington. E.O. Salo and T.W. Cundy (eds.). pp. 277-288.

Management decisions in the streamside zone may profoundly affect practices in adjacent areas (reaching to the ridge top and beyond). Issues of technical, economic, and institutional (administrative) feasibility are associated with all management practices. Harvesting systems and site conditions (terrain, timber type, etc.) must be matched to be feasible. Decision arenas for resolution of conflicts involving facts and values are identified.

Heede, B.H. 1985. Interactions between streamside vegetation and stream dynamics. In: *Conference on Riparian Ecosystems and their Management: Reconciling Conflicting Uses*. Tuscon, Arizona, April 16-18, 1985. pp. 54-58.

This paper investigates the interrelationship between vegetation and stream system hydraulics in a broad sense that considers water, sediment, geomorphology, riparian vegetation, and streamside ecosystems. A 5-year study was conducted to test a hypothesis that log steps formed by downed trees replace gravel bars to reduce bedload movement. Log steps were removed from the stream to see whether they would be replaced by gravel bars. Seventy-four percent were replaced by gravel bars. Fallen logs

were found to dissipate flow energy, maintain channel stability, decrease bedload movement, and increase water quality. The study stream was located in a mixed conifer forest of the Arizona White Mountains at a 2700-m elevation.

Heede, B.H. 1990. *Vegetation strips control erosion in watersheds*. Research Note RM-499. USDA Forest Service, Rocky Mountain Forest and Range Experiment Station.

An analysis was conducted on data collected to determine the effects of vegetation strips on erosion control. The data was collected from southwestern ponderosa pine forests, pinyon-juniper, and chaparral. In the ponderosa pine, 61 times more sediment was delivered when buffer strips were missing. This factor was 18 and 277 for pinyon-juniper and chaparral, respectively. Overland flow was also diminished from areas with buffer strips. No statistical analysis was conducted on the data.

Lantz, R.L. 1971. *Guidelines for stream protection in logging operations*. Oregon State Game Commission, Portland, Oregon. 29 pages.

This report reviews why certain logging practices in the West Coast Douglas fir region are more desirable than others for protecting fish habitat and water quality. Streams can be protected to a large extent by (1) keeping streamside vegetation intact and (2) taking precautions to eliminate or minimize soil disturbance and erosion, particularly that resulting from roads. The report emphasizes the need to change or eliminate some traditional logging practices due to the resource conflicts between and interdependence of fisheries and timber production. The report addresses the freshwater requirements of salmon and trout, the importance of protecting stream habitat, and forestry practices that can be used to protect fish habitat. The author discusses streamside management areas and road location, construction, and maintenance practices.

Lowrance, R., R. Leonard, and J. Sheridan. 1985. Managing riparian ecosystems to control nonpoint pollution. *Journal of Soil and Water Conservation*. 40(1):87-91.

This article provides a general discussion of riparian zones and factors affecting their ability to control NPS pollution. Hydrological and vegetative factors affecting pollutant removal are discussed, and a case study of an NPS control using a riparian zone buffer is presented. Riparian zone management is related to regional differences in land use and vegetative characteristics.

McClimans, R.J. 1980. Best management practices for forestry activities. In: *Watershed Management*. Boise, Idaho, July 21-23, 1980. C.W. Johnson (ed.). American Society of Civil Engineers, Irrigation and Drainage Division, Committee on Watershed Management. pp. 694-705.

This paper defines critical combinations of site conditions for which BMPs are needed to minimize adverse impacts on soil and water resources. The document also includes assessment methodologies, as well as charts and graphs for the selection and application of appropriate BMPs. Forest practices are grouped according to their capacity to cause water pollution, the nature of the more commonly applied BMPs to control pollution, and site considerations. Guides, based on slope of land and distance from water, are provided to determine whether a particular BMP is necessary for the particular group of activities. Graphs developed to determine BMP applicability are presented, and the selected BMPs are discussed for each group of forest activities. Specifications for some BMPs are also presented.

Miller, E. 1987. *Effects of forest practices on relationships between riparian area and aquatic ecosystems*, In: Managing Southern Forest for Wildlife and Fish: A Proceedings. General Technical Report SO-65. USDA Forest Service, Southern Forest Experiment Station. pp. 40-47.

This paper presents an outline of the relationship between riparian and stream communities to help foresters better understand the objectives underlying streamside management designs. Topics reviewed in this paper include food energy, large organic debris, stream temperature, streambank and bed stability, terrestrial/aquatic buffer, and streamflow. These topics are discussed both as they relate to management of the riparian forest and riparian vegetation and the stream environment. Over 40 references are cited in this paper.

Neuman, L. 1987. Silviculture and best management practices. In: *Erosion Control: You're Gambling Without it.* International Erosion Control Association. pp. 145-155.

This report presents information on the types of impairments typical of forestry activities and provides information on management techniques that may be used to minimize the impacts. The practices presented in this paper include timber harvesting, site preparation, and road construction and drainage. Erodibility factors, assigned to Florida soils by the SCS, and slope determine a site's sensitivity to erosion, and the paper presents site sensitivity classes for Florida soils. This classification is related to suggested BMP usage and implementation. Many useful tables of specifications for when and how to construct the practices are presented.

New York State Department of Environmental Conservation, Division of Water. 1986. *Stream corridor management: A basic reference manual.*

Chapter 6 (Best Management Practices) provides an in depth discussion of BMPs relating to stream corridor management. This document discusses numerous BMPs not directly related to forestry, but the information is generally useful for forestry applications. Many standard forestry stream BMPs, such as crossings and culverts, are discussed also. Contents include: Stream Problems, Techniques for Assessing Land Use Impacts on Water Quantity and Quality, Steps for Solving the Problem (A Planning and Problem-solving Framework), Stream Conservation Options and Choices for Local Government, Best Management Practices, and Implementing a Program in Your Community.

Nieswand G.H., R.M. Hordon, T.B. Shelton, and B. Chavooshian. 1990. Buffer strips to protect water supply reservoirs: A model and recommendations. *Water Resources Bulletin.* 26(6):959-966.

This paper discusses the development of a parameter-based model for buffer strip width determination for use in New Jersey, as part of a comprehensive watershed management project. The model is primarily intended for application to all watersheds above water supply intakes or reservoirs. Input requirements for the model include a combination of slope, width, and time of travel. Development of the model and its application to a watershed in New Jersey are discussed. The application results in a recommended buffer strip width that ranges from 50 to 300 feet, depending on a number of assumptions, and from 6-13% of the watershed area above the protected waterbody (reservoir) being occupied by the buffer.

Steinblums, I., H.A. Froehlich, and J.K. Lyons. 1984. Designing stable buffer strips for stream protection. *Journal of Forestry.* 82(1):49-52.

Failure of buffer strips due to blowdowns, disease, and logging is a recurring problem and can cause stream channels to load with debris, leading to sediment storage or erosion. This article reports a study of environmental factors that affect buffer strip stability and stream shading. On 40 streamside buffer strips in the

Cascade Mountains of western Oregon, buffer strip stability was found to be a function of one vegetation and six topographic equation variables, and shading was related to three characteristics of buffer strips and one of adjacent clearcuts. Topographic maps and aerial photographs were used to supplement field observations. Stability and shading effectiveness of proposed buffer strips can be evaluated using the equations presented in the paper and data collected through site reconnaissance and topographic maps.

Trimble, G.R., and R.S. Sartz. 1957. How far from a stream should a logging road be located? *Journal of Forestry*. 55(5):339-341.

Observations were made along a forest road that traverses a well- stocked northern hardwood forest of somewhat uneven age in the Hubbard Brook Experimental Forest in the White Mountains of New Hampshire. Data are plotted as a relationship between degree of slope and distance sediment is carried by storm runoff, yielding recommended widths of filter strips for various conditions. A rule of thumb is a filter strip 25 feet wide on level ground with a 2-foot increase in width for each 1% increase in slope of the land between road and stream.

Whitman R. 1989. Clean water of multiple use? Best management practices for water quality control on the national forests. *Ecology Law Quarterly*. 16(4):909.

This article summarizes the nature and extent of the environmental problems around which conflicts revolve, and shows how state and federal laws, including NEPA, CWA and the National Forest Management Act, interact to protect water quality through forest planning. The paper also assesses the success of BMPs in protecting water quality, explains why BMPs are not always implemented even when legally prescribed, and identifies those settings where, even if fully implemented, BMPs fail. Finally, the author proposes some administrative and institutional reforms designed to correct these shortcomings. The article contains a review of the water quality problems associated with timber harvesting; the various statutes relating to forest practices; the roles of EPA, the states, and the Forest Service in water quality protection; and the effectiveness of BMPs. The suggested reforms include restructuring incentives to protect environmentally sensitive areas and restructuring state water quality standards for forestry-related NPS pollution.

Anderson, H.W., M.D. Hoover, and K.G. Reinhart. 1976. *Forests and water: Effects of forest management on floods, sedimentation, and water supply*. USDA Forest Service. General Technical Report PSW-18. 115 pages.

Andrus, C., and H.A. Froehlich. 1988. Riparian forest development after logging or fire in the Oregon Coast Range: Wildlife habitat and timber value. In:: *Streamside Management: Riparian Wildlife and Forestry Interactions*. University of Washington. Institute of Forest Resources. No. 59. pp. 139-151.

Baumgartner, D.M. (ed). 1981. *Interior west watershed management: Proceedings of a symposium*. Spokane, Washington, April 8-10, 1980. Washington State University, Cooperative Extension Service. 288 pages.

Belt, G.H., J. O'Laughlin, and T. Merril. 1992. *Design of forest riparian buffer strips for the protection of water quality: Analysis of scientific literature*. University of Idaho, Wildlife and Range Policy Analysis Group Report No. 8. 35 pages.

Borg, H., A. Hordacre, and F. Batini. 1988. Effects of logging in stream and river buffers on watercourses and water quality in the southern forest of Western Australia. *Australian Forestry*. 51 (98-105).

Brazier, J.R., and G.W. Brown. 1973. *Buffer strips for stream temperature control*. Oregon State University, School of Forestry, Forest Research Laboratory. Research Paper 15.

Curtis, W.R. 1966. Forest zone helps minimize flooding in the Driftless Area. *Journal of Soil and Water Conservation*. 21:101- 102.

Ice, G.G. 1989. Guidelines and approaches for forest riparian management: State forest practice rules. In: *Forestry on the Frontier, Proceedings of the 1989 Society of American Foresters National Convention*. Spokane, Washington. pp. 94-98.

Megahan, W.F. 1983. Appendix C: Guidelines for reducing negative impacts of logging. In: *Tropical watersheds: Hydrologic and soils response to major uses or conversions*. L.S. Hamilton and P.N. King (eds.). Westview Press, Boulder, Colorado. pp. 143-154.

Mumper, D., D.R. Gibbons, L. Wilson, and M.J. Golde. 1987. Best management practices in the streamside zone. In: *Streamside Management: Forestry and Fishery Interactions*. University of Washington. E.O. Salo and T.W Cundy (eds.). Institute of Forest Resources. No. 57. pp. 441-457.

NCASI. 1984. *Forestry management practices and cumulative effects on water quality and utility*. National Council of the Paper Industry for Air and Stream Improvement. Technical Review Bulletin No. 435.

NCASI. 1987. *Managing Oregon's riparian zone for timber, fish and wildlife*. National Council of the Paper Industry for Air and Stream Improvement. Technical Bulletin No. 514.

Payne, N.J., J.C. Feng, and P.E. Reynolds. 1990. Off-target deposits and buffer zones required around water for aerial glyphosate applications. *Pesticide Science*. 30(2):183-198.

Payne, N.J., B.V. Helson, K.M.S. Sundaram, and R.A. Fleming. 1988. Estimating buffer zone widths for pesticide applications. *Pesticide Science*. 24(2):147-161.

Robison, E.G., and R.L. Beschta. 1990. Identifying trees in riparian areas that can provide coarse woody debris to streams. *Forest Science*. 36(3):790-801.

Salo, E.O., and T.W. Cundy (eds.). 1987. *Streamside management forestry and fishery interactions*. College of Forest Resources, University of Washington. 471 pages.

Swank, G.W. 1985. Streamside management units in the Pacific Northwest. In: *Conference on Riparian Ecosystems and Their Management: Reconciling Conflicting Uses*. USDA Forest Service, April 16-18. pp. 435-438.

USDA Forest Service. 1991. *Riparian forest buffers: Function and design for protection and enhancement of water resources*.

USDA Forest Service and USEPA. 1978. *Streamside management zone statutes and ordinances, criteria and institutional arrangements serving water quality objectives on state and private forest lands*. pp. 10-22.

Wong, S.L., and R.H. McCuen. 1981. *The design of vegetative buffer strips for runoff and sediment control*. University of Maryland, Department of Civil Engineering.

COSTS AND EFFECTIVENESS OF BMPs

Cubbage, F.W. 1987. Costs of forest water quality protection. In: *Forestry and Water Quality: A Policy Workshop for State Foresters*. Oklahoma City, Oklahoma, July 6-9, 1987.

This paper presents a review of the costs of forestry NPS controls, including agency administrative costs, direct costs to landowners or timber operators (e.g., plan preparation), and indirect costs on timber supplies. Forest practice costs are reviewed for California, Massachusetts, Nevada, Alaska, Idaho, Oregon, and Washington. The various approaches used by these states and their effect on implementation cost are analyzed

as well. The approach used by forestry and other agencies for implementing the voluntary or required practice rules greatly affects the various costs of program implementation, as well as who bears the costs. Criteria used to select the means of controlling NPS pollution must include BMP effectiveness, political and social acceptability, and economic efficiency.

Cubbage, F.W., and P. Lickwar. 1990. *Estimating the costs of water quality protection on private forest lands in Georgia.* Georgia Forestry Commission, Research Division.

The purpose of the information presented in this paper is to quantify the operational costs of implementing various forestry best management practices, with emphasis placed on practices associated with road construction. This paper presents very good cost information on the following: road construction, stream crossings, broad-based dips, water bars, seed, fertilizer, mulch. The information is useful because the costs are based on various physiographic classifications (i.e., coastal plain, piedmont, or mountain).

Curtis, J.G., D.W. Pelren, D.B. George, V.D. Adams, and J.B. Layzer. 1990. *Effectiveness of best management practices in preventing degradation of streams caused by silvicultural activities in Pickett State Forest, Tennessee.* Center for the Management, Utilization and Protection of Water Resources, Tennessee Technological University for the Tennessee Department of Conservation, Division of Forestry and the Tennessee Wildlife Resources Agency. 197 pages.

This study was undertaken to evaluate the effectiveness of BMPs applied to timber harvest operations in Pickett Forest. The effects on water quality, fish production, and macroinvertebrates, and the presence of herbicides in streams were studied. The BMPs employed were SMZs, road placement on ridgetops and high elevations, skid trails kept at least 14 m from streams, harvest during the driest season and maximum soil stability, logging of small, dispersed stands, seeding and mulching of disturbed areas, broad-based dips on the haul road, and a period of 10 years before the area would be logged again. Herbicides were applied to two stands. Hardwoods 75 mm dbh or less were thin line sprayed with a mixture of Garlon (active ingredients triclopyr and 2,4-D), Sidekick, and diesel fuel. Picloram was injected into all hardwoods 255 mm dbh or greater. Concentrations of herbicides in streams following the treatments was low: 2,4-D @ <0.02-0.08l. Based on available toxicity data, the levels detected were not biologically harmful. However, care is needed during application to minimize transport to surface waters. Extensive data relating to all of the BMPs employed during the study are presented in the paper .

Dykstra, D.P., and H.A. Froehlich. 1976. Costs of stream protection during timber harvest. *Journal of Forestry*. 74(10): 684-687.

This article analyzes the cost of three stream protection alternatives: conventional felling with channel cleanup; cable- assisted directional felling; and use of buffer strips. The study was conducted along 10 deeply incised headwater stream channels in western Oregon. None of the three alternatives was clearly preferable on a majority of the study areas. The least- cost alternative on four of the areas was a 55-foot-wide buffer strip ($20.02 to $27.77 per MBF). On three of the remaining areas, conventional felling was the least expensive ($20.83 to $23.97 per MBF), and on the other three, cable-assisted directional felling was the least expensive ($18.79 to $26.30 per MBF).

Ellefson, P.V., and P.D. Miles. 1984. Economic implications of managing nonpoint forest source of water pollutants: A midwestern perspective. In: *Mountain Logging Symposium Proceedings*. West Virginia University, June 5-7, 1984. P.A. Peters and J. Luchok (eds.). pp. 107-119.

Economic evaluations of 6 forest practices

designed to enhance water quality from 18 timber harvesting operations in the Midwest were carried out. Net revenue reductions ranged from 1.2% with redesign of landing and skid trail locations to 26.4% with buffer strip requirements. Nine operations were profitable with application of all six practices. Limited production function information hinders such analyses.

Heede, B.H. 1990. *Vegetation strips control erosion in watersheds*. Research Note RM-499. USDA Forest Service, Rocky Mountain Forest and Range Experiment Station.

An analysis was conducted on data collected to determine the effects of vegetation strips on erosion control. The data was collected fromsouthwestern ponderosa pine forests, pinyon-juniper, and chaparral. In the ponderosa pine, 61 times more sediment was delivered when buffer strips were missing. This factor was 18 and 277 for pinyon-juniper and chaparral, respectively. Overland flow was also diminished from areas with buffer strips. No statistical analysis was conducted on the data. .

House, R., and V. Crispen. 1990. *Economic analyses of the value of large woody debris as salmonid habitat in coastal Oregon streams.* Technical Note OR-7:6512. USDI, Bureau of Land Management, Portland OR. 11 pages.

Three woody debris loading levels that result from different riparian management practices were analyzed in two stream reaches in the upper Nestucca River drainage, Oregon. The analysis included estimating summer juvenile populations of coho salmon, steelhead, and cutthroat trout and estimating the value of conifers in riparian zones for anadromous fish were compared to maximum timber harvest to determine the benefits of maintaining riparian vegetation to supply high levels of woody debris. The benefits of maintaining 2 km of stream at high levels (11.0 pieces per 100 m of stream) would be 11% higher within 20 years and 59% higher (an increase of over $100,000 in present value) after 94 years over conifer stumpage in the riparian zone. Long-term, economic benefits were found to be substantially higher for streams managed with high levels of woody debris.

Lickwar, P.M., C.A. Hickman, and F.W. Cubbage. 1991. Costs of protecting water quality during harvesting on private forestlands in the Southeast. *Southern Journal of Applied Forestry*.

Data on harvest volumes, topography, and other site and area characteristics were obtained from 22 private forest timber harvests in Alabama, Florida, and Georgia. An economic analysis was then used to estimate the marginal costs of implementing each state's recommended BMPs and a set of "enhanced" BMPs that offered increased water quality protection. Collectively, the costs of using the recommended BMPs averaged 2.9% of gross timber sale revenue, $2.34 per 1000 board feet (MBF) of timber harvested, or $12.45 per acre. The cost of implementing enhanced BMPs averaged 5.1% of gross stumpage value, $4.13 per MBF, or $21.94 per acre. Seed, fertilizer, and mulch; broad-based dips; and water bars were the most expensive practices on a total cost basis. Culvert installation, SMZs, and road relocation were less expensive for most tracts. A literature review of related studies is provided. Site location maps, site characteristics (physiographic, size, harvest method) are also given, and the economic analysis breaks the sites down by topography and BMPs implemented. This is one of the few studies available on forestry BMP implementation costs.

Lynch, J.A., and E.S. Corbett. 1981. Effectiveness of best management practices in controlling nonpoint pollution from commercial clearcuts. In: *Nonpoint Pollution Control - Tools and Techniques for the Future, Proceedings of a Technical Symposium*. pp. 213-224.

This paper reports an evaluation of the effectiveness of Pennsylvania's BMPs for controlling NPS pollution on public and private forestlands. This study was done following a commercial clearcut in central Pennsylvania. The

paired watershed method was used to evaluate changes in water quality and quantity. The commercial clearcut produced a water yield increase of 5.39 area- inches the first year following cutting. Stream turbidity on the clearcut watershed was generally higher than that on the control watershed prior to cutting, and no major increase in turbidity occurred as a result of cutting. No serious channel erosion was found on the clearcut watershed. Increases in stream temperature were generally slight. The authors conclude that the BMPs required in Pennsylvania are sufficient to control NPS pollution during and following logging.

Lynch, J.A., and E.S. Corbett. 1990. Evaluation of best management practices for controlling nonpoint pollution from silvicultural operations. *Water Resources Bulletin.* 26(1):41-52.

Fifteen years of streamflow and water quality data were evaluated to determine the effectiveness of BMPs in controlling nonpoint source pollution from a 110-acre commercial clearcut located in the Ridge and Valley Province of central Pennsylvania. In general, the BMPs analyzed effectively reduced water quality impacts associated with timber harvest. Although some increases in water quality constituents were observed, most were well below the drinking water standards although they may violate EPAs antidegradation policy. The authors suggest that buffer strips of unharvested timber provided the most protection to the streams and that improved performance may be possible through annual inspections and increasing the width of buffer strips if necessary. The information presented in this report demonstrates the potential for reductions in nonpoint source pollution possible with various BMPs.

Mormon, D. 1993. *Riparian rules effectiveness study*. Forest Practices Program, Oregon Department of Forestry. 198 pages + appendices.

The purpose of this report is to present the Forest Practices Program's Riparian Rule effectiveness study. The report describes the data collected for the study and provides an evaluation of the data. The study surveyed the pre- and post- operation stream and riparian conditions of Class I and II stream within or adjacent to 33 typical harvest units throughout Oregon. The primary focus of the data collection was to measure the resource protection provided on Class I streams through application of the rules, and to provide information on the costs and benefits of the program. The major conclusions presented in the report are as follows: 1) Class II streams experienced greater shade reduction as a result of harvesting than Class I streams; 2) existing quantities of aquatic coarse woody debris were not affected by harvesting, however, in western Oregon the future supply of woody debris was significantly reduced through the harvest of streamside trees; 3) harvesting resulted in minor reductions in snag density; 4) the projected net volume of timber retained annually on Oregons private and local government lands to meet Class I stream protection equals slightly more than 1% of annual harvest on those lands; 5) the application of riparian rules generally resulted in Class I stream protection that maintained pre-operation vegetative condition; and 6) timber retained after harvest in riparian management areas tends to be trees having lower volume and value.

Phillips, J. 1989. Nonpoint source pollution control effectiveness of riparian forests along a coastal plain river. *Journal of Hydrology.* 110:221-237.

The purpose of this research was to evaluate the NPS pollution control effectiveness of riparian environments in the lower Tar River basin, North Carolina. Soil map units, representing specific combinations of soil, topography, and vegetation characteristics, are compared in terms of their relative ability to filter nitrate in agricultural runoff. A typical riparian forest provides significant water quality protection, but there is wide variation in buffer effectiveness. A range of 15-80 m is appropriate for the soil-landform-

vegetation complexes found in the study area riparian zones, and buffer widths of 60 m, and often much less, are generally adequate on the soils likely to be used for agricultural production. The author analyzes the effectiveness of buffer widths using a detention-time model and explains the model's development and application.

Clinnick, P.F. 1985. Buffer strip management in forest operations: a review. *Australian Forestry*. 48(1):34-45.

Dykstra, D.P., and H.A. Froehlich. 1976. Stream protection: What does it cost? *Loggers Handbook*. Pacific Logging Congress, Portland, Oregon.

Ellefson, P.V., and P.D. Miles. 1985. Protecting water quality in the Midwest: Impact on timber harvesting costs. *Northern Journal of Applied Forestry*. 2:57-61.

Erman, D.C., J.D. Newbold, and K.B. Roby. 1977. *Evaluation of streamside buffer strips for protecting aquatic organisms*. California Water Resources Center, University of California, Davis, California. 48 pages.

Irland, L.C. Streamside protective corridors: Techniques for weighing costs and benefits. *Paper presented at IUFRO World Forestry Research Congress: Draft*. Ljubljana, Yugoslavia, 1986. 28 pages.

Lickwar, P.M. 1984. *Estimating the costs of water quality protection on private forest lands in the south*. Master's Thesis, University of Georgia.

Lynch, J.A., and E.S. Corbett. 1989. Effectiveness of BMP's in controlling nonpoint pollution from silvicultural operations. In: *Proceedings of the Symposium on Headwaters Hydrology*. American Water Resources Association, Bethesda, Maryland. pp. 149-157.

NCASI. 1987. *Managing Oregon's riparian zone for timber, fish and wildlife*. National Council of the Paper Industry for Air and Stream Improvement. Technical Bulletin No. 514.

NCASI. 1988. *Procedures for assessing the effectiveness of Best Managements Practices in protecting water and stream quality associated with managed forests*. National Council of the Paper Industry for Air and Stream Improvement. Technical Bulletin No. 538. 23 pages.

Olsen, E.D., D.S. Keough, and D.K. LaCourse. 1987. *Economic impact of proposed Oregon Forest Practices Rules on industrial forest lands in the Oregon Coast Range: A case study*. Oregon State University, College of Forestry, Forest Research Laboratory. Research Bulletin 61. 15 pages.

9. WETLANDS

IMPACTS ON WATER QUALITY

Askew, G.R., and T.M. Williams. 1984. Sediment concentrations from intensively prepared wetland sites. *Southern Journal of Applied Forestry*. 8(3):152-157.

This study was designed to evaluate the drainage and conversion process used by a major forest industry and to determine which aspect of the conversion process, if any, was a primary source of sediment. Suspended sediment concentrations were measured in water draining from a 5,900-acre Carolina bay undergoing conversion to loblolly pine plantations. Samples were collected during the first stormflow event of each month between January 1981 and December 1982 from subwatersheds involved in some of several phases of conversion. Suspended sediment concentration in water leaving the bay averaged only 16 mg/l for 13 storms. Road erosion and ditch installation produced the highest suspended sediment concentrations. Suspended sediment concentrations decreased substantially with increasing distance from the sediment source. Logging and site preparation activities did not cause an appreciable increase in suspended sediment when equipment did not operate in the drainage ditches. This study indicates that main haul roads and new drainage ditches are the sources of much of the increased suspended sediments found in drainage from managed forests in the lower coastal plain. The authors conclude that the impact of these activities can be minimized by using a drainage system that contains a length of main channel between sediment sources and sensitive areas.

Askew, G.R., and T.M. Williams. 1986. Water quality changes due to site conversion in coastal South Carolina. *Southern Journal of Applied Forestry*. 10(3):134-136.

A study was conducted to evaluate the effects of the drainage and conversion process on water quality. Dissolved oxygen and pH concentrations were higher in the converted watershed drainage than in the hardwood drainage; nitrate, total phosphorus, and potassium concentrations did not differ significantly. The authors concluded that rapid installation of drainage ditches is the most important aspect of conversion to avoid water quality degradation.

Bartuska, A.M. 1993. USDA Forest Service wetlands research. *Journal of Forestry* 91(5):25-28.

This article reviews current wetlands research efforts of the USFS by region. The importance of wetland and riparian areas as habitat for salmonids (Intermountain Region), watershed studies and hydrologic budgets (Northeast Region), riparian habitat restoration (Pacific Northwest Region), and buffer strips (Southern Region) are examples of current research efforts. Future efforts in forest wetlands research are expected to focus on filling the gaps in understanding wetland structure and function, ecosystem processes, restoration and rehabilitation, wetland management, quantifying the socioeconomic value of wetlands, and the landscape role of wetlands. These are briefly discussed as well.

Howard, R.J., and J.A. Allen. 1989. Streamside habitats in southern forested wetlands: Their role and implications for management. In: *Proceedings of the Symposium: Forested Wetlands of the Southern United States*. Orlando, Florida, July 12-14, 1988. USDA Forest Service. General Technical Report SE-50. pp. 97-106.

This paper summarizes recent literature concerning the value of streamside forested wetlands of the Southern United States as fish and wildlife habitat. The role of wetlands in providing fish spawning and nursery habitat during inundation, protecting water quality, and supplying cover and food to channel-dwelling fish is described. Habitat edge and vegetation composition and structural complexity for wildlife are examined, as well as the effects of soil

moisture and proximity of permanent surface water on wildlife species distribution. Lastly, management practices and recommended widths for forested streamside buffer zones are also presented.

Neary, D.G., N.B. Comerford, and L.W. Swift. Land and riparian interactions with sediment in the southern United States. In: *Proceedings of Technical Workshop on Sediments*. Corvallis, Oregon, February 3-7, 1992. U.S. Environmental Protection Agency and USDA Forest Service.

This paper presents a review of the literature and includes the following: a synthesis of research results in current literature on buffer zones, determining the utility of buffer zones in protecting forested wetlands and surface waters from the sediment nonpoint source pollution impacts of silvicultural operations, and identifying information gaps and research needs. Some review information from studies on the protection afforded by buffer strips is presented.

Riekerk, H. 1983. Environmental impacts of intensive silviculture in Florida (forest soil degradation, water quality, watersheds). In: *I.U.F.R.O. Symposium on Forest Site and Continuous Productivity*. USDA Forest Service, Pacific Northwest Forest and Range Experiment Station. General Technical Report PNW-163. pp. 264-271.

Runoff and water quality from two different timber harvest practices, minimum and maximum disturbance, were compared to an undisturbed flatwood watershed. Significantly greater water yield was observed for both treatments, with the greatest increase in the maximum disturbance treatment. Water yield increases lasted for a single year. As with water yield, the greatest degradation in water quality was observed from the maximum disturbance treatment although the impact was also of short duration. The author concludes that silvicultural activities in flatwoods would not result in any long-term degradation of water quality.

Riekerk, H. 1983. Impacts of silviculture on flatwoods runoff, water quality, and nutrient budgets. *Water Resources Bulletin*. 19(1)73-80.

Runoff and water quality from two different timber harvest practices, minimum and maximum disturbance, were compared to an undisturbed flatwood watershed. The maximum disturbance consisted of machine harvesting, slash burning, windrowing, bedding, and machine planting and the minimum disturbance treatment included manual harvesting, slash chopping, bedding, and machine planting. Significantly greater water yield was observed for both treatments, with the greatest increase in the maximum disturbance treatment. Water yield increases lasted for a single year. As with water yield, the greatest degradation in water quality was observed from the maximum disturbance treatment although the impact was also of short duration. The author concludes that silvicultural activities in flatwoods would not result in any long-term degradation of water quality.

Riekerk, H. 1989. Influence of silvicultural practices on the hydrology of pine flatwoods in Florida. *Water Resources Research*. 25(4):713-710.

This paper reports the results of a study of different intensities of silvicultural practices on the hydrologic processes and water balances of pine flatwoods in Florida. Slash pine flatwoods in diked watersheds were harvested and regenerated with high and low levels of disturbance. One watershed received machine harvesting, slash burning, windrowing, bedding, and machine planting, which cause high disturbance; a second watershed received manual harvesting, slash chopping, bedding, and machine planting, which cause low disturbance. Water regimes of these watersheds were compared with an undisturbed control watershed. Water table levels were higher after harvest because of reduced evapotranspiration. The differences in water table levels due to treatment were more pronounced at deeper soil depths. Daily runoff during the first year increased somewhat in proportion to the area clearcut in each watershed. Runoff from the high-disturbance watershed was

predicted to return to normal after 11 years. A severe drought that occurred during the study on the low-disturbance watershed caused a very slow recovery of the hydrologic regime. It took a full year of normal rainfall to restore runoff patterns. High-disturbance site preparation resulted in many windrows oriented toward the drainages, less resistance to surface runoff, and some compaction of normally wet soils, resulting in less infiltration and more storm flow. The study demonstrates that silvicultural practices in coastal zone pine flatwoods significantly affect the hydrology.

Riekerk, H. 1985. Water quality effects of pine flatwoods silviculture. *Journal of Soil and Water Conservation*. 40(3):306- 308.

This study was done to assess the impacts of intensive silvicultural management practices on nonpoint source pollution in Florida's poorly drained pine flatwoods. Three watersheds in the flatwoods region of north central Florida were monitored for 6 years. Three treatments were imposed during the second year: harvest with minimum disturbance and site preparation, harvest with maximum disturbance and site preparation, and an undisturbed control. The minimum treatment included manual shortwood harvesting, slash chopping, soil bedding, and machine planting. The maximum treatment included machine tree-length harvesting, slash burning, windrowing, soil bedding, and machine planting. There were small but significant increases in pH, suspended sediment, Ca, and K, proportional to the degree of disturbance during the treatment year. Only K and Ca levels remained significant during the first posttreatment year. The author concludes that minimum disturbance practices with protective stream management zones will minimize NPS pollution.

Riekerk, H., D.G. Neary, and W.J. Swank. 1989. The magnitude of upland silviculture nonpoint source pollution in the south. In: *Proceedings of the Symposium on the Forested Wetlands of the Southern United States*. Orlando, Florida, July 12-14, 1988. USDA Forest Service, Southeast Forest Experiment Station. General Technical Report SE-50. pp. 8-18.

Streamflow water quality data from intensive silvicultural practices in the southern United States are summarized and discussed with respect to regional differences of nonpoint source pollution, and BMPs. Suspended sediment production by silviculture was low in the mountains and lower coastal plain, but high in the Piedmont and upper coastal plain regions. This was due to a combination of site preparation intensity and topographic relief. Nutrient exports in the Piedmont and upper coastal plain regions were controlled by the degree of soil disturbance and by the recovery rate of vegetation. Nutrient exports in the lower coastal plain were not much affected by intensive silviculture. Research is needed on the effects of silvicultural practices in wetlands and on the actual effectiveness of BMPs. Research and analyses of cumulative effects are also needed to determine the impacts of multiple silvicultural practices on downstream wetlands.

USDA, Forest Service. 1989. *Proceedings of the symposium: The forested wetlands of the southern United States*. Orlando, Florida, July 12-14, 1988. USDA Forest Service, Southeast Forest Experiment Station. General Technical Report SE-50. 168 pages.

The proceedings report contains 25 papers presented at the symposium, which concern nonpoint source pollution, and the protection and management of forested wetlands. The following five general categories are covered: (1) nonpoint sources of pollution and the functions and values of wetlands, (2) BMPs for forested wetlands, (3) streamside management strategies, (4) sensitive areas management, and (5) balancing BMPs and water quality standards for feasibility, economic, and functional effectiveness. The papers presented at the symposium provide extremely useful information for managers and regulatory personnel on a variety of forested wetland issues.

Verry, E.S. 1986. Forest harvesting and water: The Lake states experience. *Water Resources Bulletin*. 22(6):1039-1047.

This a summary of forest harvest and water quality in the Lakes states is separated into wetlands and uplands. Harvesting of timber from

natural peatlands will not adversely affect streamflow and water quality if conducted on frozen ground; however, increased water table fluctuations will result. In uplands, streamflow increases upon clearcut and returns to preharvest levels within 15 years. Water quality impairment and habitat destruction can be minimized if stream channels are avoided. More than 30 references to studies conducted in the Lake states are included.

Walbridge, M.R. 1993. Functions and values of forested wetlands in the southern United States. *Journal of Forestry*. 91(5):15-19.

This article quantifies the values of southern forested wetlands. The abundance and distribution of southern forested wetlands are described (e.g., 67% are along narrow stream margins, 8% are in deepwater swamps, 11% are in floodplain forests along major rivers). Based on area, an important component of southern forested wetlands lines narrow stream margins and small drainage ways. The pollution control benefits of these areas must be understood as development continues in the South. The ability of southern forested wetlands to improve the quality of surface, subsurface, and ground waters is one of their most important values. Through a review of published studies, the nutrient removal function of southern forested wetlands is discussed, with additional reference to their hydrologic and biogeochemical functions. Based on this information, the author suggests that southern forested wetlands have an important place in forest management, and management practices should minimize damage to the functions they perform.

Williams, T.M. 1989. Site preparation on forested wetlands of the southeastern coastal plain. In: *Proceedings of the Symposium on the Forested Wetlands of the Southern United States*. Orlando, Florida, July 12-14, 1988. USDA Forest Service, Southeast Forest Experiment Station. General Technical Report SE-50. pp. 67-71.

A general discussion of site preparation objectives and site preparation techniques for pine and hardwood forests in the Southeastern United States is presented. Only a qualitative review of some of the impacts from different treatments is provided.

Williams, T.M., and G.R. Askew. 1988. Impact of drainage and site conversion of pocosin lands on water quality. In: *The Ecology and Management of Wetlands, Volume 2: Management, Use and Value of Wetlands*. Hook et al. (eds.). pp. 213-218.

This study was conducted to determine whether drainage, or logging and site preparation, of forested wetlands would result in increases in nutrient and suspended sediment. The authors found increases in suspended sediment and nitrate concentrations; however, the increases were not statistically significant. This paper presents the effects of drainage on water quality, but only limited data are presented and no real conclusions are offered.

Allen, H.L., and R.G. Campbell. 1988. Wet site pine management in the southeastern United States. In: *The Ecology and Management of Wetlands, Volume 2: Management, Use and Value of Wetlands*. Hook et al., ((eds)). Timber Press, Portland, Oregon. pp. 173-184.

Ewel, K.C. 1985. *Effects of harvesting cypress swamps on water quality and quantity*. Water Resources Research Center, University of Florida, Department of Forestry. Publication No. 87. 49 pages.

Gregory, J.D. 1988. Hydrologic impacts of forest water management. In: *The Ecology and Management of Wetlands, Volume 2: Management, Use and Value of Wetlands*. Hook et al. (eds.). Timber Press, Portland, Oregon. pp. 137-147.

Kuenzler, E.J. 1989. Value of forested wetlands as filters for sediments and nutrients. In: *Proceedings of the Symposium on the Forested Wetlands of the Southern United States*. Orlando, Florida, July 12-14, 1988. USDA Forest Service, Southeast Forest Experiment Station. General Technical Report SE-50. pp. 85-96.

McGarity, R.W. 1979. Ten year results of thinning and clearcutting in a muck swamp timber type. *Southern Journal of Applied Forestry*. 3:64-67.

Riekerk, J., A.C. Mace, D.G. Neary, and B.F. Swindel. 1986. Hydrologic responses to forest management in pine flatwoods and Florida's water. In: *Proceedings-Soil and Crop Science Society of Florida*. 45:163-169.

Swindel, B.F., C.J. Lassiter, and H. Riekerk. 1983. Effects of different harvesting and site preparation operations on the peak flows of streams in *Pinus elliotii* flatwoods forests. *Forest Ecology and Management*. 5:77-86.

Swindel, B.F., C.J. Lassiter, and H. Riekerk. 1983. Effects of clearcutting and site preparation on stormflow volumes of streams in Pinus elliotii flatwoods forests. *Forest Ecology and Management*. 5:245-253.

BMPs AND SPECIFICATIONS

NCASI. 1990. *Best management practices for forest wetlands: Concerns, assessment, regulations, and research.* National Council of the Paper Industry for Air and Stream Improvement. Technical Review Bulletin No. 583.

NCASI has established a forest wetland research program designed to identify forest management practices compatible with other wetland functions. This technical bulletin is a collection of papers that address concerns about forest wetland management, assessment techniques to evaluate wetland functions and values, industry programs designed to address wetland function protection, and opportunities for cooperative research. Sample paper titles include: The NCASI Forested Wetlands Environmental Research Program; EPA Region 4 Guidance on Agricultural and Silvicultural Exemptions; Integrating the North American Waterfowl Management Plan into Forest Management; EPA's Environmental Monitoring and Assessment Program (EMAP); Determining the Cumulative Effects of Forested Wetlands: EPA's Research Program, and Choices for Research and Monitoring Designs; Wetlands Harvesting; Opportunities for Cooperative Research on Forest Management and Wetland Function; Forested Wetlands Research in the Forest Service and Coordination with Other Researchers.

Riekerk, H., D.G. Neary, and W.J. Swank. 1989. The magnitude of upland silviculture nonpoint source pollution in the south. In: *Proceedings of the Symposium on the Forested Wetlands of the Southern United States.* Orlando, Florida, July 12-14, 1988. USDA Forest Service, Southeast Forest Experiment Station. General Technical Report SE-50. pp. 8-18.

Streamflow water quality data from intensive silvicultural practices in the southern United States are summarized and discussed with respect to regional differences of nonpoint source pollution, and BMPs. Suspended sediment production by silviculture was low in the mountains and lower coastal plain, but high in the Piedmont and upper coastal plain regions. This was due to a combination of site preparation intensity and topographic relief. Nutrient exports in the Piedmont and upper coastal plain regions were controlled by the degree of soil disturbance and by the recovery rate of vegetation. Nutrient exports in the lower coastal plain were not much affected by intensive silviculture. Research is needed on the effects of silvicultural practices in wetlands and on the actual effectiveness of BMPs. Research and analyses of cumulative effects are also needed to determine the impacts of multiple silvicultural practices on downstream wetlands.

USDA, Forest Service. 1989. *Proceedings of the symposium: The forested wetlands of the southern United States*. Orlando, Florida, July 12-14, 1988. USDA Forest Service, Southeast Forest Experiment Station. General Technical Report SE-50. 168 pages.

The proceedings report contains 25 papers presented at the symposium, which concern nonpoint source pollution, and the protection and management of forested wetlands. The following five general categories are covered: (1) nonpoint sources of pollution and the functions and values of wetlands, (2) BMPs for forested wetlands, (3) streamside management strategies, (4) sensitive areas management, and (5) balancing BMPs and water quality standards for feasibility, economic, and functional effectiveness. The papers presented at the symposium provide extremely useful information for managers and regulatory personnel on a variety of forested wetland issues.

Windsor, C.L. 1989. Recommended management practices for forested wetlands road construction. In: *Proceedings of the Symposium on the Forested Wetlands of the Southern United States*. Orlando, Florida, July 12-14, 1988. USDA Forest Service, Southeast Forest Experiment Station. General Technical Report SE-50. pp. 51-53.

This paper reviews 15 provisions of section 404 of the Federal Water Pollution Control Act. The provisions must be met for construction of forest roads in wetlands without a permit. BMPs developed by the states of Georgia, Florida, and South Carolina that relate to wetland road construction are also reviewed. An example of road construction and the BMPs used during the construction is discussed. Three management practices that should be avoided include (1) pushing fill material into small streams, thinking that it will be removed during the next wet season after logging has been completed; (2) inadequate size or wrong placement of culverts; and (3) use of a long fill with an inadequate number of culverts or culverts placed at the wrong height. Grading roads flat and leaving the berm along the outside edges of the road should be avoided. A suggestion is given for preventing beavers from stopping up culverts (a common problem in the south).

Allen, H.L., and R.G. Campbell. 1988. Wet site pine management in the southeastern United States. In: *The Ecology and Management of Wetlands, Volume 2: Management, Use and Value of Wetlands*. Hook et al. (eds). Timber Press, Portland, Oregon. pp. 173-184.

Lea, R. 1988. Management of eastern United States bottomland hardwood forests. In: *The Ecology and Management of Wetlands, Volume 2: Management, Use and Value of Wetlands*. Hook et al. (eds.). Timber Press, Portland, Oregon. pp. 185-194.

McGarity, R.W. 1979. Ten year results of thinning and clearcutting in a muck swamp timber type. *Southern Journal of Applied Forestry*. 3:64-67.

Terwilliger, V.J., and K.C. Ewel. 1986. Regeneration and growth after logging Florida pond cypress domes. *Forest Science*. 32(2): 493-506.

COSTS AND EFFECTIVENESS OF BMPs

Cubbage, F.W., M.A. Elfner, and T.G. Harris, Jr. 1991. Economic values of forested wetlands. In: *Southern Forest Economics Workers Meeting*. Washington, DC, February 20-22, 1991. 14 pages.

The economic value of forested wetlands was calculated through market analysis and a cost-benefit analysis to determine whether a policy of protecting wetlands from destruction is warranted. This unbiased approach to the wetland issue bridges the gap between conservationists and timber harvesters by assigning monetary values to the market evaluation of wetland forest products. Despite

these calculations, the author concludes that overall wetland protection will be determined by political, not economic, criteria.

NCASI. 1990. *Best management practices for forest wetlands: Concerns, assessment, regulations, and research.* National Council of the Paper Industry for Air and Stream Improvement. Technical Review Bulletin No. 583.

NCASI has established a forest wetland research program designed to identify forest management practices compatible with other wetland functions. This technical bulletin is a collection of papers that address concerns about forest wetland management, assessment techniques to evaluate wetland functions and values, industry programs designed to address wetland function protection, and opportunities for cooperative research. Sample paper titles include: The NCASI Forested Wetlands Environmental Research Program; EPA Region 4 Guidance on Agricultural and Silvicultural Exemptions; Integrating the North American Waterfowl Management Plan into Forest Management; EPA's Environmental Monitoring and Assessment Program (EMAP); Determining the Cumulative Effects of Forested Wetlands: EPA's Research Program, and Choices for Research and Monitoring Designs; Wetlands Harvesting; Opportunities for Cooperative Research on Forest Management and Wetland Function; Forested Wetlands Research in the Forest Service and Coordination with Other Researchers.

Neary, D.G., N.B. Comerford, and L.W. Swift. Land and riparian interactions with sediment in the southern United States. In: *Proceedings of Technical Workshop on Sediments*. Corvallis, Oregon, February 3-7, 1992. U.S. Environmental Protection Agency and USDA Forest Service.

This paper presents a review of the literature and includes the following: a synthesis of research results in current literature on buffer zones, determining the utility of buffer zones in protecting forested wetlands and surface waters from the sediment nonpoint source pollution impacts of silvicultural operations, and identifying information gaps and research needs. Some review information from studies on the protection afforded by buffer strips is presented.

10. MODELING

MODELING WATER QUALITY IMPACTS

Basak, N., and J.J.C. Picot. 1984. Lagrangian simulation of forest pesticide spray dispersion and deposition. In: *Proceedings of Symposium on the Future Role of Aviation in Agriculture.* P.W. Voisey (ed).

A Monte Carlo technique using Lagrangian trajectory calculation for the motion of suspended droplets in the atmosphere was used to calculate aerial spray droplet dispersion in the atmosphere and subsequent deposition on foliage and the ground. This is a highly technical paper describing the physics of deposition and dispersion of aerially-applied pesticides.

Beasley, D.B., and D.L. Thomas. 1989. *Application of water quality models for agricultural and forested watersheds.* University of Georgia, Agricultural Engineering Department. Southern Cooperative Series Bulletin No. 338. 116 pages.

The information presented in this report covers three main objectives of the initial research: (1) to evaluate, compare, and test existing hydrologic/water quality models for use in simulating the effects of forestry and agricultural practices on the quality, quantity, and utilization of surface and subsurface waters; (2) to modify, develop, and/or adapt process models of water, sediment, and chemical transport for surface and subsurface flow; and (3) to assemble selected water quality and quantity data from existing facilities for use in model evaluation and comparison. This is a summary paper on the strengths, limitations, and past uses of several well-known models.

Berry, J.D. 1975. Modeling the impact of logging debris in streams. In: *Proceedings of the Watershed Management Symposium.* Logan, Utah, August 11-13, 1975. American Society of Civil Engineers, Division of Irrigation and Drainage. pp. 676-680.

This paper describes a dissolved oxygen balance model that would enable foresters to predict the on-site and downstream impact of debris loading and to locate areas where residue removal is necessary or alternate harvest techniques should be used.

Bilanin, A.J., M.E. Teske, J.W. Barry, and R.B. Ekblad. 1989. AGDISP: The aircraft spray dispersion model, code development, and experimental validation. *Transactions of the American Society of Agricultural Engineers.* 32(1):327-334.

The USDA FS and the DOD Atmospheric Sciences Laboratory have continued the development of the AGDISP (AGricultural DISPersal) computer code which predicts the deposition of material released from helicopters or fixed-wing aircraft. The features of the code are reviewed and the predictive capability of the code is assessed by comparison with field test data. Code applications and limitations are also discussed.

Bilanin, A.J., M.E. Teske, J.W. Barry, and R.B. Ekblad. 1990. USDA Forest Service aerial spray dispersion models AGDISP and FSCBG. I. Model validation. In: *Pesticides in the Next Decade: The Challenges Ahead, Proceedings of the 3rd Nat'l Research Conference on Pesticides.* November 8-9, 1990. D.L Weigmann (ed.).

The idealized flow field models that form the basis for the USDA FS aerial spray dispersion models AGDISP and FSCBG are reviewed. This is a technical paper that presents the equations that form the basis of the model.

Bilanin, A.J., M.E. Teske, J.W. Barry, and R.B. Ekblad. 1990. USDA Forest Service aerial spray dispersion models AGDISP and FSCBG. II. Model validation. In: *Pesticides in the Next Decade: The Challenges Ahead, Proceedings of the 3rd Nat'l Research Conference on Pesticides.* November 8-9, 1990. D.L. Weigmann (ed.).

The suite of field measurements that form the basis for the USDA FS aerial spray dispersion models AGDISP and FSCBG are reviewed. This model comparison perspective summarizes the current model validation efforts undertaken by the USDA FS in the areas of data collection and comparison with existing models, and improvements to the models.

Bruce, R.R., L.A. Harper, R.A. Leonard, W.M. Snyder, and A.W. Thomas. 1975. A model for runoff of pesticides from small upland watersheds. *Journal of Environmental Quality*. 4(4):541-548.

A mathematical model was developed describing the rate and quantity of runoff water from separate rainfall events on a watershed and the rate and quantity of sediment and pesticides transported. Excellent simulations were obtained.

Bush, P.B., D.G. Neary, J.W. Taylor, and J.G. Dowd. 1991. Use of computer models to evaluate potential herbicide runoff from silvicultural operations. In: *Proceedings of the Sixth Biennial Southern Silvicultural Research Conference.* , October 30 - November 1, 1990. USDA Forest Service, Southeast Forest Experiment Station, General Technical Report SE-70-650-658.

The increased use of herbicides in forestry throughout the South in the past decade has generated a need for tools to assess the environmental fate and impacts of these chemicals in forested watersheds. A variety of environmental simulation models, ranging from simple empirical models to complex process models are presented. These models are very useful in selecting among alternative herbicides based on environmental considerations and in guiding the development of monitoring plans.

Cline, R., G. Cole, W. Megahan, R. Patten, and J. Potyondy. 1981. *Guide for predicting sediment yields from forested watersheds.* USDA Forest Service, Northern Region and Intermountain Region.

A sediment yield prediction procedure was developed by a work group composed of soil scientists, hydrologists, and watershed specialists of the Forest Service Northern Region, Intermountain Region, and the Intermountain Forest and Range Experiment Station (R1/R4). This is a detailed document that contains basic information which has been used extensively in sediment transport model development.

Dissmeyer, G.E., and G.R. Foster. *Modifying the universal soil loss equation for forest land.*

The subfactor approach to the Universal Soil Loss Equation (USLE) was used to develop a procedure for estimating cover-management (C) factor values for eastern forest conditions. The subfactor approach allows one to estimate erosion systematically for new situations where no data are available, based on an evaluation of site-specific conditions. The major subfactors operating in many forests are (1) amount of bare soil, (2) canopy, (3) soil reconsolidation, (4) high organic matter content, (5) fine roots, (6) residual binding effect, (7) onsite storage, (8) steps, and (9) contour tillage. Each of these is discussed in this chapter. The approach for the adaption of the USLE to eastern forest conditions is summarized. The method should be useful for adaptation of the USLE to other situations.

Falletti, D.A. 1977. Sediment prediction in wildland environments: A review. In: *Proceedings of National Conference on Soil Erosion.* Purdue University, West Lafayette, IN, May 24-26, 1976. pp. 183-192.

This paper presents a review of sediment prediction tools assessed by the Forest Service. The sediment prediction tools were reviewed based on their relation to forest and rangeland applications. The review information suggested that the models used by field scientists lagged behind those used by research and academic

communities. The author listed the following characteristics that predictive sediment models should contain: modular in structure within a comprehensive framework; predict sediment loadings from all stream orders, but particularly first order; facilitate comparative evaluation of alternatives; represent time and probability variables; represent spatial variability of conditions and activities within a diverse landscape; utilize available or readily obtainable data; and be available for use by field-level scientists and be compatible with the decision-making process.

Fausch, K.D., C.L. Hawkes, and M.G. Parsons. 1988. *Models that predict standing crop of stream fish from habitat variables: 1950-1985.* USDA Forest Service, Pacific Northwest Research Station. General Technical Report PNW-GTR-213. 52 pages.

The document presents a comprehensive review of a diverse array of models that predict standing crop of stream fish from measurable characteristics of the environment. The purpose of the review was to organize the models diversity by the types of habitat (independent) variables found significant, the mathematical structure, the size of the data sets used to develop the models, and how well the models fit these data. The authors have highlighted investigations they felt used sound approaches to model development, testing, and interpretation so that others might follow that lead.

Hammond, C., D. Hall, S. Miller, and P. Swetik. 1992. *Level I Stability Analysis (LISA) documentation for version 2.0.* USDA Forest Service, Intermountain Research Station, Ogden, Utah. General Technical Report INT-285.

The LISA computer program is a tool to help estimate the relative stability of natural slopes or landforms. LISA results are intended to support management decisions at the multiproject or resource allocation level of planning. The primary use of the results is to make qualitative, relative comparisons between the stability of landforms and to identify areas that should be targeted for additional analysis. LISA can also be used to estimate the relative decrease in stability of a landform after timber harvest due to a potential reduction in estimated tree root strength and an increase in ground water levels. It can also be used for risk analysis, such as an expected monetary value decision analysis. This report provides comprehensive information required to use LISA.

Haskins, D.M. 1987. A management model for evaluating cumulative watershed effects. In: *Proceedings of the California Watershed Management Conference.* Sacramento, California, November 18-20, 1986. University of California, Wildland Resources Center. Report No. 11. pp. 125-130.

This paper addresses the project-level application of a model for evaluating cumulative watershed effects. Forest-planning-level application parallels it but at a broader scale. The model and its development are described, and examples of its application to project-level work are given.

Hillman, G.R., and J.P. Verschuren. 1988. Simulation of the effects of forest cover, and its removal, on surface water. *Water Resources Research.* 24(2): 305-314.

A distributed, physically based mathematical model was developed to simulate the effects of forestry operations on both soil water and streamflow. The model's primary usefulness rests in its capacity to simulate soil water movement and redistribution, on a distributed basis, in response to the processes of infiltration, evaporation, and transpiration.

Hornbeck, J.W., C.A. Federer, and R.S. Pierce. 1987. Effects of whole-tree clearcutting on streamflow can be adequately estimated by simulation. In: *Forest Hydrology and Watershed Management, Proceedings of an International Symposium of the General Assembly of the International Union of Geodesy and Geophysics at Vancouver, B.C., Canada.* Vancouver, Britsh Columbia, August, 1987. R.H. Swanson et al. (eds.). IAHS-AISH Publication No. 167, Canada. pp. 565-573.

A range of values was assigned to parameters of the BROOK hydrologic model to simulate streamflow for fast, medium, and slow regrowth on whole-tree clearcut basins in Maine, New Hampshire, and Connecticut. Data are presented to show how the simulated results compare with measured data.

Ketcheson, G.L. 1986. *Sediment rating equations: An evaluation for streams in the Idaho batholith.* General Technical Report INT-213. USDA Forest Service, Intermountain Research Station. 12 pages.

Sediment data from streams in the Idaho batholith were used to develop suspended, bedload, and total sediment rating equations. The equations are discussed in terms of statistical significance and their usefulness for documenting management impacts. Sediment yields were estimated using the rating equation and streamflow data. These yields were compared with those estimated from a time-integration method. Rating equation and time- integration estimates were significantly different in the Silver Creek research area. Time-integration estimates more closely matched those from sediment dams.

Maxwell, J.R., and D.G. Neary. 1991. Vegetation management effects on sediment yields. In: *Proceedings of the Fifth Interagency Sedimentation Conference, Vol. 2.* Las Vegas, Nevada, March 18-21, 1991. Interagency Committee on Water Data, Subcommittee on Sedimentation. pp 55-63, Section 12.

This paper presents the results of a regional analysis of the cumulative effects of vegetation management (fire, mechanical, herbicides, manual, biological) on sediment yield. Three Environmental Impact Statements (EIS) were prepared for three physiographic regions in the south and erosion was modeled for each region on a variety of landtypes and watersheds. In general, the results indicated greater sediment yields from road systems and cropland. In addition, greater sediment yields were typically observed from private lands. The data from the modeling indicated sediment yields could be reduced by favoring herbicide and low-intensity prescribed fire as a means of site preparation over mechanical and severe fire methods.

McGurk, B.J. 1989. Predicting stream temperature after riparian vegetation removal. In: *Proceedings of the California Riparian Systems Conference.* Davis, California, September 22-24, 1988. USDA Forest Service, Pacific Southwest Forest and Range Station. pp. 157-164.

This paper reports on field work at two streams in California that evaluates Brown's stream temperature change prediction technique (Brown 1970) and an empirical equation developed in Oregon. One of the sites was a clearcut site and the other was a mature fir forest. Larger diurnal temperature fluctuations were observed in the water flowing through the clearcut site than in the undisturbed area above the clearcut site. The mature fir forest also had a large diurnal water temperature variation. A 5.6 °C temperature rise was observed through a 380-m clearcut that exposed the stream channel, and Brown's equation predicted a change of 6.1 °C. Brown's exposed surface area model may be a good choice for land managers because it requires a minimum of field data that are relatively simple to obtain. A technique that includes the effect of shade recovery after timber harvest is suggested for use during long-range harvest planning.

Potyondy, J.P., G.F. Cole, and W.F. Megahan. 1991. A procedure for estimating sediment yield from forested watersheds. In: *Proceedings of the Fifth Interagency Sedimentation Conference, Vol. 2.* Las Vegas, Nevada, March 18-21, 1991. Interagency Committee on Water Data, Subcommittee on Sedimentation. Section 12, pp 46-54.

The operational sediment yield model used by the Boise National Forest is described. The model is a local adaptation of the model developed by the U.S. Forest Service for application in the Idaho Batholith. The model is commonly used in the preparation of environmental assessments and impact statements as a tool to evaluate the effects of alternative timber harvest activities, road location and design, and the application of erosion mitigation practices. The model estimates on-site erosion, modifies the amount of erosion according to general land unit characteristics, delivers the eroded material to the stream system, and routes the eroded material to downstream sites where its effects are interpreted.

Reinig, L., R.L. Beveridge, and J.P. Potyondy. 1991. *BOISED user's guide and program documentation.* USDA Forest Service. 27 pages.

This document includes a user guide and program documentation for a sediment prediction model used in the Boise and Payette National Forests. Program analysis steps, execution, and output are described in detail.

Ryan, J.A., I.G. Morison, and J.S. Bethel. 1974. Ecosystem modeling of a forested river basin. *Water Resources Bulletin.* 10:703-709.

This paper describes the efforts of researchers at the College of Forest Resources, University of Washington, to model the forest ecosystem of the Snohomish River Basin in the Cascade Mountains of western Washington. They used a general system model with submodels of product conversion processes, forest production processes, recreation supply processes, wildlife and fisheries supply processes, and the interactions of these processes with water and the atmosphere. The model emphasized the monitoring of NPS as well as point source impacts rather than predicting short- term hydrographs. The significance of impacts varied with land use patterns and the goals of the modeler. The model was able to predict hydrologic conditions for both large and small scales. The water subsystem model responded to management decisions by interpreting the effects of management options selected by the modeler for 40-acre cells within the Basin. The model then determined which streams were immediately affected, defined the watersheds contributing to these streams, and extracted from a resource data bank the information needed to define model parameters. Mean flow discharge on a monthly and annual basis was then calculated for the impacted subwatersheds as well as 21 major Basin watersheds. Water quality responses predicted for these watersheds include suspended sediment concentration, temperature increases due to stream exposure, dissolved oxygen concentrations, the effects of fertilization on nitrogen content, biocide and herbicide effects, and residues from product conversion processes.

Sullivan, K., J. Tooley, K. Doughty, J.E. Caldwell, and P. Knudsen. 1990. *Evaluation of prediction models and characterization of stream temperature regimes in Washington.* Washington Department of Natural Resources, Olympia, Washington. Timber/Fish/Wildlife Report No. TFW-WQ3-90-006.

A temperature study was conducted in 1988 to develop a method to address temperature sensitivity on a site and basin scale. Data were collected from forest streams extensively (92 sites) throughout the state to develop a temperature screening method and intensively at a smaller number of sites (33) to evaluate the predictive capabilities of existing reach and basin temperature models. This report presents the results of the temperature study and provides a preliminary evaluation of the effectiveness of riparian management regulations based primarily on temperature modeling.

USDA Forest Service. Undated. ***Forest hydrology: Hydrologic effects of vegetative manipulation, Part II.***

This document is concerned with the manipulation of vegetation and the subsequent effects that may be expected from water yield. The techniques, procedures, and guidelines contained in the document are designed for use by field foresters to assess past, present, and future vegetation manipulation practices on the water and watershed resource. The guidelines are intended to aid in the optimum management of the forest resource while maintaining values placed on it by silvicultural, social, economic, and ecological constraints.

USDA Forest Service. 1993. ***SHADOW. Stream Temperature Management Program User's Manual, Version 2.3.*** **USDA Forest Service, Pacific Northwest Region. 20 pages.**

The microcomputer program SHADOW was developed as a "front end" to Brown's temperature prediction equations. A key element in Brown's equations is the amount of unshaded stream, which the user must estimate qualitatively. However, users often fail to take into account stream orientation, terrain slope, and vegetation characteristics. The SHADOW program aids the user in estimating the amount of unshaded stream and maximum stream temperature. It is a physically based model designed to be used within the time constraints of most project planning efforts, and it can be used for individual stream reaches or for basins. The User's Manual fully describes the use, data requirements, and application of the program. Numerous figures illustrate how to accurately estimate values for required variables. The program requires a PC AT (386 or 486), Lotus 1-2-3 version 2.01 or higher, and a printer. Copies of the program and documentation are available from the Regional Watershed Staff of the Pacific Northwest Region in Portland, Oregon.

USDA Forest Service. 1991. ***Water and sediment yields (WATSED).*** **USDA Forest Service, Northern Region, Missoula Montana.**

WATSED is a water and sediment yield prediction model developed by the USDA Forest Service. The model was designed to simulate the effects of water and sediment from watersheds with intermingled ownership. This document is the user's guide for the model.

USEPA. 1980. ***An approach to water resources evaluation of non- point silvicultural sources (a procedural handbook).*** **U.S. Environmental Protection Agency, Athens GA.**

This useful handbook provides an analysis methodology that can be used to describe and evaluate changes in water resources resulting from nonpoint silvicultural activities. It covers only the pollutant generation and transport processes and does not consider the economic, social, and political aspects of pollution control. The document contains significant amounts of data to aid with the selection of BMPs.

USEPA. 1992. ***Compendium of watershed-scale models for TMDL development.*** **U.S. Environmental Protection Agency, Office of Water, Washington, DC. EPA/841/R-92-002.**

This document identifies the most widely used watershed-scale models that can facilitate the TMDL process. It is intended to help water quality managers and other potential users decide which model best suits their needs and available resources. This is a summary document that provides the strengths and limitations of various watershed models.

Van Sickle, J., and S.V. Gregory. 1990. Modeling inputs of large woody debris to streams from falling trees. ***Canadian Journal of Forest Research.*** **20(10):1593-1601.**

This paper presents a generalized model for estimating the amount of large woody debris delivered to streams from stands of mixed tree heights and species composition. The estimates of debris input were based on the density (trees/area), tree size distribution, and tree-fall probability of the riparian stand adjacent to the stream. The model was applied to an old-growth coniferous stand in Oregon's Cascade Mountains.

Debris pieces in the stream were generally shorter than predicted by the model, probably because of bole breakage during tree fall. The authors discuss the coupling of the model to a stream dynamics model to give land managers a tool to explore the long-term consequences of management alternatives for woody debris inputs to streams and floodplains.

Adams, T.N., and K. Sullivan. 1988. *The physics of forest stream heating: A simple model.* Weyerhaeuser Technical Report.

Barber, B.S. 1982. *Application and evaluation of the Gospel-Hump SNOWSED model on a small forested watershed in north-central Idaho.* University of Idaho, Moscow, Idaho. 135 pages.

Belt, G.H. 1980. *Predicting streamflow changes caused by forest practices using the Equivalent Clearcut Area Model.* Bulletin 32. University of Idaho Forest, Wildlife, and Range Experiment Station.

Beschta, R.L. 1987. *Conceptual models of sediment transport in streams, sediment transport in gravel-bed rivers.* John Wiley & Sons Ltd., New York. pp. 387-419.

Beschta, R.L., and J. Weatherred. 1984. *TEMP-84: A computer model for predicting stream temperatures resulting from the management of streamside vegetation.* U.S. Department of Agriculture, Watershed Systems Development Group, Fort Collins, Colorado. WSDG-AD-00009.

Burns, R.G. 1978. *An improved sediment delivery model for piedmont forests.* Master's Thesis, University of Georgia, School of Forest Resources, 72 pages.

Burns, R.G., and J.D. Hewlett. 1983. A decision model to predict sediment yield from forest practices. *Water Resources Bulletin.* 19(1):9-14.

Burton, T.A., and J.P. Potyondy. 1992. *Guidelines for the use of the BOISED sediment yield model and the fisheries habitat condition index in forest plan implementation on the Boise National Forest.* Boise National Forest Report. USDA Forest Service.

Dumbauld, R.K. 1984. Modeling of aerial spray drift and canopy penetration. In: *Chemical and Biological Controls in Forestry.* Washington, D.C. W.Y. Garner and J. Harvey (eds.). ACS Symposium Series 238.

Foster, G.R., L.D. Meyer, and C.A. Onstad. 1977. A runoff erosivity factor and variable slope length exponent for soil loss estimates. *Transactions of the ASAE.* 20(4):683-687.

Gerhardt, N. 1992. Comparison of measured and modeled sediment yields on selected streams of the Nez Perce National Forest. In: *Abstracts of the Second Annual Nonpoint Source Water Quality Monitoring Results Workshop.* Boise State University, January 14- 16, 1992. Sponsored by: Idaho Department of Health and Welfare, Department of Environmental Quality. pp. 11.

Heller, D.A., J.R. Maxwell, and M. Parsons. 1983. *Modeling the effects of forest management on salmonid habitat.* USDA Forest Service, Pacific Northwest Region. 63 pages.

James, D.E., and M.J. Hewitt. Modeling nonpoint source pollution in the Blackfoot river drainage. In: *Proceedings of Technical Workshop on Sediments.* Corvallis, Oregon, February 3-7, 1992. U.S. Environmental Protection Agency and USDA Forest Service.

Lane, L.J., and M.A. Nearing (eds). 1989. *USDA erosion prediction projects: Hillslope profile model documentation.* USDA ARS National Soil Erosion Laboratory, West Lafayette, Indiana. NSERL Report No. 2.

Megahan, W.F. 1974. *Erosion over time on severely disturbed granitic soils: A model.* USDA Forest Service, Intermountain Forest and Range Experiment Station. Research Paper INT-156.

Morse, W.L. 1970. Stream temperature prediction model. *Water Resources Research.* 6(1):290-302.

Nutter, W.L., T.T. Kacs, P.B. Bush, and D.G. Neary. 1984. Simulation of herbicide concentrations in stormflow from forested watersheds. *Water Resources Bulletin*. 20(6): 851-858.

Prellwitz, R.W. 1988. *SSIS and SCHFS-Preliminary slope stability analyses with the HP41 programmable calculator*. USDA Forest Service, Intermountain Research Station, Missoula, Montana.

Simons, D.B., R.M. Li, T.J. Ward, and L.Y. Shiao. 1982. Modeling of water and sediment yields from forested drainage basins. In: *Workshop on sediment budgets and routing in forested drainage basins: Proceedings*. F.J. Swanson (ed.). USDA Forest Service, Pacific Northwest Forest and Range Experiment Station, Portland, Oregon. General Technical Report PNW-141. pp. 24-38.

Van Sickle, J., and R.L. Beschta. Supply-based models of suspended sediment transport in streams. *Water Resources Research*. 19(3):768-778.

Willis, R., D.R. Anderson, and J.A. Dracup. 1975. Steady-state water quality modeling in streams. *Journal of the Environmental Engineering Division*. 101(EE2):245-258. American Society of Civil Engineers.

Wischmeier, W.H. 1976. Use and misuse of the Universal Soil Loss Equation. *Journal of Soil and Water Conservation*. 31:5-9.

Ziemer, R.R., J. Lewis, R.M. Rice, and T.E. Lisle. 1991. Modeling the cumulative watershed effects of forest management strategies. *Journal of Environmental Quality*. 20:36-42.

MODELING EFFECTS OF BMPs

Bauer, S.B., G.W. Harvey, and T.A. Burton. Idaho 319 Nonpoint source program summary: Forest roads inventory and stabilization report. In: *Proceedings of Technical Workshop on Sediments*. Corvallis, Oregon, February 3-7, 1992. U.S. Environmental Protection Agency and USDA Forest Service.

An inventory of forest road stability was conducted in the Idaho Clearwater basin. Roads causing the greatest impact on stream water quality were identified and priority stream segments and roads were selected based on the results of an empirical sedimentation model. The model simulated sediment yields using the following mitigation measures: full vegetation of fill slopes; full vegetation of cut slopes; cut slope gradient decreased 10 percent; cut slope gradient decreased 20 percent; road tread graveled; and road tread paved. In general, rehabilitation of cut slopes and relocation away from streams were the most effective measures for reducing sediment. .

Beasley, D.B., and D.L. Thomas. 1989. *Application of water quality models for agricultural and forested watersheds*. University of Georgia, Agricultural Engineering Department. Southern Cooperative Series Bulletin No. 338. 116 pages.

The information presented in this report covers three main objectives of the initial research: (1) to evaluate, compare, and test existing hydrologic/water quality models for use in simulating the effects of forestry and agricultural practices on the quality, quantity, and utilization of surface and subsurface waters; (2) to modify, develop, and/or adapt process models of water, sediment, and chemical transport for surface and subsurface flow; and (3) to assemble selected water quality and quantity data from existing facilities for use in model evaluation and comparison. This is a summary paper on the strengths, limitations, and past uses of several well-known models.

Burns, R.G., and J.D. Hewlett. 1983. A decision model to predict sediment yield from forest practices. *Water Resources Bulletin.* 19(1):9-14.

The authors propose a sediment hazard index based on the amount of exposed mineral soil and its proximity to streams as a means to choose among BMPs. Forest managers need to predict sediment yield to perennial streams following forestland operations, but the universal soil loss equation (USLE) is not directly applicable to forest operations because of the heterogeneous soil surface conditions left by harvesting, site preparation, and planting. The model described includes rainfall erosivity, soil erodibility and average land slope, together with the sediment hazard index (W). A paired watershed experiment in the central Georgia Piedmont was used to estimate parameters in the model. The 80-acre experimental basin was clearcut, drum roller chopped twice, and machine planted. The standard error of estimate of sediment yield was computed to be about 50 lb/ac per 4-month sampling period. Use of William's erosivity index (storm flow times peak flow) reduced the standard error to 33 lb/ac. A graph of sediment delivery versus sediment hazard index is provided, and the index can be used to design and evaluate forest operations in advance. The authors note that application of the method presumes the use of streamside management zones and sensible roading standards.

Cline, R., G. Cole, W. Megahan, R. Patten, and J. Potyondy. 1981. *Guide for predicting sediment yields from forested watersheds.* USDA Forest Service, Northern Region and Intermountain Region.

A sediment yield prediction procedure was developed by a work group composed of soil scientists, hydrologists, and watershed specialists of the Forest Service Northern Region, Intermountain Region, and the Intermountain Forest and Range Experiment Station (R1/R4). This is a detailed document that contains basic information which has been used extensively in sediment transport model development.

Dissmeyer, G.E. 1980. Predicted erosion rates for forest management activities and conditions in the southeast. In: *U.S. Forestry and Water Quality: What Course in the 80's?* Richmond, Virginia, June 19-20, 1980. Water Pollution Control Federation and Virginia Water Pollution Control Association. pp. 42-49.

Erosion prediction has improved for forestland during the past 3 years. The new procedure has been validated, with the predicted rates comparing well with measured rates. The new procedure is a modification of the cover-management (C) factor of the Universal Soil Loss Equation. Using this modification, representative rates are presented to compare erosion between various forest management activities and conditions, and to show the recovery trends in erosion for various disturbances.

Fight, R.D., L.D. Garrett, and D.L. Weyermann (eds.). 1990. *SAMM: A prototype southeast Alaska multiresource model.* USDA Forest Service, Pacific Northwest Research Station. General Technical Report PNW-GTR-255. 109 pages.

An environmental assessment method was used by an interdisciplinary team of forest specialists to gain an understanding of resource interactions and tradeoffs resulting from forest management activities in southeast Alaska. A forest multiresource projection model (Southest Alaska Multiresource Model (SAMM)) was developed in the process. The model was proclaimed to be capable of characterizing and displaying interactions of four major resources over a 150-year rotation: timber, wildlife, hydrology, and fisheries. At the time the document was published, full use of the model for quantitative analysis was not available; only qualitative planning assessment were recommended.

Gregory, R., E. Niemi, and R. Mendelsohn. 1989. A model for evaluating the impacts of forest management regulations. *Journal of Environmental Management*. 29:129-144.

This paper addresses the need of forest-management agencies to anticipate the impacts of regulations governing forest practices and outlines a model for evaluating the economic impacts of proposed changes in the forest environment. The approach described is based on two premises. First, the primary effect of changes of forest management rules is on the environment and therefore linkages between the rule changes, environmental impacts, and then economic values must be developed. Second, both market and nonmarket effects must be evaluated.

Hornbeck, J.W., C.A. Federer, and R.S. Pierce. 1987. Effects of whole-tree clearcutting on streamflow can be adequately estimated by simulation. In: *Forest Hydrology and Watershed Management, Proceedings of an International Symposium of the General Assembly of the International Union of Geodesy and Geophysics at Vancouver, B.C., Canada*. Vancouver, Britsh Columbia, August, 1987. R.H. Swanson et al. (eds.). IAHS-AISH Publication No. 167, Canada. pp. 565-573.

A range of values was assigned to parameters of the BROOK hydrologic model to simulate streamflow for fast, medium, and slow regrowth on whole-tree clearcut basins in Maine, New Hampshire, and Connecticut. Data are presented to show how the simulated results compare with measured data.

Hornberger, G.M., K.J. Beven, B.J. Cosby, and D.E. Sappington. 1985. Shenandoah watershed study: Calibration of a topography-based, variable contributing area hydrological model to a small forested catchment. *Water Resources Research*. 21(12):1841-1850.

This paper reports on work done to calibrate TOPMODEL, a model devised by Beven and Kirkby (1979), for White Oak Run in the Shenandoah National Park. This research is part of the Shenandoah Watershed Study, which began in 1979 and aims to assess the impact of acid precipitation on soils and streams in the Park. TOPMODEL is a topography-based, variable-contributing-area model of catchment hydrology. It was adapted for continuous simulation and extended to take account of observed processes in White Oak Run. Automatic calibration of the model was attempted using eight different objective functions. All objective functions were indifferent to many of the model parameters, and thus parameter estimation could not be done reliably. On the basis of results from a regionalized sensitivity analysis, the original model structure was greatly simplified. The parameters of the simplified model, which produced fits to the measured data nearly as well as did the more complex model, were estimated well using a sum of squared errors criterion. The authors discuss how TOPMODEL was calibrated for this application and difficulties encountered in doing so.

Lewis, J., and R.M. Rice. 1990. Estimating erosion risk on forest lands using improved methods of discriminant analysis. *Water Resources Research*. 26(8):1721-1733.

This study developed a method for estimating the risk that logging or road construction will produce a critical erosion site. A critical site is defined as any 2-acre square area enclosing more than 200 yd^3 of erosional voids. In this study, a population of 638 timber harvest areas in northwestern California was sampled for data related to the occurrence of critical amounts of erosion. Separate analyses were done for forest roads and logged areas. Three-variable equations were developed that can be used to compute the probability that logging or road construction on a given site in northwestern California will cause severe erosion. Three important site conditions relate to erosion risk: the force of gravity, the convergence of subsurface water, and the strength of materials. This work suggests that models can provide satisfactory estimates for the risk of large

erosion events. The variables in the equations should be easy for foresters to estimate in the field. The authors provide a glossary and explanation of terms and variables related to the equations developed in the paper.

Nieswand G.H., R.M. Hordon, T.B. Shelton, and B. Chavooshian. 1990. Buffer strips to protect water supply reservoirs: A model and recommendations. *Water Resources Bulletin.* 26(6):959-966.

This paper discusses the development of a parameter-based model for buffer strip width determination for use in New Jersey, as part of a comprehensive watershed management project. The model is primarily intended for application to all watersheds above water supply intakes or reservoirs. Input requirements for the model include a combination of slope, width, and time of travel. Development of the model and its application to a watershed in New Jersey are discussed. The application results in a recommended buffer strip width that ranges from 50 to 300 feet, depending on a number of assumptions, and from 6-13% of the watershed area above the protected waterbody (reservoir) being occupied by the buffer.

Potyondy, J.P., G.F. Cole, and W.F. Megahan. 1991. A procedure for estimating sediment yield from forested watersheds. In: *Proceedings of the Fifth Interagency Sedimentation Conference, Vol. 2.* Las Vegas, Nevada, March 18-21, 1991. Interagency Committee on Water Data, Subcommittee on Sedimentation. Section 12, pp 46-54.

The operational sediment yield model used by the Boise National Forest is described. The model is a local adaptation of the model developed by the U.S. Forest Service for application in the Idaho Batholith. The model is commonly used in the preparation of environmental assessments and impact statements as a tool to evaluate the effects of alternative timber harvest activities, road location and design, and the application of erosion mitigation practices. The model estimates on-site erosion, modifies the amount of erosion according to general land unit characteristics, delivers the eroded material to the stream system, and routes the eroded material to downstream sites where its effects are interpretated.

Steinblums, I., H.A. Froehlich, and J.K. Lyons. 1984. Designing stable buffer strips for stream protection. *Journal of Forestry.* 82(1):49-52.

Failure of buffer strips due to blowdowns, disease, and logging is a recurring problem and can cause stream channels to load with debris, leading to sediment storage or erosion. This article reports a study of environmental factors that affect buffer strip stability and stream shading. On 40 streamside buffer strips in the Cascade Mountains of western Oregon, buffer strip stability was found to be a function of one vegetation and six topographic equation variables, and shading was related to three characteristics of buffer strips and one of adjacent clearcuts. Topographic maps and aerial photographs were used to supplement field observations. Stability and shading effectiveness of proposed buffer strips can be evaluated using the equations presented in the paper and data collected through site reconnaissance and topographic maps.

Sullivan, K., J. Tooley, K. Doughty, J.E. Caldwell, and P. Knudsen. 1990. *Evaluation of prediction models and characterization of stream temperature regimes in Washington.* Washington Department of Natural Resources, Olympia, Washington. Timber/Fish/Wildlife Report No. TFW-WQ3-90-006.

A temperature study was conducted in 1988 to develop a method to address temperature sensitivity on a site and basin scale. Data were collected from forest streams extensively (92 sites) throughout the state to develop a temperature screening method and intensively at a smaller number of sites (33) to evaluate the predictive capabilities of existing reach and basin temperature models. This report presents the results of the temperature study and provides a

preliminary evaluation of the effectiveness of riparian management regulations based primarily on temperature modeling.

Burton, T.A., and J.P. Potyondy. 1992. *Guidelines for the use of the BOISED sediment yield model and the fisheries habitat condition index in forest plan implementation on the Boise National Forest*. Boise National Forest Report. USDA Forest Service.

James, D.E., and M.J. Hewitt. Modeling nonpoint source pollution in the Blackfoot river drainage. In: *Proceedings of Technical Workshop on Sediments*. Corvallis, Oregon, February 3-7, 1992. U.S. Environmental Protection Agency and USDA Forest Service.

Prellwitz, R.W. 1988. *SSIS and SCHFS-Preliminary slope stability analyses with the HP41 programmable calculator*. USDA Forest Service, Intermountain Research Station, Missoula, Montana.

Rasmussen, W.O., R.N. Weisz, P.F. Ffolliott, and R.D. Carder. 1980. Planning for forest roads-A computer-assisted program for selection of alternative corridors. *Journal of Environmental Management*. 11:93-104.

USDA Forest Service. 1991. *Water and sediment yields (WATSED)*. USDA Forest Service, Northern Region, Missoula Montana.

USEPA. 1980. *An approach to water resources evaluation of non- point silvicultural sources (a procedural handbook)*. U.S. Environmental Protection Agency, Athens GA.

Ziemer, R.R., J. Lewis, R.M. Rice, and T.E. Lisle. 1991. Modeling the cumulative watershed effects of forest management strategies. *Journal of Environmental Quality*. 20:36-42.

11. WATER QUALITY MONITORING

METHODS AND PROCEDURES

Corner, R., J. Bassman, B.C. Moore, and B. Zamora. 1992. The application of on-site characterizations of vegetation and soils for regulating water quality impacts from forestry practices. *North American Lake Management Society Journal.*

Water quality and vegetation and soil parameters were measured over a 1-year period on three sites subjected to clearcut harvesting and scarification site preparation. The paper includes information on the potential application of on-site vegetation and soil standards for regulating nonpoint water pollution from forestry activities, including advantages and disadvantages in comparison with water quality standards.

Cullen, P. 1990. Biomonitoring and environmental management. *Environmental Monitoring and Assessment*. 14:107-114.

The role of biomonitoring data in determining the health of aquatic systems is reviewed. Information on the objectives, pressures, principles, and tools for biotic monitoring are discussed in this general review.

Dissmeyer, G.E. 1993. *Methods for evaluating the effectiveness of forestry best management practices in meeting water quality goals or standards: Second Draft*. 189 pages.

The focus of this document is monitoring BMP effectiveness in protecting the water quality of small order streams. The objectives are to insure monitoring projects consider all factors influencing NPS pollution; to design monitoring projects that sort out real impacts of BMPs; to review parameters to consider when monitoring BMP effectiveness; to summarize representative monitoring methods appropriate for NPS variables; and to provide examples of BMP effectiveness monitoring and decisions. Monitoring methods discussed included on-slope. chemical and physical, channel geomorphology, habitat, biological, and aquatic vegetation and zooplankton.

Hankin, D.G. 1984. Multistage sampling designs in fisheries research: Application in small streams. *Canadian Journal of Fisheries and Aquatic Sciences*. 41:1575-1561.

This paper argues that the usual practice of selecting stream sections of equal length for estimating the total number of fish in a stream is ill-advised on both biological and statistical grounds, and that a preferable practice is to allow stream sections to vary in size according to natural habitat units. The latter method allows for alternative two-stage sampling designs to take advantage of the probable strong correlation between habitat unit sizes and fish numbers. Relative performances of four alternative two-stage designs are contrasted in terms of precision, relative cost, and overall cost-effectiveness. Choice among alternative designs depends primarily on the correlation between fish numbers and habitat unit sizes, on the total number of stream sections, and on sample size. The author recommends choices among the design alternatives based on these criteria.

Hankin, D.G. 1986. *Sampling designs for estimating the total number of fish in small streams*. Research Paper PNW-360. USDA Forest Service, Pacific Northwest Forest and Range Experiment Station.

This report reviews the sources of error in estimating the total number of fish in small streams. Error of estimation arises from two sources: (1) extrapolation from the small number of sampled stream sections to the entire stream and (2) errors of estimation of fish numbers within sampled sections. This report shows that errors arising from the first source will usually be far larger than those arising from the second source. Total errors of estimation can be reduced by making sampled sections equivalent to natural habitat units. Entire pools or riffles should be

sampled rather than fixed-length sections of streams. The relative performances of three alternative sampling designs, which can be used when sampled sections are equivalent to natural habitat units, are contrasted in terms of accuracy and cost- effectiveness. Accuracy of estimation can be dramatically improved if sampling designs account for the usually strong, positive correlation between fish numbers and habitat unit sizes. The report presents information on basic sampling theory concepts, traditional two-stage sampling design, and three alternative two-stage sampling designs.

Hoffman, R.J. 1986. A horizontal intragravel pipe for sampling water quality in salmonid spawning gravel. *North American Journal of Fisheries Management*. 6:445-448.

A sampler, the horizontal intragravel pipe, was developed for collecting samples of intragravel water in salmonid spawning gravel. The paper provides good information on the advantages associated with this method.

Kunkle, S., W.S. Johnson, and M. Flora. 1987. *Monitoring stream water for land-use impacts: A training manual for natural resource management specialists*. National Park Service, Water Resources Division, Ft. Collins, CO.

The purpose of this document is to suggest strategies for designing and implementing simple, cost-effective surveys of water quality impacts resulting from land use in and around National Park Service areas. Specifically, monitoring strategies presented in the document address forestry, agricultural, urbanization, recreation, mining, and oil and gas development practices. This handbook provides a strategy for designing a problem-oriented water quality monitoring plan, identifying sources of suspected water pollution caused by different land uses, and recognizing when additional study of a water quality problem may be required.

Leister, R.L. 1985. Monitoring silvicultural activities for water quality. In: *Proceedings of Forestry and Water Quality: A Mid- South Symposium*. University of Arkansas, May 8-9, 1985. B.G. Blackmon (ed.). University of Arkansas, Department of Forestry Resources, Little Rock, Arkansas. pp. 177-183.

In this talk, Mr. Leister discusses the training and monitoring activities of the Arkansas Forestry Commission (AFC) that were initiated in 1982. Goals were set for all county foresters, including monitoring at least two sites per county per month on privately-owned and industrial forests. Training to select and monitor sites, to apply and evaluate BMPs, and to recognize potential water quality problems was well underway within 6 months. The first few years of monitoring were conducted statewide on a variety of types of forest sites in an attempt to build a base on the impacts of various practices on forestland sites and on streams and rivers. In the first 3 years of the program, the AFC monitored 1,666 sites totaling 143,595 acres. Monitoring began immediately following the silvicultural activity and continued for 4 years. Ownership of forestlands in Arkansas is summarized according to U.S. Forest Service Survey data.

MacDonald, L.H., A.W. Smart, and R.C. Wissmar. 1991. *Monitoring guidelines to evaluate the effects of forestry activities on streams in the Pacific Northwest and Alaska*. U.S. Environmental Protection Agency, Seattle, Washington. EPA/910/9-91-001.

This document provides significant guidance for designing water quality monitoring projects and selecting monitoring parameters. Although the focus is on forest management and streams in the Pacific Northwest and Alaska, a broader perspective is taken, and much of the information is widely available.

NCASI. 1980. *Research and field investigation of the impact of southern forestry management practices on receiving water quality and utility*. National Council of the Paper Industry for Air and Stream Improvement. Technical Bulletin No. 337.

This is an assembly of papers and abstracts of presentations made at the 1980 NCASI Southern Regional Meeting. The papers describe work

under way at universities, individual company programs, programs in the South being conducted by USDA Forest Service, and aquatic biology. Sample titles include: Regional Road Project-Management Options to Control Erosion; Assessment of NPS Pollution from Intensive Forest Practices in the South Central Region, Texas; Demonstration of Sensitive Area Mechanical Site Preparation; The Use of Macroinvertebrates as Indicators of Stream Quality Changes; and Report on Ongoing Programs and Information Needs Relating to Southern Forest Practices and Water Quality.

Oregon Department of Forestry. 1992. *Forest herbicide application: Water sampling study.* Oregon Department of Forestry, Forest Practices Program.

The purpose of this report is to present the results of a water monitoring study conducted by the Forest Practices Program to determine the effectiveness of forest chemical rules in preventing stream contamination from herbicide applications. The study was not conducted using the rigorous QA/QC protocols typical of field research studies but was conducted to provide general insight into forest chemical rule effectiveness.

Ponce, S.L. 1980. *Statistical methods commonly used in water quality data analysis.* USDA Forest Service, Fort Collins, CO. Technical Paper WSDG-TP-00001.

The purpose of this handbook is to review several selected statistical methods commonly used in water quality data analysis. It is intended to be used by forest hydrologists in conjunction with FS Technical Paper WSDG-TP-00002.

Ponce, S.L. 1980. *Water quality monitoring programs.* USDA Forest Service, Ft. Collins, CO. Technical Paper WSDG-TP-00002.

The purpose of this paper is to summarize the various types of water quality monitoring commonly carried out on National Forest System lands, and to provide a series of guidelines to aid the forest hydrologist with problem definition, establishing study objectives, locating past work, data analysis, locating sampling stations, selecting water quality constituents, determining sampling frequency, and collecting and handling samples.

Schultz, B. 1992. *Montana forestry best management practices implementation monitoring: The 1992 forestry BMP audits final report.* Montana Department of State Lands, Forestry Division, Missoula, Montana. 32 pages.

This report summarizes the findings of Montana's 1992 forestry BMP audits. The audits evaluate whether BMPs are being applied and whether they are effectively limiting NPS pollution. Three audit teams evaluated up to 58 practices on 46 sites for a total of 2,029 practices rated for BMP application. Eight-seven percent of the practices rated on all sites met BMP requirements. Nine high-risk BMPs, the most important for protecting watersheds, were evaluated separately, and 72% of these met application requirements. Most sites-40 of 46-had at least one minor departure from BMP application; 20 of 46 sites had at least one major departure. On 21 of 46 sites, audit teams noted that a change in stream crossing would have prevented or reduced sediment discharge. The wider SMZs were, the fewer were the impacts in the SMZ from harvest practices. The greatest departure from BMPs, as well as the most impacts, was associated with road drainage. Application and effectiveness of BMPs were highest on state lands, followed by federal and industrial sites and nonindustrial private sites. The study recommends that the audits be continued; education programs be continued; site owners and logging contractors attend the audits; landowners and contractors develop remedies for the problems noted; and the audit process be instituted for other land uses, including mining, livestock grazing, agriculture, and subdivision development.

Solomon, R.M., and P.E. Avers. 1987. *A water quality monitoring framework to satisfy legal requirements*. American Water Resources Association. Technical Publication Series TPS 87-2. pp. 231-242.

The paper discusses the development of water quality monitoring requirements as they relate to the Forest Service. A monitoring framework that will meet legal requirements is suggested. The framework includes three types of monitoring: (1) implementation, or determining whether monitoring plans were implemented as designed; (2) effectiveness, or determining whether the prescribed practices meet their objectives; and (3) validation, or investigating whether coefficients, models, and standards are valid to meet policy, laws, and regulations. Examples of each type of monitoring are given, and the usefulness of monitoring as a feedback mechanism for management decision-making is discussed.

USEPA. 1988. *Effectiveness of agricultural and silvicultural nonpoint source controls: Final report*. U.S. Environmental Protection Agency, Region 10, Seattle, Washington.

This document presents an analysis of specific monitoring methods and monitoring programs for nonpoint source controls associated with silvicultural and agricultural practices. From the analysis, information is provided to aid in determining base guidelines for monitoring the effectiveness of NPS control programs.

USEPA. 1989. *Rapid bioassessment protocols for use in streams and rivers: Benthic macroinvertebrates and fish*. U.S. Environmental Protection Agency, Office of Water, Washington DC. EPA/444/4-89- 001.

The primary purpose of this document is to provide states with a practical technical reference for conducting cost-effective biological assessments of lotic systems. The scope of the document is applicable to priority setting, point and nonpoint source evaluations, use attainability analyses, trend monitoring, and initial screening.

USEPA. 1987. *Surface water monitoring: A framework for change*. U.S. Environmental Protection Agency, Office of Water, OPPE, Washington, DC.

This report presents the findings and recommendations of a major EPA study on surface water monitoring activities conducted by the Agency. The results are based on more than 150 structured interviews with key state and federal managers, and numerous less formal discussions with EPA and state scientific and technical staff. The report presents the findings on where surface water monitoring is today, why the present state/EPA program is not adequate to meet emerging needs, and where and how changes should be made.

USEPA. 1991. *Watershed monitoring and reporting for section 319 national monitoring program projects*. U.S. Environmental Protection Agency.

Section 319 of the Clean Water Act requires that EPA develop both a national framework and monitoring guidelines for the National Monitoring Program. Key aspects of the national framework have been developed and are summarized in this document. This document also provides monitoring and reporting guidelines.

Weller, C.G. 1990. Monitoring engineering activities. In: *Proceedings of the National Workshop on Monitoring Forest Plan Implementation*. Minneapolis, Minnesota, May 14-17. USDA Forest Service. pp. 75-79.

This is a series of four tables that list monitoring requirements for engineering activities within the Forest Service and other land management agencies. Table 1 lists the requirements of 36 CFR 219. Additional requirements for monitoring transportation systems, found in 36 CFR 212, 23 CFR 650 and 1230, and P.L. 88-657, are listed in Table 2. Requirements for monitoring drinking water, for water pollution control, and for solid waste disposal, recovery, and resource conservation and recovery are listed in Table 3. Table 4 contains a more comprehensive listing of engineering activity

monitoring standards and guides, with references to federal regulations. Specifically, Table 4 lists items to monitor, project standards, and requirements for implementation, effectiveness and validation monitoring.

Blackmon, B.G. (ed). 1985. *Forestry and water quality: A mid- south symposium*. Little Rock, Arkansas, May 8-9, 1985. Arkansas Cooperative Extension Service, University of Arkansas.

Clark, W.H. 1990. *Coordinated nonpoint source water quality monitoring program for Idaho*. Idaho Department of Health and Welfare, Division of Environmental Quality, Boise, Idaho. 139 pages.

Dissmeyer, G.E. 1991. Monitoring BMP compliance, identifying implementation problems, and implementation vs. other types of monitoring. In: *Southern Group of State Foresters Workshop on Implementation Monitoring of Forestry Best Management Practices*. Atlanta, Georgia, January 23-25, 1990. USDA Forest Service, Southern Region. pp. 80-84.

Hankin, D.G., and G.H. Reeves. 1988. Estimating total fish abundance and total habitat area in small streams based on visual estimating methods. *Canadian Journal of Fisheries and Aquatic Sciences*. 45:834-844.

Hirsch, R.M. 1988. Statistical methods and sampling design for estimating step trends in surface-water quality. *Water Resources Bulletin*. 24(3):493-503.

Jones & Stokes Associates, Inc. 1973. *A method for regulating timber harvest and road construction activity for water quality protection in northern California, Volume I: Procedures and methods*. California State Water Resources Control Board.

Lenat, D.R. 1988. Water quality assessment of streams using a qualitative collection method for benthic macroinvertebrates. *Journal of the North American Benthological Society*. 7:222-233.

Miller, D.L., P.M. Leonard, R.M. Hughes, J.R. Karr, P.B. Moyle, L.H. Schrader, B.A. Thompson, R.A. Daniels, K.D. Fausch, G.A. Fitzhugh, J.R. Gammon, D.B. Halliwell, P.L. Angermeier, and D.J. Orth. 1988. Regional applications of an index of biotic integrity for use in water resources management. *Fisheries*. 13(5):12-20.

NCASI. 1984. *A guide to monitoring streamwater quality following forestry herbicide concentration*. National Council of the Paper Industry for Air and Stream Improvement. Technical Bulletin No. 430. 40 pages.

NCASI. 1988. *Procedures for assessing the effectiveness of Best Managements Practices in protecting water and stream quality associated with managed forests*. National Council of the Paper Industry for Air and Stream Improvement. Technical Bulletin No. 538. 23 pages.

Neary, D.G. 1983. Monitoring herbicide residues in springflow after an operational application of hexazinone. *Southern Journal of Applied Forestry*. 17(4):217-223.

Neary, D.G., P.B. Bush, and J.L. Michael. 1986. Herbicides in southern forestry-Improving water quality. In: *39th Proceedings - Southern Weed Science Society*. pp. 335-341.

Thomas, R.B. 1985. *Measuring suspended sediment in small mountain streams*. USDA Forest Service. General Technical Report PSW-83. 9 pages.

DATA ANALYSIS AND STUDY DESIGN

Aumen, N.G., T.J. Grizzard, and R.H. Hawkins. 1989. *Water quality monitoring in the Bull Run watershed, Oregon*. Bureau of Water Works Task Force Final Report to City of Portland, Oregon. 108 pages.

This report presents the findings of a task force commissioned to address concerns over the adequacy of a monitoring program in the Bull Run watershed in Portland, OR. The task force

was specifically charged with assessing the adequacy of the existing program to determine compliance with water quality standards and the adequacy of the existing monitoring program to assess the effects of land management practices such as forestry operations.

Dissmeyer, G.E. 1993. *Methods for evaluating the effectiveness of forestry best management practices in meeting water quality goals or standards: Second Draft*. 189 pages.

The focus of this document is monitoring BMP effectiveness in protecting the water quality of small order streams. The objectives are to insure monitoring projects consider all factors influencing NPS pollution; to design monitoring projects that sort out real impacts of BMPs; to review parameters to consider when monitoring BMP effectiveness; to summarize representative monitoring methods appropriate for NPS variables; and to provide examples of BMP effectiveness monitoring and decisions. Monitoring methods discussed included on-slope. chemical and physical, channel geomorphology, habitat, biological, and aquatic vegetation and zooplankton.

Ice, G.G. 1989. The effectiveness of silvicultural nonpoint source control programs for several southern states. In: *Proceedings of the Symposium Forested Wetlands in the Southern United States*. Orlando, Florida, July 12-14, 1988. USDA, Forest Service. USDA Forest Service, Southeastern Forest Experiment Station. pp. 163-168.

This article identifies and summarizes studies evaluating the effectiveness of BMPs in minimizing deleterious impacts to stream quality. Assessment techniques include water quality monitoring, site inspections, questionnaires, and modeling.

Martin, C.W., R.S. Pierce, G.E. Likens, and F.H. Bormann. 1986. *Clearcutting affects stream chemistry in the White Mountains of New Hampshire*. USDA Forest Service, Northeastern Forest Experiment Station. Research Paper NE-579.

Stream water samples were collected from watersheds that were completely harvested and from uncut watersheds. Differences in stream chemistry were monitored over a 4-year period. Constituents sampled for included specific conductance, pH, nitrate, ammonium, calcium, magnesium, sodium, potassium, sulfate, and chloride.

Troendle, C.A., and R.M. King. 1985. The effect of timber harvest on the Fool Creek watershed, 30 years later. *Water Resources Research*. 21(12):1915-1922.

The Fool Creek watershed at the Fraser Experimental Forest, Colorado, was harvested using a pattern of alternating clearcut and forested strips in 1956. After 30 years of postharvest record, subtle impacts on the hydrology of the watershed were detected that had not been significant in the past.

Gerhardt, N. 1992. Comparison of measured and modeled sediment yields on selected streams of the Nez Perce National Forest. In: *Abstracts of the Second Annual Nonpoint Source Water Quality Monitoring Results Workshop*. Boise State University, January 14- 16, 1992. Sponsored by: Idaho Department of Health and Welfare, Department of Environmental Quality. pp. 11.

Moore, D.G. 1975. Impacts of forest fertilization on water quality in the Douglas fir region-A summary of monitoring studies. In: *Proceedings of the 1974 National Convention of the Society of American Foresters*. New York, September 22-26, 1974. pp. 209-219.

Solomon, R.M., and P.E. Avers. 1987. *A water quality monitoring framework to satisfy legal requirements*. American Water Resources Association. Technical Publication Series TPS 87-2. pp. 231-242.