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# THE ROLE OF ENVIRONMENTAL MONITORING IN RESPONSIBLE PROJECT MANAGEMENT

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**Abstract.** A comprehensive (or targeted) environmental monitoring program should be required of major projects as a part of their life cycle, and the resultant information should be used in environmentally responsible management and decisionmaking. Such management can be aided by specific data on various environmental media and other natural and cultural resource features. Current monitoring considerations are focused on the implementation of mitigation measures. Additional valid purposes of environmental monitoring are illustrated via eight case studies. A comprehensive or targeted environmental monitoring program should use extant monitoring data and coordinate with pertinent governmental monitoring systems. Program planning and implementation should delineate objectives related to expected key impacts, select pertinent indicators (variables), determine sampling location and frequency and analytical requirements, predevelop response strategies (management actions), and schedule periodic reporting. Incorporation of environmental monitoring requirements in the environmental impact assessment process in the United States would optimally require a combined effort of the U.S. Congress, the Council on Environmental Quality (CEQ), and each federal agency. Such requirements should be included in an amended National Environmental Policy Act (NEPA), addressed in modified CEQ regulations that delineate project types/sizes and/or criteria that can be applied to trigger such considerations, and incorporated as appropriate in specific agency guidelines/regulations.

## INTRODUCTION

In the first two decades of practice in the preparation of environmental assessments (EAs) and environmental impact statements (EISs) in the United States, emphasis has been primarily directed toward identifying, quantifying (if possible), and assessing (interpreting) the anticipated environmental impacts of proposed projects during their construction and operational stages. Environmentally responsible management requires, however, that appropriate considerations be given to key anticipated and experienced impacts over the entire life cycle of a major project, plan, or program, including the planning, construction, operational, and decommissioning phases. This requirement should be incorporated in the environmental impact assessment (EIA) process in the United States, and it should be specifically addressed in EISs prepared on such major actions.

Comprehensive environmental monitoring refers to the set of activities that provide chemical, physical, geological, biological, and other environmental, social, or health data required by environmental managers (EPA, 1985). A targeted monitoring program could include elements related to environmental media (air, surface/ground water, soil, and noise), biological features (plants, animals, and habitats), visual resources, social impacts, and human health. Pertinent ele-

ments should be selected based on the project type, baseline environmental sensitivity, and expected impacts. Components within the broad definition of environmental monitoring include: planning the collection of environmental data to meet specific objectives and environmental information needs; designing monitoring systems and studies; selecting sampling sites; collecting and handling samples; conducting laboratory analyses; reporting and storing the data; assuring the quality of the data; and analyzing and interpreting the data and making the data available for use in decisionmaking (EPA, 1985).

An integrating term being used in some countries to denote life-cycle environmental management is "post-project analysis" (PPA). PPAs refer to environmental studies undertaken during the implementation phase (prior to construction, during construction or operation, and at the time of abandonment) of a given activity after the decision to proceed has been made (ECE, 1990). Such studies can include comprehensive or targeted environmental monitoring, evaluation of the collected data and information, environmentally focused decisionmaking as appropriate, and implementation of the management decisions. PPA could be viewed as a continuous cycle over the life of a project, plan, or program.

Examples of environmentally responsible project management decisions that can be based on monitoring data and that can be beneficial in terms of minimizing adverse impacts and enhancing environmental management include: (1) reducing power production (and resultant atmospheric emissions) at a coal-fired power plant when atmospheric dispersion conditions are limiting; (2) planning training activities at a military installation so as not to coincide with the use of certain

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- (CEQ) Council on Environmental Quality. 1978. National Environmental Policy Act: Interpretation of Procedural Provisions, Final Regulations. 40 CFR 1500-1508. 43 F.R. 55978-56007.
- Culhane, P.J., T.V. Armentano, and H.P. Friesema. 1985. State-of-the-Art Science and Environmental Assessments: The Case of Acid Deposition. *Environmental Management* 9(5): 365-378.
- Culhane, P.J., H.P. Friesema, and J.A. Beecher. 1987. *Forecasts and Environmental Decisionmaking: The Content and Predictive Accuracy of Environmental Impact Statements*. Westview Press, Boulder, CO.
- (DOE) U.S. Department of Energy. 1992. National Environmental Policy Act: Implementing Procedures and Guidelines Revocation, Final Rule. 10 CFR 1021. 57 F.R. 15122-15150.
- Drucker, P. 1954. *The Practice of Management*. Harper & Row, New York.
- Drucker, P. 1976. A Users' Guide to MBO. *Public Administration Review* 36(January): 12-19.
- Duinker, P.N. 1989. Ecological Effects Monitoring in Environmental Impact Assessment: What Can It Accomplish? *Environmental Management* 13(6): 797-805.
- (ELI) Environmental Law Institute. 1980. Enforcing the Commitments Made in Environmental Impact Statements. *Environmental Law Reporter* 10(August): 10,153-10,158.
- (EPA) U.S. Environmental Protection Agency. 1986. Environmental Auditing Policy Statement (July 9, 1986). *Environmental Law Reporter* 17: 35,001-35,006.
- (FPI) Federal Publications Inc. 1992. *The Environmental Audit*. Washington, DC.
- (FS) U.S. Forest Service. 1982. National Forest Land and Resource Management Planning. 36 CFR 219.12(k). 47 F.R. 43026-43052.
- (FS) U.S. Forest Service. 1988. Forest Plan Monitoring and Evaluation Process. In *Land and Resource Management Planning Handbook*, FSH 1909.12. Washington, DC.
- Friesema, H.P., and P.J. Culhane. 1976. Social Impacts, Politics, and the Environmental Impact Statement Process. *Natural Resources Journal* 16(April): 339-356.
- Greeno, J.L. 1983. *Environmental Auditing*. John Wiley, New York.
- Harrison, L.L. 1984. *Environmental Auditing Handbook: A Guide to Corporate and Environmental Risk Management*. McGraw-Hill, New York.
- Hunsaker, D.B., and D.W. Lee. 1987. Assessing the Environmental Impacts of Low Probability, High Consequence Events. In *Audit and Evaluation in Environmental Assessment and Management: Canadian and International Experience*, B. Sadler, ed. Environment Canada and The Banff Centre, Ottawa, Ontario.
- Lindblom, C.A. 1959. The Science of "Muddling Through." *Public Administration Review* 19(Spring): 78-88.
- Liroff, R.A. 1976. *A National Policy for the Environment: NEPA and Its Aftermath*. Indiana University Press, Bloomington, IN.
- Little, Arthur D., Inc. 1981. *Environmental Auditing: A Forum on Current Corporate Practices and Future Trends*. A. D. Little, Inc., Center for Environmental Assurance, Cambridge, MA.
- Loucks, O.L. 1982. Evaluating and Predicting Ecological Effects of Coal Combustion for Electric Power: An Overview of the Wisconsin Power Plant Study. The Institute of Ecology, Indianapolis.
- Mangun, W.R. 1989. Environmental Impact Assessment as a Tool for Wildlife Policy Management. In *Policy Through Impact Assessment*, R.V. Bartlett, ed. Greenwood Press, Westport, CT.
- March, J.G., and H.A. Simon. 1958. *Organizations*. John Wiley, New York.
- Marcus, L.G. 1979. A Methodology for Post-EIS Monitoring. U.S. Geological Survey Circular 782. Washington, DC.
- Martin, R.G., et al. 1983. Adequacy and Predictive Value of Fish and Wildlife Planning Recommendations at Corps of Engineers Reservoir Projects. Sport Fishing Institute, Washington, DC.
- McCallum, D.R. 1987. Follow-up to Environmental Impact Assessment: Learning from the Canadian Experience. *Environmental Monitoring and Assessment* 8(May): 199-215.
- Munro, D.A., T.J. Bryant, and A. Matte-Baker. 1986. Learning from Experience: A State-of-the-Art Review and Evaluation of Environmental Impact Assessment Audits. Report En 107-3/6-1986E for Canadian Environmental Assessment Research Council, by Naivasha Consultants, Sidney, B.C.
- Murdock, S.H., F.L. Leistritz, R.R. Hamm, and S.S. Hwang. 1982. An Assessment of Socioeconomic Assessments: Utility, Accuracy, and Policy Considerations. *Environmental Impact Assessment Review* 3(December): 333-350.
- Perry, J.A., D.J. Schaeffer, H.W. Kerster, and E.E. Herricks. 1985. The Environmental Audit II: Applications to Stream Network Design. *Environmental Management* 9(3): 199-208.
- Quade, E.S. 1966. Systems Analysis Techniques for Programming-Planning-Budgeting. Rand Corporation, Santa Monica, CA.
- Reed, P. 1983. Environmental Audits and Confidentiality. *Environmental Law Reporter* 10 (October): 10,303-10,308.
- Sadler, B., ed. 1987. *Audit and Evaluation in Environmental Assessment and Management: Canadian and International Experience*. Proceedings of the Conference on Follow-up/Audit of EIA Results, The Banff Centre, October, 1985. 2 volumes. Environment Canada, Ottawa, Ontario.
- Schaeffer, D.J., H.W. Kerster, J.A. Perry, and D.K. Cox. 1985. The Environmental Audit I: Concepts. *Environmental Management* 9(3): 191-198.
- Schweitzer, D.L., and M.J. MacNaughton, eds. 1990. Proceedings [of] National Workshop on Monitoring Forest Plan Implementation. U.S.D.A. Forest Service, Washington, DC.
- Sigal, L., and G. Cada. 1991. NEPA Compliance Auditing. *The Environmental Professional* 13(2): 174-177.
- Sokolik, S.L., and D.J. Schaeffer. 1986. Environmental Audit III: Improving the Management of Environmental Information for Toxic Substances. *Environmental Management* 10(3): 311-317.
- Tomlinson, P., and S. F. Atkinson. 1987. Environmental Audits: Proposed Terminology. *Environmental Monitoring and Assessment* 8(May): 187-198.
- (USHR) U.S. House of Representatives, Committee on Merchant Marine and Fisheries. 1987. Office of Environmental Quality Authorizations for Fiscal Years 1987, 1988, and 1989. H.R. 2020, Report 100-166, June 18, Washington, DC.
- (USHR) U.S. House of Representatives, Committee on Merchant Marine and Fisheries. 1991. Office of Environmental Quality Authorizations for Fiscal Years 1992, 1993, 1994, 1995, and 1996. H.R. 1271 (March 4). Also, Staff Memorandum, March 6. Washington, DC.
- Zillman, D.N., and P. Gentles. 1990. NEPA's Evolution: The Decline of Substantive Review. *Environmental Law* (Symposium Issue on NEPA at Twenty) 20(3): 505-532.



training areas for breeding or nesting by threatened or endangered animal species; (3) planning and implementation of a metals removal system at an industrial wastewater treatment plant so as to minimize metals uptake in aquatic food chains downstream of the wastewater discharge; and (4) changing surface water reservoir water levels and water release patterns to optimize dissolved oxygen concentrations in the water phase during various seasons. To serve as a specific example, Spellerberg (1991) has described the following three ways in which species monitoring data can be used in environmental management: (1) to establish a basis for the sustainable use of populations, (2) to detect and minimize the detrimental environmental impacts, and (3) to provide data that can be used as a scientific basis for conservation. Species monitoring for conservation planning is necessary because many species are close to extinction. This data can be used to devise conservation measures while monitoring the status of the species.

To provide a proper context and demonstrate pertinent considerations for environmental monitoring, this paper is organized into five sections: (1) background information; (2) purposes of environmental monitoring; (3) illustrations of selected purposes via brief descriptions of eight case studies; (4) planning considerations for monitoring programs; and (5) recommendations for emphasizing environmental monitoring in the EIA process in the United States.

### BACKGROUND INFORMATION

Current Council on Environmental Quality (CEQ) regulations for implementing the National Environmental Policy Act (NEPA) in the United States enunciate the principle of post-EIS environmental monitoring in Sections 1505.3 and 1505.2(c) (CEQ, 1978). Section 1505.3 states, "Agencies may provide for monitoring to assure that their decisions are carried out and should do so in important cases. Mitigation and other conditions established in the environmental impact statement or during its review and committed as part of the decision shall be implemented by the lead agency or other appropriate consenting agency." Section 1505.2(c) states, "At the time of its decision or, if appropriate, its recommendation to Congress, each agency shall prepare a concise public record of decision. The record, which may be integrated into any other record prepared by the agency, shall state whether all practicable means to avoid or minimize environmental harm from the alternative selected have been adopted, and if not, why they were not. A monitoring and enforcement program shall be adopted and summarized where applicable for any mitigation."

The CEQ regulations primarily focus on monitoring in conjunction with the implementation of mitigation measures. Mitigation includes: (1) avoiding the impact altogether by not taking a certain action or parts of an action; (2) minimizing impacts by limiting the degree or magnitude of the action and its implementation; (3) rectifying the impact by repairing, rehabilitating, or restoring the affected environment; (4) re-

ducing or eliminating the impact over time by preservation and maintenance operations during the life of the action; (5) and/or compensating for the impact by replacing or providing substitute resources or environments (CEQ, 1978). Monitoring could be used to determine the effectiveness of each of the types of mitigation measures (Smith, 1989).

Several agencies have included monitoring information related to mitigation measures in their EIA guidelines. The U.S. Army includes enforcement and effectiveness monitoring as an integral part of any environmental mitigation system (DA, 1988). Enforcement monitoring refers to mitigation performed as described in environmental documentation. Effectiveness monitoring measures the success of the mitigation effort and/or the environmental effect.

Only minimal attention has been given to comprehensive or targeted environmental monitoring in conjunction with major actions subjected to the EIA process in the United States. In contrast, other countries such as Canada, member states of the European Community, and many developing countries have focused attention on environmental monitoring. Some reasons why environmental monitoring and, in particular, post-EIS monitoring have been given minimal attention in the United States include:

1. It is not required in the current EIA process; the emphasis has been on getting the EIS completed so the project can be started.
2. Monitoring requirements may be included, or are assumed to be included, as part of environmental media (air, surface or ground water, and/or noise) or other permit conditions (Section 404, habitat, plant or animal species, and/or cultural resources).
3. A presumption exists that numerous federal, state, and even local monitoring networks could be used if necessary and that they would meet project/plan/program monitoring needs, if any.
4. There is resistance to planning and implementing a monitoring program, since collected data could be used by regulatory agencies as a basis for notification of violations, or even the levying of fines.
5. Agency staffing and funding may be limited. For example, monitoring is an important element in the U.S. Bureau of Land Management's (BLM) rangeland management and grazing allotment program; however, BLM officials attribute their inability to perform all needed monitoring largely to staff shortages and the need to concentrate on other rangeland management tasks (GAO, 1992).

Some reasons other countries are interested in monitoring (whereas the United States has not emphasized this topic)



include: (1) extant environmental monitoring programs may be minimal in scope, particularly in developing countries; (2) the emphasis in the EIA process is on life cycle environmental management and not just on getting initial project/plan/program approval via the preparation of an EIS (many countries refer to the EIS as an environmental impact assessment—EIA); (3) the absence of a highly structured legalistic environmental management system which focuses attention on regulatory compliance, legislative violations, fines, and possibly lawsuits; and (4) the recognition of the opportunity to gather environmental data and to use it to increase understanding of environmental transport and fate processes and ecological stresses.

### PURPOSES OF ENVIRONMENTAL MONITORING

Sadler and Davies (1988) describe three types of environmental monitoring that might be associated with the life cycle of a project. These include baseline monitoring, effects or impact monitoring, and compliance monitoring. Baseline monitoring is the measurement of environmental variables during a representative preproject period to determine existing conditions, ranges of variation, and processes of change. Effects or impact monitoring involves the measurement of environmental variables during project construction and operation to determine changes that may have been caused by the project. Finally, compliance monitoring takes the form of periodic sampling and/or continuous measurement of levels of waste discharge, noise, or similar emissions to ensure that conditions are observed and standards are met. Pre-EIS monitoring includes baseline monitoring, while post-EIS monitoring encompasses effects or impact monitoring and/or compliance monitoring.

Numerous purposes (and implied benefits) can be delineated for pre-and/or post-EIS environmental monitoring. For example, Marcus (1979) identified the following six purposes or uses of information from the conduct of post-EIS monitoring:

1. Provides information for documentation of the impacts that result from a proposed federal action, with this information enabling more accurate prediction of impacts associated with similar federal actions.
2. Could warn agencies of unanticipated adverse impacts or sudden changes in impact trends.
3. Could provide an immediate warning whenever a preselected impact indicator approaches a preselected critical level.
4. Provides information that could be used by agencies to control the timing, location, and level of impacts of a project. Control measures would involve preliminary planning as well as the possible implementation of regulation and enforcement measures. If an

intergovernmental monitoring system is used, it would facilitate appropriate response measures.

5. Provides information that could be used for evaluating the effectiveness of implemented mitigation measures.
6. Provides information that could be used to verify predicted impacts and thus validate impact prediction techniques. Based on these findings, the techniques (e.g., mathematical models) could be modified or adjusted as appropriate.

In the context of human health impacts, biological monitoring can be used to relate environmental media concentrations to potential health effects (Schweitzer, 1981). One type of biological monitoring is simply to measure the chemicals that accumulate in species indigenous to the local area. It can be hypothesized that chemicals not detected at significant levels of air, water, or soil might accumulate to higher levels in biota because of the multiple routes of exposure. A second type of biological monitoring is the measurement of biological responses to chemical contaminants using either indigenous biological species or species introduced into the area of concern. Considerable documented information is available on the use of different organisms as biomonitors (OME, 1989). Finally, the most direct approach may be medical investigations and human surveillance to identify possible health impacts on nearby populations. A variety of techniques may be applicable, ranging from routine chemical analyses of blood, urine, and breath to investigations of impacts on responses of the nervous and immunological systems (Schweitzer, 1981; Burtan, 1991).

Five categories of objectives for social impact assessment monitoring (Krawetz et al., 1987) are: (1) to document compliance with expected performance (e.g., inspection, surveillance in terms of regulatory permits, and contractual agreements); (2) to achieve impact management, i.e., project control to ensure that problems do not develop that interfere with construction through delays or cost overruns; (3) to facilitate research and development, including straight documentation, enhancing technical capacity for future project planning, evaluating predictions, and testing specific hypotheses; (4) to establish credibility (public assurance); and (5) to provide evidence of change, including determination of status, trend monitoring, and early warning systems.

Environmental monitoring can also serve as a basic component of a periodic environmental regulatory auditing program for a project (Allison, 1988). In this context, auditing can be defined as a systematic, documented, periodic, and objective review by regulated entities of facility operations and practices related to meeting environmental requirements (EPA, 1986). Some purposes of environmental auditing are to verify compliance with environmental requirements, to evaluate the effectiveness of in-place environmental management systems, and/or to assess risks from regulated and unregu-



lated substances and practices. Some direct results of an auditing program include an increased environmental awareness by project employees, early detection and correction of problems and thus avoidance of environmental agency enforcement actions, and improved management control of environmental programs (Allison, 1988).

Bass and Herson (1991) have delineated four objectives of environmental monitoring as related to the California Environmental Quality Act: (1) to ensure implementation of mitigation measures during project implementation; (2) to provide feedback to agency staff and decisionmakers about the effectiveness of their actions; (3) to provide learning opportunities for improving mitigation measures on future projects; and (4) to identify the need for enforcement action before irreversible environmental damage occurs.

Spellerberg (1991) noted that monitoring is useful in distinguishing between natural change and those changes caused directly or indirectly by pollution and other impacts. Monitoring can also be useful in managing natural resources.

Recently, a multicountry task force on EIA auditing conducted a comparative analysis of 11 case studies in order to document environmental monitoring practices (ECE, 1990). Some purposes for conducting such monitoring, as delineated in the case studies, included: (1) to monitor compliance with the agreed conditions set out in construction permits and operating licenses; (2) to review predicted environmental impacts for proper management of risks and uncertainties; (3) to modify the activity or develop mitigation measures in case of unpredicted harmful effects on the environment; (4) to determine the accuracy of past impact predictions and the effectiveness of mitigation measures in order to transfer this experience to future activities of the same type; (5) to review the effectiveness of environmental management for the activity; and (6) to use the monitoring results in order to determine the compensation required to be paid to local citizens affected by a project (ECE, 1990).

The primary point to note from the above delineation of different monitoring purposes is that such purposes can be wide-ranging; therefore, monitoring purposes need to be incorporated in the planning and implementation of a monitoring effort for a project, plan, or program.

### CASE STUDIES

To illustrate the various uses of monitoring in environmental impact work, eight case studies are highlighted here. Table 1 contains a summary of the case studies in terms of project/program type, monitoring conducted, and the uses of the monitoring information. The case studies include a pest control program, a wastewater treatment facility, two lignite extraction projects, an airport modification project, an evaluation of historical and needed waste disposal practices at a nuclear facility, an existing multipurpose surface water res-

ervoir system, and a proposed multipurpose surface water reservoir.

As noted in the previous section, environmental monitoring can be incorporated in environmental impact studies for a variety of purposes. One such purpose involves the establishment of project/program need. For example, monitoring of septic tank discharges, groundwater inflow to a lake, and lake water quality and aquatic ecology was used to establish the need for a centralized wastewater collection and treatment system in the environs of Crystal Lake in Michigan (EPA, 1980). At the Savannah River Plant of the U.S. Department of Energy, located in South Carolina, monitoring of soil and groundwater quality at extant waste disposal sites was used to establish the need for both a remediation program and modified practices in waste disposal facility siting/operation (DOE, 1987).

An often cited purpose of environmental monitoring is for describing the affected environment (establishing the baseline or background conditions). The water quality monitoring in surface streams and lakes in the environs of a proposed surface lignite mine in Rusk County, Texas, is an example of baseline delineation (EPA, 1983). Another example is the noise monitoring conducted in the vicinity of a proposed airport runway modification in Oklahoma (FAA, 1988).

Another purpose for monitoring is to provide sufficient collected information so as to be able to predict (anticipate) the potential effectiveness of the project/program and/or the potential environmental impacts of the project/program. One example of the former is the pesticide effectiveness monitoring conducted as a part of a control program for the imported fire ant in nine southeastern states (APHIS, 1981). In this same study, monitoring data on pesticide residues in various environmental compartments was used as a basis for predicting the potential environmental consequences of pesticide usage. Another example of using monitoring data for impact prediction is in the airport runway modification project (FAA, 1988). Background noise data as well as noise data from various types of aircraft and their operations were used as input for a noise prediction model. This model was then used to examine the noise impacts of various alternatives.

Baseline monitoring conducted as a part of the preparation of the EIS for the surface lignite mine in Titus County, Texas, included the following components (EPA, 1990b): (1) determination of soil composition in the study area, since the project is expected to alter the soil structure, increase the bulk density, reduce the permeability, and modify the texture; (2) measurement of wheat production over a 3-year period on a 10-acre portion of post-minespoil at a nearby mine area operated by the project proponent (this monitoring information was used to predict potential wheat production on minespoil for the proposed mine); (3) measurement of hydrogeological parameters and groundwater quality via 43 wells drilled in the study area (this information was used to



**Table 1. Summary of Environmental Monitoring in Eight Case Studies**

| <b>Case Study (Reference)</b>                            | <b>Project/Program Type</b>  | <b>Monitoring<sup>1</sup></b>   | <b>Uses or Purposes of Monitoring</b>  |
|--|--|---|--|
| Fire ant control program (APHIS, 1981)                   | Pest control   | Pesticide effectiveness and pesticide residues in environmental compartments  | To describe project effectiveness and environmental consequences   |
| Wastewater treatment around Crystal Lake (EPA, 1980)     | Wastewater treatment facility  | Septic tank discharges, groundwater flow, and lake water quality and aquatic ecology  | To describe need for project and to determine effectiveness of project for water quality improvements  |
| Surface lignite mine (EPA, 1983)                         | Lignite extraction   | Water quality in surface streams and lakes and discharge permit monitoring  | To describe existing water quality and to establish basis for controlling potential impacts  |
| Airport runway extension (FAA, 1988)                     | Airport modification   | Noise from aircraft and existing ambient noise levels   | To describe baseline noise and to use as input for noise prediction model  |
| Nuclear facility waste management program (DOE, 1987)    | Waste disposal   | Soil and groundwater quality  | To establish need for project and to serve as basis for waste disposal planning  |
| Surface lignite mine (EPA, 1990)                         | Lignite extraction   | Soil composition, wheat production, hydrogeological parameters, groundwater quality, baseline flows in streams, and noise   | To describe baseline environmental conditions and to serve as "look-alike" information for project design and impact prediction  |
| Reservoir system on Tennessee River (TVA, 1991)          | Operation of 16 reservoirs and dams in Tennessee River system            | River flow, water quality (dissolved oxygen and other constituents), and effectiveness of aeration of water releases from dams  | To determine influence of reservoir operational patterns on water quality (particularly dissolved oxygen); to improve water quality and aquatic habitat by increasing minimum flow rates and aerating releases from the TVA dams to raise dissolved oxygen levels; and to extend the recreation season on TVA lakes by delaying drawdown for other reservoir operating purposes, primarily hydropower generation |
| Construction and operation of Elk Creek Lake (ACE, 1991) | Multipurpose reservoir, the third of three reservoirs in the river basin | Water temperature, turbidity, and suspended sediment; river flow rates; game fish; terrestrial habitats for eight evaluation species; monitoring at two existing reservoirs and at proposed site for Elk Creek Lake | To validate extant water quality models and to serve as a basis for predicting both single project and cumulative impacts on fisheries, water quality, and terrestrial wildlife habitat  |

<sup>1</sup> Other monitoring may have been mentioned in the EIS but not addressed herein.



estimate the probable hydrogeologic consequences of the mining operations and the dewatering requirements for the mining area; (4) measurement of baseline flows in streams in the study area via seven crest gauge monitoring stations and one continuous level monitoring gauge; and (5) conduction of a noise survey at seven receptors located in the study area (three receptors) or within 1.5 miles of the study area boundaries (four receptors) (this information documented existing conditions and will be used in assessing construction and mining impacts).

Environmental monitoring can also be used as an aid to project/program operation and management. In fact, specific post-EIS monitoring was addressed in six of the eight case studies (the pest control program, both surface lignite mines, waste disposal at a nuclear facility, the reservoir system on the Tennessee River, and construction and operation of Elk Creek Lake). The most comprehensive illustration of environmental monitoring coupled with ongoing decisionmaking was in conjunction with the operation of the 16 extant reservoirs and dams in the Tennessee River system (TVA, 1991).

A targeted pre- and post-EIS environmental monitoring program was described in the final EIS Supplement No. 2 for the Elk Creek Lake project. A portion of this monitoring effort was attributable to the decision of the Federal Ninth Circuit Court of Appeals in the case of *Oregon Natural Resources Council v. Marsh*. The Ninth Circuit ruled in this case that the EIS and EIS Supplement No. 1 for the Elk Creek Lake project did not fully comply with the requirements of the National Environmental Policy Act (NEPA). Subsequent review of the case by the U.S. Supreme Court reversed in part the decision of the Ninth Circuit Court. As directed by the order of the U.S. District Court, EIS Supplement No. 2 was prepared to comply with the opinions of the U.S. Supreme Court, the Ninth Circuit Court of Appeals, and the U.S. District Court for the District of Oregon (ACE, 1991). Monitoring for several water quality, fisheries, and terrestrial habitat parameters was conducted at two existing reservoirs and dams (Applegate Dam and Lost Creek Dam) and the proposed site for Elk Creek Dam in the Rogue River Basin. The Elk Creek project is a concrete dam and reservoir to be located on Elk Creek, approximately 1.7 miles upstream from its confluence with the Rogue River. The project was authorized by Congress in 1962 as one of three dams in the Rogue Basin Project. Project purposes include flood control, irrigation, water supply, and recreation (ACE, 1991).

Water quality and terrestrial habitat modeling was used to analyze single project and cumulative impacts related to the Elk Creek lake project. Water quality models used for evaluating temperature, turbidity, and suspended sediment impacts included the Water Resources Engineers, Inc., model (WRE), two Corps of Engineers models (the WESTEX model and the CE-THERM-R1 model), and a U.S. Environmental Protection Agency (EPA) model (QUAL II). Four

physical parameters (land cover, soils, slope, and stream network) were monitored in a remote sensing/GIS (geographic information system) analysis of suspended sediment/turbidity. Fisheries resources studies for salmon and steelhead populations assessed changes in emergence timing of fry from river gravel; the abundance of juvenile fish and their size, growth rate, and migration timing; and the abundance, migration timing, prespawning mortality, and spawning of adult fish. Eight terrestrial species in the Rogue River Basin were studied by using the Habitat Evaluation Procedures of the U.S. Fish and Wildlife Service (ACE, 1991).

It should be evident from these illustrations of the various purposes of environmental monitoring that such monitoring might be conducted prior to, during, or after environmental impact studies and the preparation of EISs. Each monitoring program in the eight case studies was unique and a function of the project/program type and geographical location. While essentially no information on the costs of the environmental monitoring efforts was included in the eight case studies, it should be noted that these efforts can be expensive. Monitoring costs for a specific study are a function of numerous factors, including availability of extant data, number and types of parameters to be monitored, length of the monitoring program, and data management and interpretation needs.

## PLANNING A MONITORING PROGRAM

Careful planning and implementation of an environmental monitoring program is necessary to meet the potential purposes of monitoring. Three considerations are important in planning monitoring programs in the United States. First, an abundance of environmental monitoring data is routinely collected by various governmental agencies and the private sector. These data need to be identified, aggregated, and interpreted, since information is often compiled but never interpreted relative to the quality of the environment being monitored. Second, environmental monitoring programs are expensive to plan and implement. Every effort should be made to use or modify extant monitoring programs. Third, owing to overlapping environmental management and monitoring responsibilities of many local, state, and federal governmental agencies, it may be necessary carefully to coordinate environmental monitoring planning with several agencies.

Several conceptual models exist for the planning and implementation of environmental monitoring programs (Marcus, 1979; Spellerberg, 1991). Marcus (1979) described two phases: development of a monitoring system and implementation and operation of a monitoring system. Figure 1 identifies 11 work elements associated with development of a monitoring system (Marcus, 1979). Work elements 1 through 3 are related to the preparation and results of an EIS. Agency coordination is addressed in work elements 4, 5 and 9. The monitoring objectives should be related to the anticipated impacts of the action (work element 6). Work elements 7 and 8 on determining and reviewing data requirements are



the key technical elements. They require detailed planning based on scientific rationale. Examples of specific tasks in work elements 7 and 8 are included in Table 2 (Marcus, 1979). Finally, it will probably be necessary to adjust the post-EIS monitoring program to coincide with available budgetary resources. Several iterations may be necessary to achieve a workable monitoring system (work elements 10 and 11).

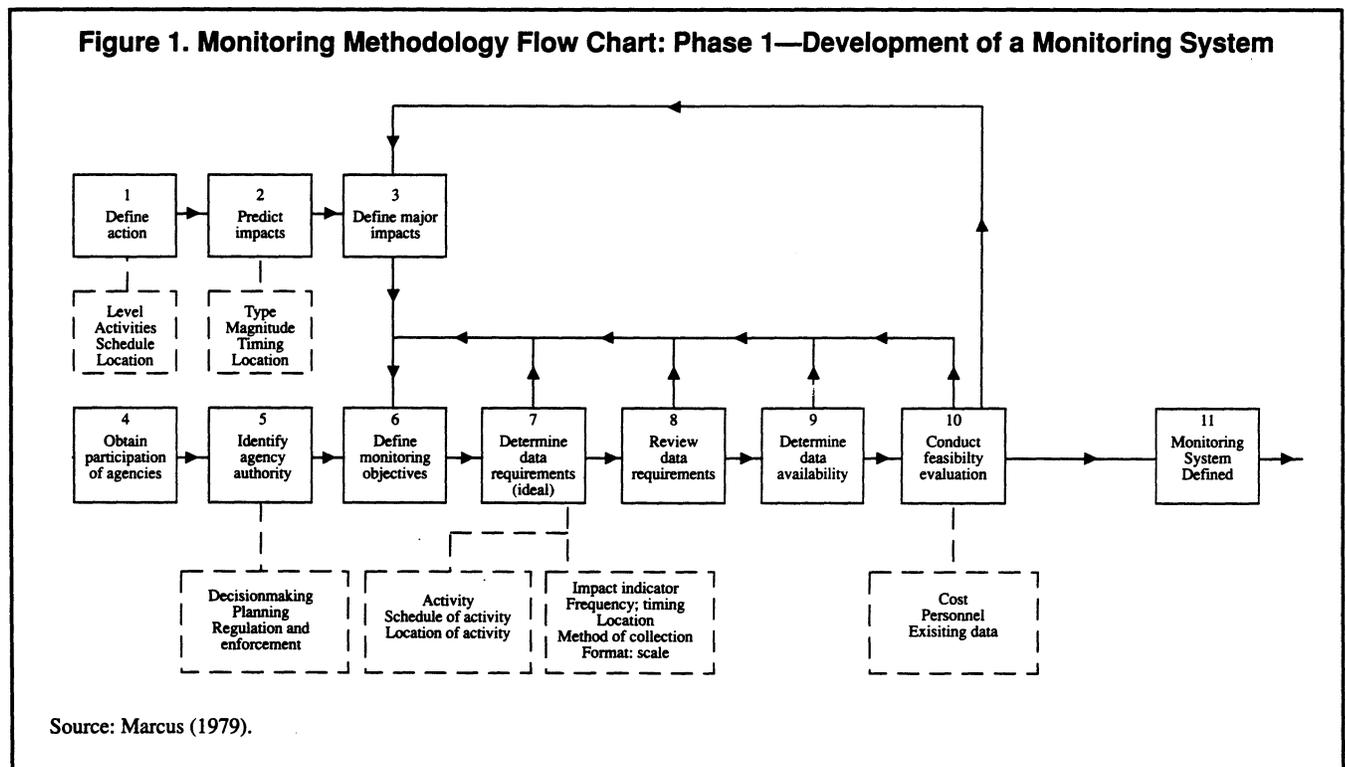
The second phase of a post-EIS monitoring program involves the implementation and operation of the monitoring system, and Figure 2 delineates the work elements (Marcus, 1979). Work element 12 on implementing the monitoring system may require considerable effort in obtaining specific interagency agreements and necessary funding. Work elements 13 through 15 involve data collection, analysis, and evaluation. Evaluation of impacts will involve the predetermination of criteria to be used for interpretation. These criteria should be based on legal or institutional limits, professional judgment, and public inputs. Development of appropriate response plans to impact trends (work element 16) can be time-consuming and technically difficult and may require considerable coordinating efforts. Finally, it is vitally important that annual summary reports, or reports at more frequent intervals, be prepared to document the findings and resultant responses to the post-EIS monitoring program (work element 17).

Several fundamental books and articles would be useful in the detailed planning and implementation of a monitoring program. The following noninclusive references are available:

for air quality monitoring, Noll and Miller (1977) and Lodge (1989); for surface water quality monitoring, Canter (1985) and Loftis et al. (1989); for ground water quality monitoring, Aller et al. (1989); for noise monitoring, Lipscomb and Taylor (1978); for species and habitat monitoring, Green (1979), Roberts and Roberts (1984), Brown and Dycus (1986), Horner et al. (1986), Gray (1988), Ontario Ministry of the Environment (OME, 1989), and Spellerberg (1991); for social impact assessment monitoring, Krawetz et al. (1987); and for health effects monitoring, Schweitzer (1981) and Burtan (1991). General references that encompass several types of environmental monitoring include Gilbert (1987), Cheremisinoff and Manganiello (1990), and Keith (1991).

Figure 3 depicts a generic conceptual framework for developing an environmental monitoring plan for biological and ecological monitoring (Spellerberg, 1991). The framework can be adapted in principle to the monitoring of environmental media, visual impacts, socioeconomic/social impacts, and health impacts. The first step in Figure 3 is to define the monitoring objectives. In many monitoring schemes, the objectives either are not stated or are so complex that they become meaningless (Spellerberg, 1991). The second step is to determine the places where the monitoring will take place.

The third step in Figure 3 is to make sure the data collected are documented for future use. When monitoring programs extend over long periods of time, those working on the project change, so the need arises for methods to assure the retention of such data, which should be accessible and understandable to successive monitors. Also, arrangements must be made for





**Table 2. Tasks Associated with Determining and Reviewing Data Requirements in Planning a Monitoring Program**

| Work Element                                      | Tasks  |
|---|--|
| <p>7<br/>Determine data requirements (ideal).</p> | <ol style="list-style-type: none"> <li>1. Reevaluate impacts on the basis of monitoring objectives; eliminate overlap in monitoring objectives and monitoring effort.</li> <li>2. Select impact indicators. (These are the parameters that must be monitored to assess the magnitude of impacts. Several parameters may be indicative of a particular impact. Any impact indicator should be selected on the basis of its utility for decisionmaking, planning, regulation, and enforcement.)</li> <li>3. Determine frequency and timing of data collection. (Frequency of data collection should be the minimum necessary for trend analysis, enforcement of regulations, and correlation of cause and effects. For some parameters the timing of data collection may be more important than the frequency level; for example, collection of water quality data during a major runoff event is more important than a precise data collection frequency. Timing of data collection should relate to the timing of activities causing the impact. Different phases of an action may produce different impacts that persist after an activity ceases.)</li> <li>4. Determine monitoring sites or collection areas. (These should be based on the location of the activities causing the impacts, predictions of areas most likely to be affected, and locations where integrated measurements would assist in gaining comprehensive understanding.)</li> <li>5. Determine method of data collection.</li> <li>6. Determine data type and storage format. (Data format possibilities include statistical tables, charts, graphs, summaries, maps, map overlays, computer printouts, and graphics. Criteria for selecting suitable formats include: easy and convenient access to data by all users, intelligibility, interrelatability among formats, and ease of updating.)</li> <li>7. Determine data analysis method.</li> </ol> |
| <p>8<br/>Review data requirements.</p>            | <ol style="list-style-type: none"> <li>1. Review data needs for conformance with monitoring objectives.</li> <li>2. Revise data needs as necessary to meet monitoring objectives</li> </ol>  |

Source: Marcus (1979).

data collection and storage. The success of a monitoring program depends not only on good planning and logistical support but also on coordination with other related programs.

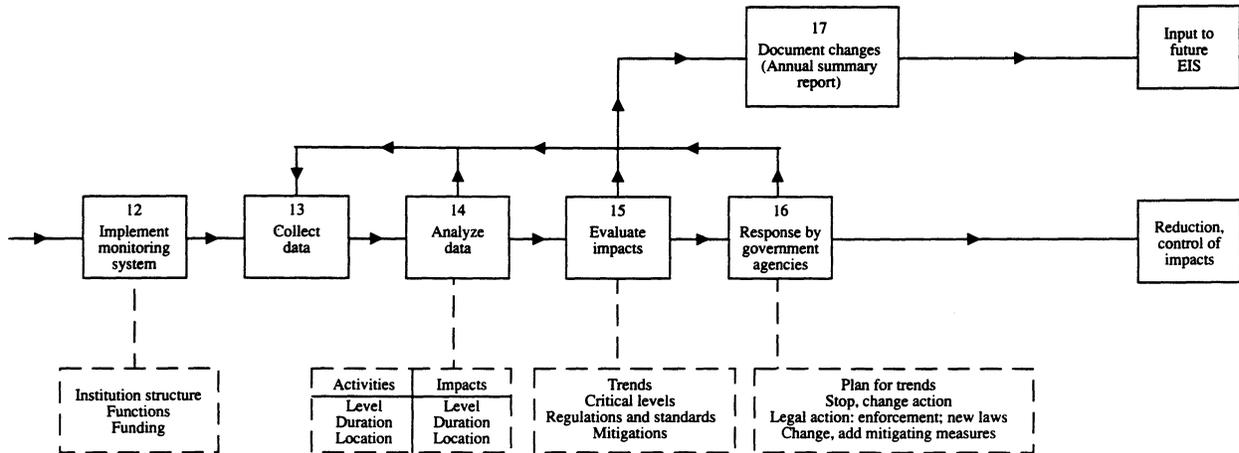
The fourth step involves the process of selecting the variables. The ideal variable and process would have a wholly ecological basis, but logistic limitations (finance, time, and effort) may override these considerations. Due to such logistic limitations, methods for collection of data from the field or assemblage of data from other sources should therefore be considered along with the choice of parameters. Indicators and composite indices can be useful in monitoring studies. Ecological indicators for six resource categories have been identified for the EPA's Ecological Monitoring and Assessment Program (EMAP) (EPA, 1990a). Diatoms can be used as aquatic indicators, since they respond rapidly to changes in many ecological characteristics, and it is rela-

tively easy to obtain large numbers of diverse individuals in a monitoring program (Dixit et al., 1992). Monitoring data can be aggregated into pertinent indices to reflect the composite quality of different environmental categories. Several indices for the biological environment have been developed; one example is an Index of Biotic Integrity (IBI) for stream fish assemblages used in both North America and Europe (Oberdorff and Hughes, 1992).

The next step involves the preliminary data-gathering and baseline surveys. Before the planning of biological monitoring can start, biological information from published sources or preliminary field studies should be assembled. Finally, the analysis and presentation of the data must be considered, remembering who will use the data to make recommendations (Spellerberg, 1991).

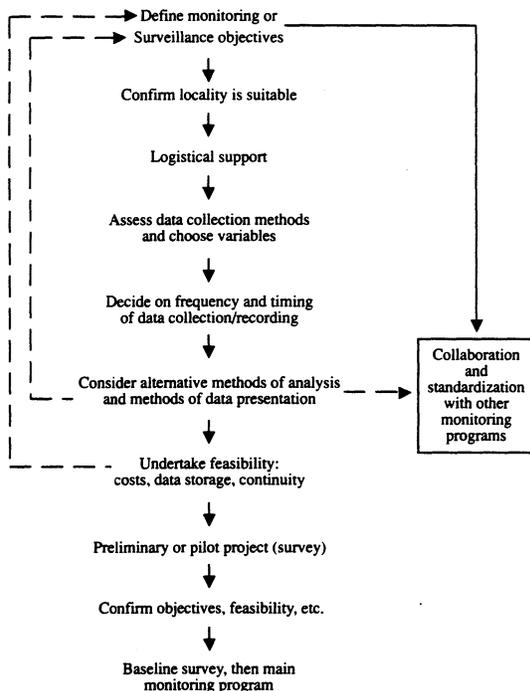


**Figure 2. Monitoring Methodology Flow Chart: Phase 2—Implementation and Operation of a Monitoring System**



Source: Marcus (1979).

**Figure 3. Conceptual Plan for a Monitoring Program**



Source: Spellerberg (1991).

It may be possible to coordinate a project- or region-specific monitoring program with an ongoing program. For example, the EPA's EMAP, mentioned above, monitors the status and trends of the nation's near-coastal waters, forests, wetlands, agroecosystems, inland surface waters, and arid lands. The near-coastal component of EMAP consists of estuaries, coastal waters, coastal and estuarine wetlands, and Great Lakes (Paul et al., 1991). Review of this EPA program status can ascertain its relevance to project- or region-specific biological or ecological monitoring needs.

Numerous specific problems and issues may be encountered in the planning and implementation of monitoring programs. For example, Schweitzer (1981) identified several issues of concern; selected examples include:

1. Statistical aspects are an important factor in the design of a monitoring program. A statistician on the planning team can help insure that adequate consideration is given to these aspects both in designing the program and in formatting and interpreting the data. Statistical issues in planning a monitoring program can include both technical and qualitative dimensions, with the former being more easily addressed (Stevens and Olsen, 1992).
2. Access to preferred sampling sites is not always possible. The sampling plan should be sufficiently flexible to compensate for such problems.



3. A quality assurance program involving surrogate recoveries, inter- and intra-laboratory duplicates, and field and laboratory blanks is essential. Each data point should be individually validated as acceptable data, and precision and accuracy data should be developed for each data set. The quality assurance program may account for 0 percent to 20 percent of the monitoring costs.
4. Special efforts are needed to minimize holding times between sampling and analysis. However, extended holding times beyond two weeks may be unavoidable. In that event, appropriate storage procedures are particularly important to prevent excessive decay of the samples.
5. Contaminants associated with the sampling and analytical techniques are difficult to avoid, and data suspected of such contamination should be considered for discarding.

Potential problems that may be encountered when utilizing environmental data from extant monitoring systems include: (1) the likely absence of a quality-control program, particularly for older data; (2) difficulties in matching and integrating data on common resources from diverse sources of information; and (3) the general absence of information on data interpretation, or even how to interpret it.

## RECOMMENDATIONS

The basic premise addressed in this paper is that targeted (or comprehensive) post-EIS monitoring programs should be planned and implemented for selected projects with potentially significant negative impacts. To facilitate and institutionalize such programs, certain action is needed. Specifically, it is recommended that the U.S. Congress should conduct hearings and then modify NEPA to include a specific requirement for environmental monitoring considerations in the EIA process. The CEQ should then conduct hearings and modify its regulations to incorporate monitoring considerations and delineate project types/sizes and/or criteria that can be applied to trigger such considerations. Each federal agency with specific EIA guidelines/regulations should then modify its respective guidelines/regulations to incorporate monitoring considerations and delineate details on project types/sizes and/or criteria that could be used to trigger such considerations.

To facilitate these recommendations, CEQ should issue generic technical guidance on planning and implementing target environmental monitoring programs, and federal agencies should also issue project-specific technical guidance on such programs. Information previously discussed for planning monitoring programs could be used by CEQ and various agencies to develop the necessary technical guidance. A critical issue would be the careful delineation of triggering levels which would activate the monitoring planning process. Finally, and perhaps most importantly, Congress, CEQ, and

pertinent federal agencies should allocate both general and project-specific funds to implement the monitoring process.

An alternative might include the above recommendations along with the provision of technical guidance and funding. Modification of NEPA could occur later as monitoring program successes are documented. The least desirable alternative from a national perspective would be for only a few federal agencies to modify their EIA guidelines/regulations to incorporate monitoring considerations. It is unlikely that this would produce any type of uniformity in monitoring requirements due to such potentially diverse efforts.

Some guidelines and policies for environmental monitoring and auditing in relation to the EIA process have been proposed by Sadler and Davies (1988). The concept is that monitoring should be an integral part of the EIA of major projects with environmentally significant impacts. Monitoring can be initially structured by screening and scoping, subsequently refocused at the stage of impact analysis, and continue through the implementation and operational phases to provide data on impacts.

Selected principles and recommendations associated with postproject analysis (PPA) as developed by the task force mentioned earlier from 11 case studies are as follows (ECE, 1990):

1. Post-project analysis should be used to complete the EIA process for major projects by providing the necessary feedback in the project implementation phase both for proper and cost-effective management and for EIA process development.
2. A preliminary plan for the PPA should be prepared during the environmental review of a project; the PPA framework should be fully developed when the EIA decision on the project is made.
3. The development of hypotheses to test should be a part of PPAs. The hypotheses will depend greatly on the nature of the PPA and may involve comparisons of impacts with predictions or with standards, or they may relate to how well the environmental management system worked.
4. As a tool for managing PPAs, advisory boards consisting of industry, government, contractors, independent experts, and public representatives should be used. Such boards with well-defined terms of reference increase the credibility and quality of the PPA.
5. Public participation in the PPA should be encouraged, and PPA reports should be made public.

A pragmatic action that would ensure consideration of environmental monitoring in the EIA process in the United States



would be the inclusion of a documentation requirement. The CEQ regulations do not currently include an EIS section on environmental monitoring (CEQ, 1978); however, monitoring documentation is incorporated by many countries or groups. For example, the format for EIS reports on water resources projects in southeast Asian and Pacific countries requires a description of the monitoring program (ESCAP, 1990). The monitoring program should be designed so that the environmental agency receives monitoring reports that ensure that all necessary environmental protection measures are being carried out as listed in the approved project plan. The format for environmental assessment reports for projects being financed by the World Bank includes a description of the monitoring plan regarding environmental impacts and performance. The plan should specify the type of monitoring, who would do it, how much it would cost, and what other inputs (e.g., training) are necessary (WB, 1989).

### SUMMARY

Comprehensive or targeted monitoring can be used as an integral component of responsible life cycle environmental management of major projects. The current EIA process in the United States is focused on monitoring in conjunction with the implementation of mitigation measures. Additional valid purposes of environmental monitoring include, but are not limited to, establishing baseline conditions, documenting and managing experienced impacts, evaluating the effectiveness of mitigation measures, and validating impact prediction techniques.

Planning and implementation of a comprehensive or targeted environmental monitoring program should include use of extant monitoring data and coordination with pertinent governmental monitoring systems. Program planning includes defining objectives related to expected impacts, selection of pertinent indicators (variables), and determination of sampling location and frequency and analytical requirements. Implementation includes developing response strategies (management actions) and periodic reporting. Postproject analysis (PPA) is a term used in some countries to denote the role of environmental monitoring in life cycle project management.

Incorporation of environmental monitoring requirements in the EIA process in the United States would optimally require a combined effort of Congress, CEQ, and each federal agency. However, federal agencies could implement monitoring requirements on an agency-specific basis. While such requirements might be viewed as overly complicated and even unnecessary, they would provide a positive basis for the environmental management of major projects over their life cycle. This would be a logical outgrowth of the EIS-focused nature of the EIA process which has existed in the United States since the passage of NEPA.

### REFERENCES

- (ACE) U.S. Army Corps of Engineers. 1991. Elk Creek Lake, Rogue River Basin, Oregon. Final Environmental Impact Statement, Supplement No. 2. Portland District, Portland, OR.
- Aller, L., T.W. Benneh, G. Hackett, R.J. Petty, J.H. Lehr, H. Sedoris, D.M. Neilsen, and J.E. Denne. 1989. Handbook of Suggested Practices for the Design and Installation of Ground-Water Monitoring Wells. EPA 600/4-89/034. National Water Well Association, Dublin, OH.
- Allison, R.C. 1988. Some Perspectives on Environmental Auditing. *The Environmental Professional* 10:185-188.
- (APHIS) Animal and Plant Health Inspection Service. 1981. Cooperative Imported Fire Ant Program, Final Programmatic Environmental Impact Statement. U.S. Department of Agriculture, Washington, DC.
- Bass, R.E., and A.I. Herson. 1991. The California Environmental Quality Act, A Step-by-Step Approach. Jones and Stokes Associates, Sacramento, CA.
- Brown, R.T., and D.L. Dycus. 1986. Characterizing the Influence of Natural Variables During Environmental Impact Analysis. *Rationale for Sampling and Interpretation of Ecological Data in the Assessment of Freshwater Ecosystems*. American Society for Testing and Materials, Philadelphia, pp. 60-75.
- Burtan, R.C. 1991. Medical Monitoring's Expanding Role. *Environmental Protection* 2(6):16-18.
- Canter, L.W. 1985. *River Water Quality Monitoring*. Lewis Publishers, Chelsea, MI.
- (CEQ) Council on Environmental Quality. 1978. National Environmental Policy Act—Regulations. 43(230) F.R. 55978-56007.
- Cheremisnoff, P.N., and B.T. Manganiello. 1990. *Environmental Field Sampling Manual*. Pudvan Publishing Company, Northbrook, IL.
- (DA) U.S. Department of the Army. 1988. Environmental Effects of Army Actions. Regulation 200-2. 53(221) F.R. 46322-46361.
- Dixit, S.S., J.P. Smol, J.C. Kingston, and D.F. Charles. 1992. Diatoms: Powerful Indicators of Environmental Change. *Canadian Journal of Fisheries and Aquatic Sciences* 49(1):128-141.
- (DOE) U.S. Department of Energy. 1987. Final Environmental Impact Statement, Waste Management Activities for Ground Water Protection, Savannah River Plant, Aiken, South Carolina, 2 vols. Washington, DC.
- (ECE) Economic Commission for Europe. 1990. Post-Project Analysis in Environmental Impact Assessment. ECE/ENVWA/11. United Nations, Geneva, Switzerland, pp. 1-10 and 21-38.
- (EPA) U.S. Environmental Protection Agency. 1980. Environmental Impact Statement, Alternative Waste Treatment Systems for Rural Lake Projects, Case Study Number 1, Crystal Lake Area, Sewage Disposal Authority, Benzie County, Michigan. EPA-5-MI-Benzie-Crystal Lake-LA-80. Region 5, Chicago.
- (EPA) U.S. Environmental Protection Agency. 1983. Draft Environmental Impact Statement: Martin Lake D Area Lignite Surface Mine, Henderson, Rusk County, Texas. EPA 906/83-003. Region 6, Dallas.
- (EPA) U.S. Environmental Protection Agency. 1985. Resource Document for the Ground Water Monitoring Strategy Workshop. Office of Ground Water Protection, Washington, DC.
- (EPA) U.S. Environmental Protection Agency. 1986. Environmental Auditing Policy Statement. 51(131) F.R. 25004.
- (EPA) U.S. Environmental Protection Agency. 1990a. Environmental Monitoring and Assessment Program: Ecological Indicators. EPA/600/3-9/060. Las Vegas, NV.
- (EPA) U.S. Environmental Protection Agency. 1990b. Monticello B-2 Area Surface Lignite Mine, Titus County, Texas. Draft Environmental Impact Statement. EPA 906/04-90-003. Dallas.



- (ESCAP) Economic and Social Commission for Asia and the Pacific. 1990. Environmental Impact Assessment—Guidelines for Water Resources Development. ST/ESCAP/786. Bangkok, Thailand.
- (FAA) Federal Aviation Administration. 1988. Final Environmental Assessment for Max Westheimer Airpark, Norman, Oklahoma. Oklahoma City, OK.
- (GAO) U.S. General Accounting Office. 1992. Rangeland Management: Interior's Monitoring Has Fallen Short of Agency Requirements. GAO/RCED-92-51. Washington, DC.
- Gilbert, R.O. 1987. *Statistical Methods for Environmental Pollution*. Van Nostrand Reinhold, New York.
- Gray, R.H. 1988. Overview of a Comprehensive Environmental Monitoring and Surveillance Program: The Role of Fish and Wildlife. PNL-SA-15922. Battelle Pacific Northwest Labs, Richland, WA.
- Green, R.H. 1979. *Sampling Design and Statistical Methods for Environmental Biologists*. John Wiley and Sons, New York.
- Horner, R.R., J.S. Richey, and G.L. Thomas. 1986. Conceptual Framework to Guide Aquatic Monitoring Program Design for Thermal Electric Power Plants. *Rationale for Sampling and Interpretation of Ecological Data in the Assessment of Freshwater Ecosystems*. American Society for Testing and Materials, Philadelphia, pp. 86-100.
- Keith, L.H. 1991. *Environmental Sampling and Analysis: A Practical Guide*. Lewis Publishers, Chelsea, MI.
- Krawetz, N.M., W.R. MacDonald, and P. Nichols. 1987. A Framework for Effective Monitoring. Canadian Environmental Assessment Research Council, Hull, Quebec.
- Lipscomb, D.M., and A.C. Taylor, eds. 1978. *Noise Control Handbook of Principles and Practices*. Van Nostrand Reinhold, New York.
- Lodge, J.P., ed. 1989. *Methods of Air Sampling and Analysis*, 3d ed. Lewis Publishers, Chelsea, MI.
- Loftis, J.C., R.C. Ward, R.D. Phillips, and C.H. Taylor. 1989. An Evaluation of Trend Detection Techniques for Use in Water Quality Monitoring Programs. EPA/600/S3-89/037. U.S. Environmental Protection Agency, Center for Environmental Research Information, Cincinnati, OH.
- Marcus, L.G. 1979. A Methodology for Post-EIS (Environmental Impact Statement) Monitoring. Geological Survey Circular 782. U.S. Geological Survey, Washington, DC.
- Noll, K.E., and T.L. Miller. 1977. *Air Monitoring Survey Design*. Ann Arbor Science Publishers, Ann Arbor, MI.
- Oberdorff, T., and Hughes, R.M. 1992. Modification of an Index of Biotic Integrity Based on Fish Assemblages to Characterize Rivers of the Seine Basin, France. *Hydrobiologia* 228:117-130.
- (OME) Ontario Ministry of the Environment. 1989. Investigation, Evaluation, and Recommendations of Biomonitoring Organisms for Procedures Development for Environmental Monitoring. MIC-90-00873/WEP. Toronto, Ontario.
- Paul, J.F., F. Holland, J.K. Summers, S.C. Schimmel, and J.K. Scott. 1991. EPA's Environmental Monitoring and Assessment Program: An Ecological Status and Trends Program. EPA/600/D-91/250. U.S. Environmental Protection Agency, Narragansett, RI.
- Roberts, R.D., and T.M. Roberts. 1984. *Planning and Ecology*. Chapman and Hall, New York.
- Sadler, B., and M. Davies. 1988. Environmental Monitoring and Audit: Guidelines for Post-Project Analysis of Development Impacts and Assessment Methodology. Centre for Environmental Management and Planning, Aberdeen University, Aberdeen, Scotland, pp. 3-6 and 11-14.
- Schweitzer, G.E. 1981. Risk Assessment Near Uncontrolled Hazardous Waste Sites: Role of Monitoring Data. *Proceedings of National Conference on Management of Uncontrolled Hazardous Waste Sites*. Hazardous Materials Control Research Institute, Silver Spring, MD, pp. 238-247.
- Smith, E.D. 1989. Future Challenges of NEPA: A Panel Discussion. CONF-891098-10. Oak Ridge National Laboratory, Oak Ridge, TN.
- Spellerberg, I.F. 1991. *Monitoring Ecological Change*. Cambridge University Press, Cambridge, England, pp. 181-182.
- Stevens, D.L., and A.R. Olsen. 1992. Statistical Issues in Environmental Monitoring and Assessment. EPA/600/R-92/073. U.S. Environmental Protection Agency, Research Triangle Park, NC.
- (TVA) Tennessee Valley Authority. 1991. Tennessee River and Reservoir System Operation and Planning Review. Final Environmental Impact Statement. TVA/RDG/EQS — 91/1. Knoxville, TN.
- (WB) World Bank. 1989. Operational Directive 4.00, Annex A: Environmental Assessment. Washington, DC.

