Environmental Effects Monitoring Manual

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Abstract

Environmental effects monitoring is the repetitive measurement of attributes of environmental components to test specific hypotheses for the purposes of establishing causal relationships. This manual is concerned with: 1) environmental effects monitoring programs directed at assessing the effectiveness of environmental protection measures in a regulatory setting; and 2) effects monitoring programs directed at improving the practice of environmental impact assessment. Environmental effects monitoring programs capable of detecting environmental effects are essential if we are to learn from experience. Information generated from environmental effects monitoring programs can benefit future environmental assessment activities by providing for better monitoring plans; better mitigation plans; enhanced predictive capability for assessing potential effects; and improvements in environment impact assessment procedures. Without monitoring there is no mechanism for evaluating the success of the environmental protection measures undertaken. Environmental effects monitoring provides important feedback that allows for more effective planning and an adaptive response based on an assessment of the effectiveness of environmental protection measures.

This manual is based on practical experience, empirical case studies, and a review of the literature. It outlines general principles for environmental effects monitoring to guide practitioners. By following the recommendations for designing monitoring systems outlined in this manual, users will be able to develop an environmental effects monitoring program to suit their objectives.

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1.0 Introduction

Environmental assessment programs in North America have been estimated to cost billions of dollars annually, yet in most jurisdictions the means to assess their effect on the environment does not exist. Although environmental assessments are based on our best understanding of the environmental effects, it is critical that long-term monitoring activities be in place to confirm the effectiveness of these programs in achieving their environmental goals and to corroborate the science upon which they are based (Bromberg 1990).

In Canada, the Canadian Environmental Assessment Act (Bill C-78) makes provision for a follow-up program designed to: 1) verify the accuracy of environmental assessment predictions; and 2) determine the effectiveness of measures to mitigate the environmental impacts of projects. Plans for the follow-up programs will become a key component of final assessment reports. These plans will be made available to the public. Environmental effects monitoring is the essential part of these follow-up programs. It is environmental effects monitoring programs that provide the feedback loops in our environmental assessment practices.

Effects monitoring data collected on environmental components (e.g. fish, birds, water quality) provides information about the current status of our environment. Comparison of these data with standards, environmental objectives, or other baselines allows us to evaluate the success of environmental protection measures. As well, monitoring forces us to examine the actual impacts of human activities on the environment.

This manual is primarily concerned with environmental effects monitoring. It is specifically concerned with: 1) environmental effects monitoring programs directed at assessing the effectiveness of environmental protection measures in a regulatory setting; and 2) effects monitoring programs directed at improving the practice of environmental impact assessment.

After defining environmental effects monitoring, this manual outlines nine general principles to which all environmental effects monitoring programs should adhere. These principles have been developed through the experience and are based on: 1) case studies of environmental effects monitoring programs; and 2) a critical review of published information on environmental monitoring programs.

By following the recommendations for designing monitoring systems outlined in this manual, the user will be able to develop an environmental effects monitoring program for his or her application.

2.0 Effects Monitoring in Environmental Assessment

2.1 What is Environmental Effects Monitoring?

Most practitioners agree that environmental monitoring is the repetitive and systematic measurement and collection of data **on** environmental components. The term "Environmental Effects Monitoring" (EEM) has been defined as the repetitive measurement of environmental parameters to test specific hypotheses (LGL Ltd. et al. 1984). Conover (1985) added to this definition the notion that EEM measures changes for the purpose of establishing **cause-effect** relationships. This manual uses the following definition of EEM:

> *Environmental effects monitoring is the repetitive measurement of attributes of environmental components to test specific hypotheses for the purposes of establishing causal relationships.*

The implications of this definition are:

1. environmental effects monitoring programs should occur over a number of years with sampling occurring periodically (e.g. annually) during the life the program;

2. environmental effects monitoring programs should be designed to scientifically test hypotheses; and

3. environmental effects monitoring programs should attempt to establish causal relationships between human activities and their effects.

2.2 How is the Monitoring Data Used?

Environmental effects monitoring programs may generate a considerable amount of data. These data are used for a number of different purposes. For example, in the case of new works and undertakings, the effects monitoring data may used to:

1. measure baseline environmental conditions in the area that might be impacted by the proposed project to help determine whether the proposed project and its anticipated impacts are acceptable;

2. establish trends in environmental quality during project construction and operation; and

3. assess the significance of environmental effects and determine whether more stringent controls are required.

In general, environmental effects monitoring programs will collect data for one or more of the following purposes:

1. to establish a baseline, that is, gathering information on the basic site characteristics prior to development or to establish current conditions;

2. to establish long term trends in natural, unperturbed systems to establish natural baselines;

3. to estimate inherent variation within the environment, which can be compared with the variation observed in the affected area; and

4. to make comparisons between different situations (e.g. pre-development and post development; upstream and downstream; at different distances from a source) to detect changes.

2.3 Why is Environmental Monitoring Essential?

Environmental effects monitoring programs provide the necessary information to:

1. design improvements for the practice of environmental impact assessment; and

2. assess the effectiveness of environmental protection measures in a regulatory setting.

Feedback from effects monitoring programs is used to determine:

1. whether more stringent environmental protection measures are needed; and

2. to improve the effectiveness of the federal environmental assessment process over time.

2.3.1 Improving the Practice of Environmental Impact Assessment

In recent years, the effectiveness of EIA studies has come under serious challenge, and repeated calls have been made for a new, more scientifically sound approach to forecasting environmental effects. Unfortunately, despite the large number of impact predictions that have been formulated, few attempts have been made to test previous predictions (Marmorek et al. 1986; Munro et al. 1986; Bernard et al. 1989). As a result, many inaccurate predictions are probably being propagated in the ongoing EIA process.

Environmental effects monitoring programs capable of detecting environmental effects are essential if we are to learn from experience. Information generated from environmental effects monitoring programs can benefit future environmental assessment activities by providing for better monitoring plans; better mitigation plans; enhanced predictive capability for assessing potential effects; and improvements in environment impact assessment procedures.

2.3.2 Assessing the Effectiveness of Environmental Protection Measures

Without monitoring there is no mechanism for evaluating the success of the environmental protection measures undertaken. Environmental effects monitoring provides important feedback that allows for more effective planning and an adaptive response based on an assessment of the effectiveness of environmental protection measures. Formal impact assessment usually ends with the project approval. Normally a number of environmental operating conditions are laid down upon granting of approval. These, along with any conditions set out in permits and licences, become part of the environmental management regime for the project. Any monitoring that is undertaken is usually done in this regulatory context. Compliance monitoring is almost always undertaken in some way, shape, or form to ensure adherence to these conditions.

Effects monitoring is required to assess whether the various environmental protection measures are effective in attaining the goals of environmental protection. Without an effects monitoring program, it not possible to say one way or the other if the environment is being protected. Without effects monitoring programs, the environmental assessment system has no mechanism for evaluating its performance against its goals. Environmental effects monitoring can help to:

1. determine compliance of a pollution control program;

2. provide data for use as a part of environmental auditing;

3. describe the extent of environmental effects and resource losses; and

4. provide scientific information about the response of an ecosystem to a given set of management actions.

3.0 General Environmental Effects Monitoring Principles

Principles are basically rules or standards of good practice emphasizing what should be done. Principles are essential to ensure that EEM programs are systematically applied and directed to achieving specific objectives.

The General Principles

EEM programs should be based on the following principles:

1. All environmental effects monitoring programs must be designed so that **current and** future actions (development and environmental assessment) can benefit from the results of the program.

2. All monitoring programs should be guided by a set of specific objectives.

3. All monitoring should be based on an ecological approach that recognizes the interrelationships between ecosystem components.

4. As there are innumerable components of the ecosystem that could be monitored, all monitoring should be directed towards a manageable set of ecological indicators selected to optimize the detection of potential or actual changes.

5. All effects monitoring programs should be based on specific hypotheses designed to test cause and effect relationships.

6. Baselines, standards, or environmental objectives should be established for comparison and evaluation of monitoring results.

7. All environmental effects monitoring programs should continue long enough over time to provide sufficient evidence for a conclusive test of its hypotheses.

8. All monitoring should be based on a rigorous statistical design. Programs should have quality control and quality assurance procedures.

9. All environmental monitoring programs should contain mechanisms for auditing program performance.

3.1 Integral Part of Environmental Assessment System

An environmental effects monitoring program must be an integral part of the environmental assessment system from earliest stages of project planning and environmental impact assessment (EIA) and continue throughout all phases of a project's life. By providing information about the current status of our environment, monitoring programs provide feedback about the actual effects of human activities on the environment and the effectiveness of mitigation measures to protect the environment. This feedback is essential to ensure that those who plan development and those who manage environmental resources are supplied with a steady flow of appropriate, and reliable field information upon which to base their decisions and actions. Environmental effects monitoring programs must also provide information for follow-up activities. This is particularly true if we are to learn from one project to the next. Information generated by monitoring programs will lead to more environmentally sound designs on future projects. It will also increase the scientific understanding of environmental impacts, thereby leading to a better environmental impact assessment of future projects.

The importance of environmental effects monitoring programs can be seen by examining three major feedback loops (Figure 3.1):

1. ***Within project corrections (loop 1 - 2 - 3 - 1).*** Various environmental protection measures are implemented based on project planning and the environmental assessment. These measures taken together with the project activities lead to actual effects (Figure 3.1: link 1). Environmental effects monitoring provides information on the actual effects (Figure 3.1: link 2). The feedback that monitoring provides to management may lead to changes in the environmental operating conditions associated with the project (Figure 3.1: link 3). The actual decisions taken by managers based on monitoring information will depend on the objectives of the monitoring program. These changes will in turn lead to a new set of environmental effects.

2. ***EIA process helps monitoring design which in turn provides information to EIA process (loop*** 4 - 5 - 6 - 7). The identification and analysis of issues that is undertaken in the early stages of the EIA process helps define the monitoring program plan (Figure 3.1: link 4). The plan directs the monitoring program (Figure 3.1: link 5). Often monitoring data (usually describing baseline environmental conditions) is available during the impact assessment (Figure 3.1: link 6). Once the assessment is complete the monitoring plan will be revised based on the findings of the environmental assessment (Figure 3.1: link 7).

3. ***Environmental effects monitoring programs provide information for follow-up activities (loop 8 - 9).*** Environmental monitoring data provides the information upon which environmental follow-up programs can evaluate the success of environmental protection measures and determine the accuracy of impact predictions (Figure 3.1: link 8). Once the evaluation is complete this information will lead to better mitigations, more effective EIA procedures, increased predictive capability, and improved monitoring programs for future projects (Figure 3.1: link 9).

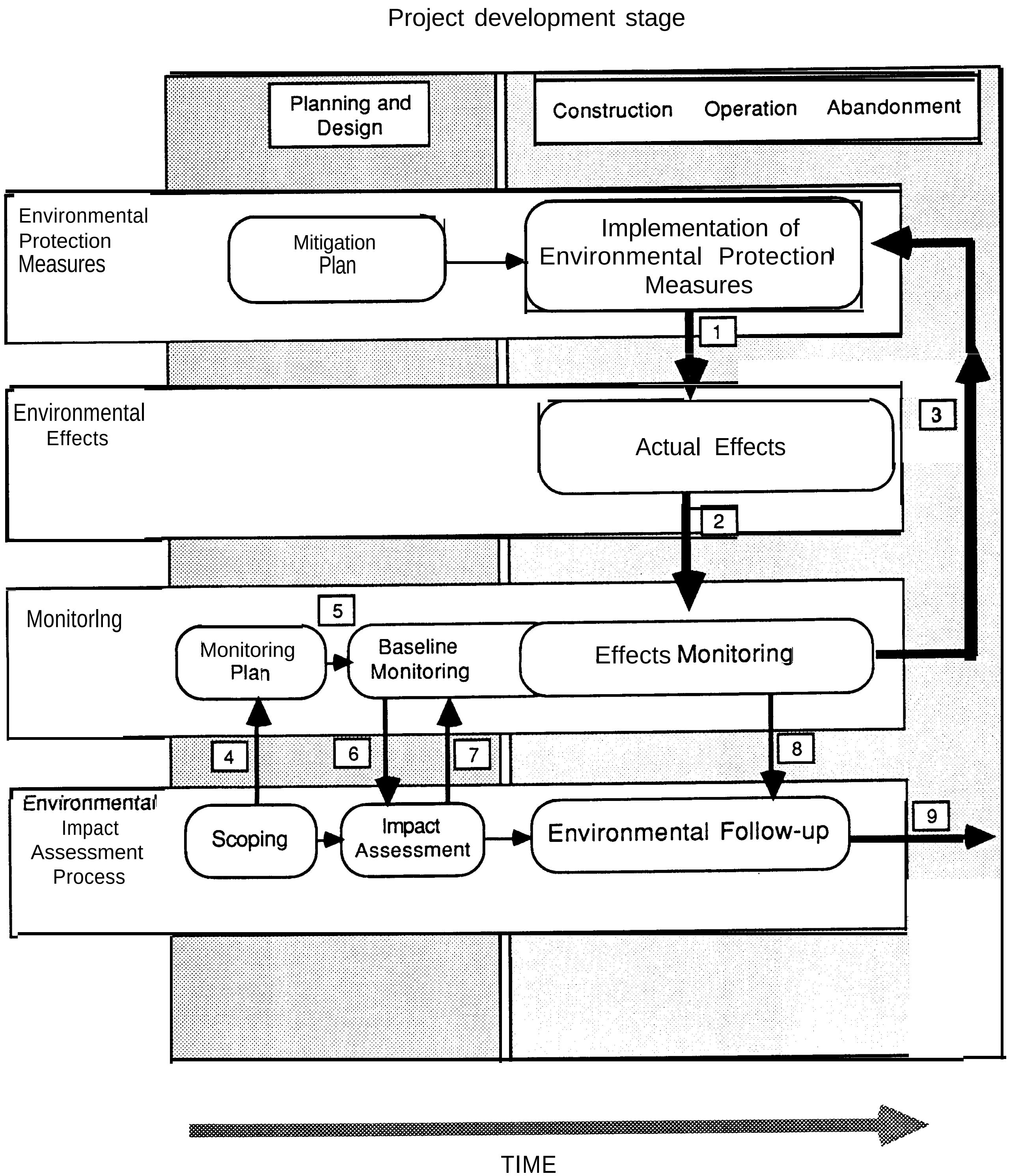

Figure 3.1: Monitoring provides important feedback for more effective planning and to revise environmental protection measures as needed.

3.2 Environmental Effects Monitoring Based on Objectives

The first step in developing any monitoring program is to determine why monitoring is necessary. Deciding on the specific objectives of the monitoring program may require input from a broad range of stakeholders. This is particularly true of environmental effects monitoring programs arising out of environmental assessment processes where decisions regarding monitoring are often made based on subjective concerns as much as on scientific evidence. Environmental effects monitoring is not simply a scientific and technical undertaking. Often broad involvement by various interest groups is necessary to ensure that the monitoring program will reassure the public that environmental protection measures are effective.

3.3 Ecological Approach

All monitoring should be based on an ecological approach that recognizes the interrelationships between various components of the ecosystem. In spite of our limited understanding of ecosystems and their functioning, an ecological approach is far better than relying on one or two variables. An ecological approach forces examination of the key relationships or linkages amongst various components. Determination of ecosystem health generally requires monitoring for a group of ecological indicators rather than reliance on a single indicator (Rapport et al. 1985).

3.4 Ecological Indicators

Environmental effects monitoring programs must have clearly defined assessment endpoints. Valued ecosystem components (Beanlands and Duinker 1983) are often chosen as endpoints of concern. Assessment endpoints are formal expressions of the actual environmental values. In many cases, assessment endpoints can be directly measured (e.g. extent of habitat for an endangered species), however in other cases, direct measurement is impossible or impractical (e.g. sustainable development of fisheries). Ecological indicators or measurement endpoints must correspond to, or be predictive of, assessment endpoints (Suter 1990). The relationship among environmental values, assessment endpoints, and ecological indicators is shown in Figure 3.2. In this case, the environmental values relate to a maintenance of a sustainable fishery to provide long term environmental, social, and economic benefits. One assessment endpoint that would be of interest to a decision maker is “changes in the abundance of harvestable fish”. One ecological indicator that could used in the determination of this assessment endpoint is “fish population by size class”.

The complexity of most ecosystems makes it impractical to measure a wide range of ecological components. A smaller set of ecological indicators must be chosen. In selecting indicators it is desirable to determine critical attributes that also reflect similar responses of other critical attributes, however until one attribute can be predicted from the response of another, multiple lines of evidence are essential (Cairns 1990).

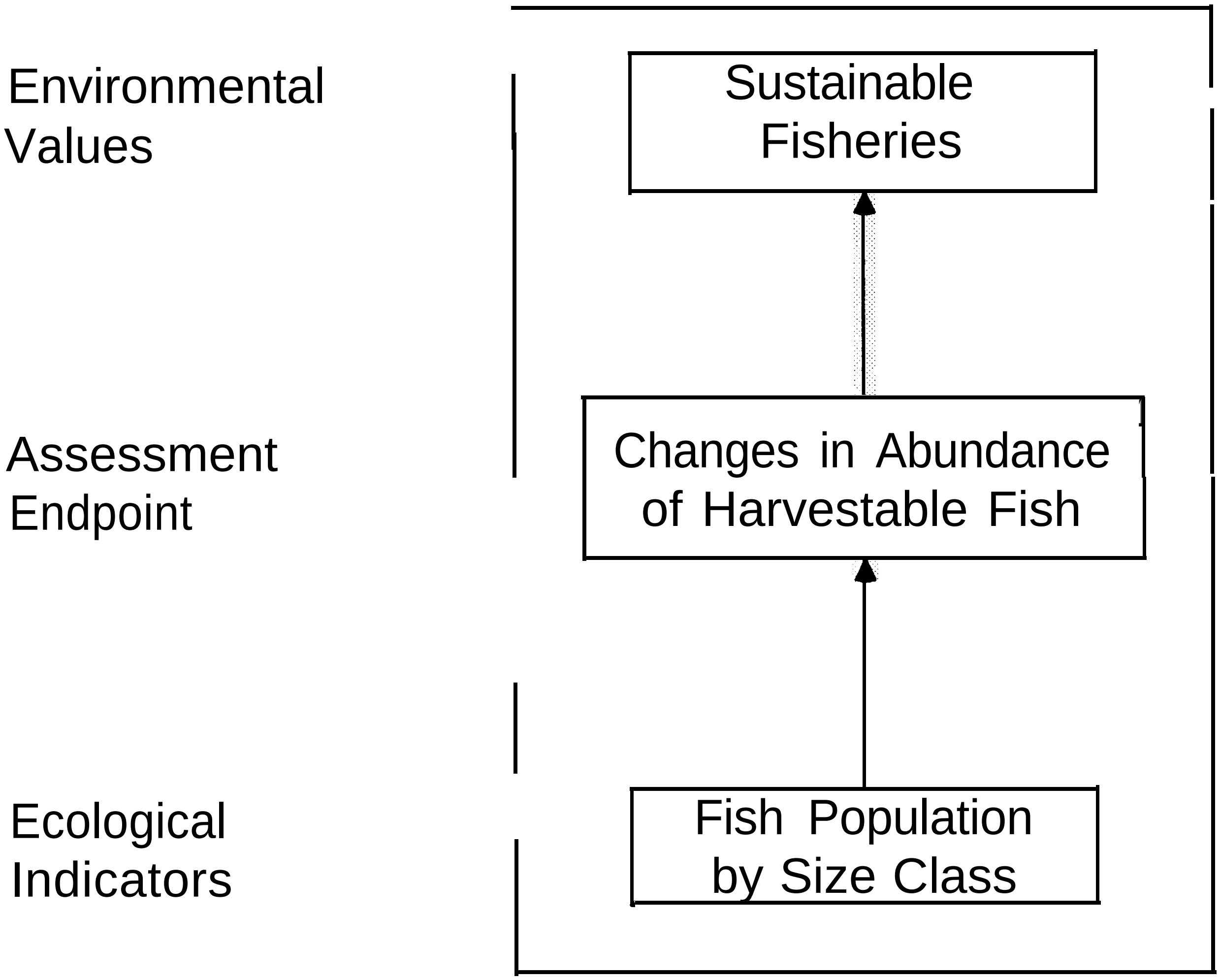

Figure 3.2: The relationship between environmental values, assessment endpoints, and ecological indicators.

In an environmental impact assessment context, the choice of indicators is related to the assessment of the significance of the environmental components (Everitt 1987). In general, significance or importance of environmental components may be based on: 1) legal status (e.g. rare and endangered species); 2) political or public concerns (e.g. resource use conflicts); or 3) scientific judgement (e.g. ecological importance).

If possible, the indicators chosen should be easily understood by non-technical participants in the program.

3.5 Based on Impact Hypotheses

While it is necessary to define project activities, select ecological indicators to be monitored, identify relevant standards, and establish baseline conditions, this alone is not sufficient. Effects monitoring programs should address specific questions. EEM programs must be based on impact hypotheses that spell out our current understanding of the causal relationships between the activities and the ecological indicator. If this is done then EEM will increase our understanding of the causal relationship, and that increased understanding may be incorporated into future environmental management actions.

An impact hypothesis is a set of statements that links human activities with their potential effects. Every impact hypothesis has three primary parts that must be defined:

1. *activities* - that which is the potential cause of the effect;

2. *valued component or ecological indicator* - that which is the measure of the effect; and

3. *linkages* - the set of statements that link the activities to the indicator.

An impact hypothesis outlines the current scientific understanding of the causal relations between the activities and the ecological indicator. The linkages describe the cause and effect relations based on ecological processes. In some cases the impact hypotheses will represent the relationships between a number of ecosystem components.

3.6 Baselines, Standards, and Environmental Objectives

In environmental assessment, we expect effects monitoring to provide the feedback on the response of the ecosystem to deliberate environmental management actions. Thus, results of EEM programs should lead to statements like:

> "we undertook action x and observed that the level of pollutant y in environmental component z was above acceptable standards"
>
> or

"we undertook action x and observed that the abundance of animal population y decreased by z amount"

To make these statements, we must first define:

1. the actions that we are considering;

2. the environmental components that we are interested in;

3. a set of standards or environmental objectives for comparison; and

4. a set of baseline conditions for each environmental component.

Monitoring results must be compared against either baseline results or against standards or environmental objectives. Standards are often set by regulatory agencies or are corporate or industry association standards. Results can also be compared with environmental quality objectives and criteria established by other jurisdictions. In cases where baselines are relevant, the baseline should be established as clearly as possible at the outset of the monitoring program. Establishing the baseline will require data collection and storage.

In many cases there will be no standards or baseline. In these cases, it will be necessary to establish controls to serve as the baseline. This will require sampling in a similar environment that is known to be unaffected by the proposed project (i.e. a spatial control). It may also require sampling at different times of year (i.e. temporal controls).

3.7 Monitoring Programs Must Continue Over Time

Environmental effects monitoring programs should occur over a number of years with sampling occurring periodically (e.g. annually) during the life the program. Ecological systems are such that effects may not be manifest for a number of years because of time lags (as in age structured effects on long lived species) or because of thresholds (as in the case with bioaccumulation of contaminants). Even without these complications, the inherent natural variability of ecological systems combined with the limitations of our existing statistical tools requires that a number of years of data be collected before statistically significant changes in an environmental component can be detected.

3.8 Statistical Considerations

Monitoring programs must be based on a sound statistical design and provide for quality assurance and quality control of all data. Careful consideration needs to be given to the design of sampling programs (where, when, and how many samples are to be taken). Specific protocols for collecting and laboratory analysis of data are essential. Sampling schemes should be designed to test statistical hypotheses.

3.9 Auditing Mechanisms

Monitoring programs must be audited periodically. A check is necessary to ensure whether the program objectives are still relevant. Auditing provides an evaluation of whether the data collection system and information system are providing information relevant to the questions being addressed or hypotheses being tested.

4.0 Components of an Environmental Effects Monitoring Program

The existence of an EEM program implies there is an administrator or coordinator responsible for managing the program. The monitoring program will need a data collection system for gathering data based on quality assurance and quality control protocols; and an information system for storing and retrieving data. The program must have provisions for decisions to be taken on recommendations for corrective action.

Thus, minimum components of an EEM program include:

1. decision system responsible for taking actions based on the results of the monitoring program;
2. administration responsible for planning, design, and coordination of the monitoring program;
3. information system responsible for data storage and retrieval, analysis, and reporting; and
4. data collection system responsible for sampling and quality control and quality assurance.

Failure in any one of these components will lead to failure in the EEM program.

4.1 Decision System

Environmental effects monitoring program must be an integral part of the environmental assessment system (see Section 3.1). Monitoring programs provide feedback about the actual effects of human activities on the environment and effectiveness of mitigation measures to protect the environment. Based on feedback, decisions will be taken to:

1. institute the changes in the environmental operating conditions associated with a given project; and
2. undertake improvement in the environmental assessment process leading to more effective EIA procedures, increased predictive capability, and improved monitoring program for future projects.

To be effective, monitoring programs must have decision making system prepared to take corrective action based on the results (Figure 4.1: links 6,7).

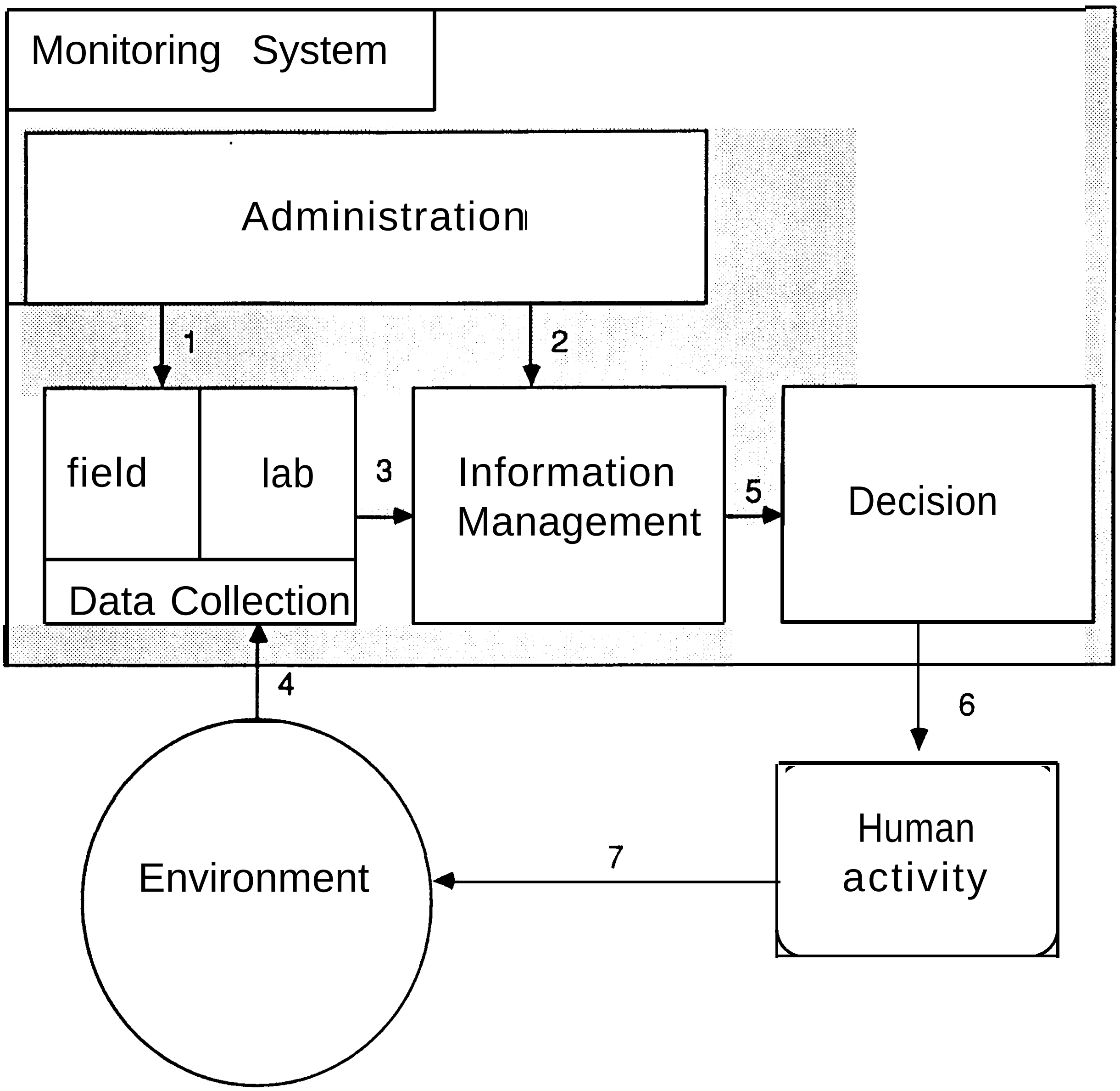

Figure 4.1: Interrelationship by major components of an EEM system.

4.2 Administrative System

The monitoring program will require an administrative system to design, plan, and oversee the conduct of all aspects of the monitoring program. The administrative system will actually be responsible for the design and operation of the data collection system and the information system (Figure 3.2: links 1,2). As most environmental effects monitoring programs require a coordinated effort of a variety of interests, the administrative system will have to be designed to allow for participation from a number of agencies and stakeholders.

For example, the pulp mill monitoring (discussed in Appendix A2) has a strong element of coordination within the program. The specific guidelines, protocols (currently under development) and requirements for an interpretative report should lead to greater consistency between monitoring programs within the industry. Greater consistency will lead to better understanding of regional and national effects of pulp mills.

4.3 Information System

The information system is simply all the databases and analytical procedures that are required to translate data collected by field programs into information that is relevant to the decision making system (Figure 3.2: link 5). To ensure that the data collection system will provide the necessary data, it is important to design the information system and, in particular, decide on the types of analysis that will be required prior to collecting any data. In most cases, it is recommended that a computer-based information system be utilized to allow efficient storage of information and as well as rapid analysis and reporting of results.

It is important that this system have clearly specified formats for interpretative reporting.

4.4 Data Collection System

The data collection system is the essentially the scientifically based field and laboratory components of the monitoring program that provide the basic data on the status of the environment. Field programs gather the basic data (Figure 3.2: link 4) and then it undergoes laboratory analysis. Protocols for sampling and laboratory analysis are necessary to ensure that programs are conducted in a rigorous and scientifically defensible manner. Quality assurance and quality control programs will ensure that the data made available to the information management system (Figure 3.2: link 3) is reliable.

5.0 The Design of Monitoring Systems

There are a number of institutional, scientific, and fiscal issues that must be addressed in the implementation of an environmental effects monitoring program. However, careful consideration of these issues in the design and planning stages will help avoid many of the pitfalls associated with environmental effects monitoring programs. Completing the tasks outlined in the following approach to the design of monitoring systems will lead to a better program.

5.1 Start with an Analysis of Issues

While monitoring may or may not be a regulatory requirement, it is seldom clear exactly what is to be monitored, by whom, when, where, and using which techniques. Because there are usually a number of subjective decisions to be made, it is important to start with an analysis of environmental issues. The scoping phase of an environmental assessment is designed to explore and focus the major issues. Scoping should provide a valuable source of information on what concerns need to be addressed by the monitoring program (see Section 3.1).

Practical experience with effects monitoring programs shows there is a wide range of public and professional concerns that are industry specific. Broad participation by a range of interests will likely be required. Stakeholders that should be included are: government environmental agencies, government regulatory agencies, environmental groups, local communities, industry, and the professional community.

5.2 Formulate Specific Objectives

It is often necessary to formulate broad objectives to satisfy the range of interests that will have a stake in the monitoring program. If this is the case, a set of more specific objectives will also have to be formulated. For example, suppose the objective is to determine the environmental quality of an estuary but most of the concerns relate to a fishery, fish populations and fish habitat that may be affected by effluent from an industrial outfall. In the design of a monitoring program more specific objectives must be developed. For example the:

General Objective: *to determine the environmental quality in the estuary*

could lead to the:

Specific Objectives: *to determine amount of degradation of fish habitat associated with the industrial effluent;*

to determine population trends in fish populations; and

to determine the any losses to the fishery.

5.3 Formulate Clear Questions Directed Toward Assessment Endpoints

Monitoring programs work best when the scientific method guides data collection, analysis, and interpretation. Hypotheses form the bridge between the somewhat more subjective issues and objectives and the somewhat more objective field sampling and analysis. Prior to stating an hypothesis, a question to be answered must be formulated. The answers to these questions are assessment endpoints. Assessment endpoints (see Section 3.4) are information a decision or policy maker might wish to know about the status of ecological resources. Assessment endpoints should have social or biological relevance and have an unambiguous operational definition. They should be susceptible to the hazard and be accessible to prediction and measurement (Suter 1990).

For example, key questions associated with the objectives defined above might be:

1. ***what proportion of fish habitat in the estuary has been degraded to the point that it is considered unproductive?;***

2. ***are fish populations declining, increasing, or staying the same?;*** and

3. ***are current levels of fish harvests sustainable?***

5.4 Construct Simple Conceptual Models of Impact

It is desirable to have simple conceptual models of the mechanisms by which impact might occur. In addition to being useful in determining which variables to monitor, these models are extremely valuable in communicating the rationale for monitoring. One of the best way to represent these conceptual models is using impact hypotheses (see Section 3.5). An impact hypothesis is simply a statement of our understanding of the mechanism of impact. For example, our key questions can be embodied within an impact hypothesis (Figure 5.1) incorporating environmental components: the fishery, fish and fish habitat.

5.4.1 Selecting Ecological Indicators

Once the impact hypothesis is well stated, monitoring effort can be concentrated on specific ecological indicators. It is necessary that the indicators chosen be relevant to the impact mechanisms, be measurable, and be appropriate to the spatial and temporal scale of disturbance/pollution. Where possible, standardized indicators with existing data series should be chosen. Other desirable characteristics of ecological indicators include: 1) low natural variability; 2) broad applicability; and 3) being diagnostic with respect to the potential cause.

Two environmental indicators relevant to our example are:

1. ***fish population by size class;*** and

2. ***area of contaminated fish habitat.***

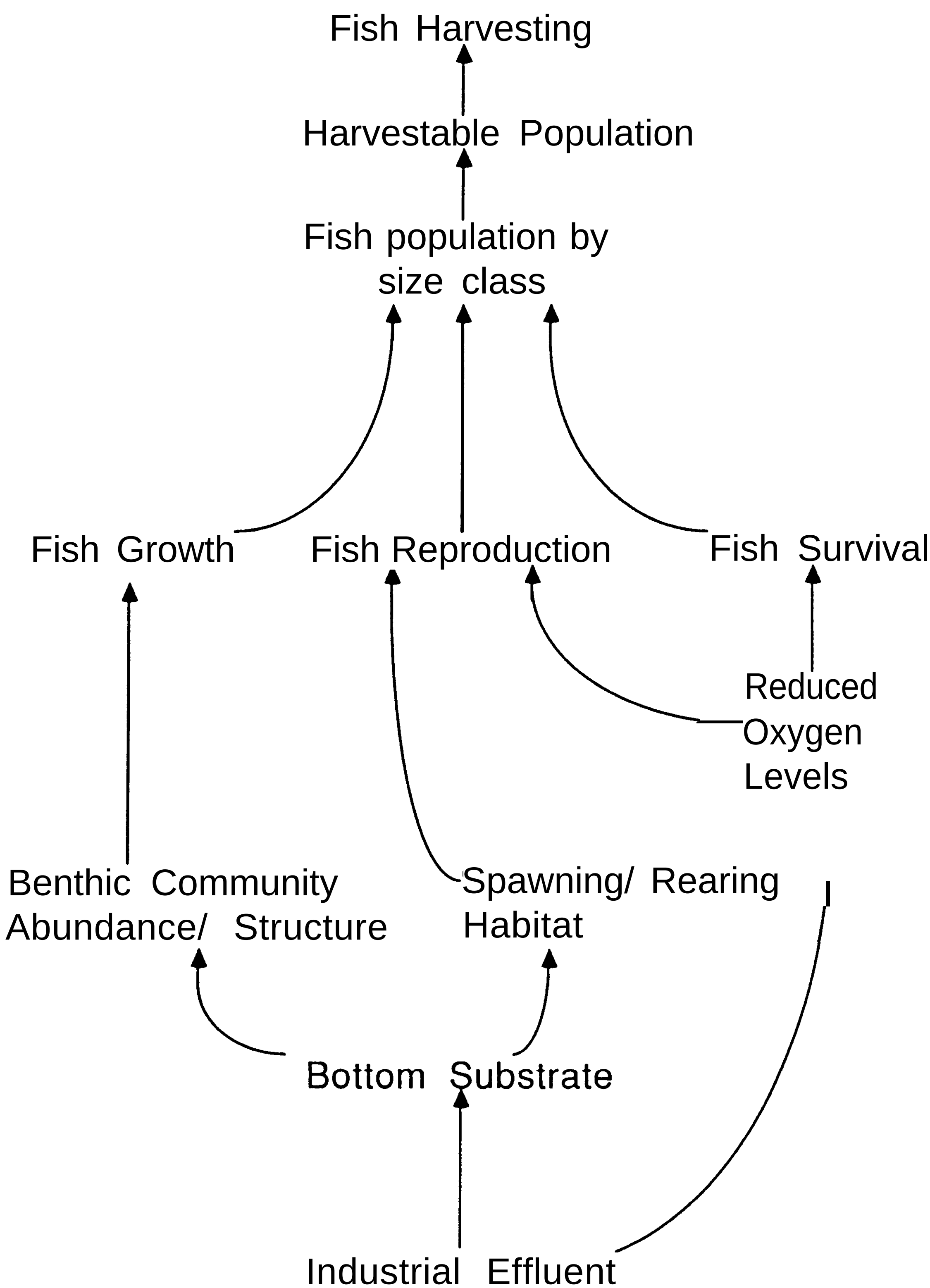

Figure 5.1: Example impact hypothesis representing the potential impact mechanism of industrial effluent on fish, fish habitat, and fish harvesting.

Criteria for Choosing Assessment Endpoints

The following criteria are useful when choosing assessment endpoints:

- accessible to prediction and measurement
- unambiguous operational definition
- social/biological relevance
- susceptible to hazard

Criteria for Selecting Environmental Indicators

The following criteria are useful in selecting environmental indicators:

- measurable
- appropriate to the scale of disturbance/pollution
- appropriate to the impact mechanism
- appropriate to temporal dynamics
- diagnostic
- standardized
- low natural variability
- broad applicability
- existing data series

5.5 Establish an Information Management System

An information system for storing, retrieving, manipulating and disseminating data must be in place to receive the results of the monitoring program as they become available. Because monitoring requires that repetitive measurements be made, the information management system needs to be capable of handling time series information for producing meaningful reports based on the analytical framework required for interpreting monitoring results.

There are a number of existing databases (e.g. NAQUADAT) and Environment Canada will be establishing regional and centralized databases for monitoring programs in major industrial sectors (e.g. Pulp and Paper, Metal Mines). In the absence of an existing database one will have to be developed.

5.5.1 Define the Framework for Data Analysis Prior to Data Collection

The content of the data analysis framework will depend on the monitoring objectives. Specific statistical methods used to analyze the data should be provided in detail, and should be chosen such that the uncertainty or error estimates in conclusions drawn from the data can be quantified. Such methods might include: 1) the use of frequency distributions; 2) analysis of variance; 3) analysis of covariance; 4) cluster analysis; 5) multiple regression analysis; 6) principal components analysis; 7) time series analysis; and 8) the application of dynamic systems models (c.f. Green 1979).

5.5.2 Reporting

It is critical that an interpretative report be prepared with recommendations related to the need for more stringent environmental protection measures and improvements in the effectiveness of environmental assessment procedures to be applied to future assessments.

5.6 Develop a Rigorous Sampling Design

The approach to sampling programs noted in the case studies reviewed in Appendix 1 were many and varied. This underscores the need for a more consistent, systematic, and statistical valid approach to sampling. Green (1987) provides a set of statistical principles of research and monitoring design:

1. Clearly formulate the question. Rephrase as a null hypothesis and an alternative hypothesis.

2. There should be a control. If it is an observational study over space and time, try to have both a spatial and temporal control.

3. Have replicate samples within treatments, areas, etc.

4. There should be a balanced (equal) and random (or at least unbiased) allocation of samples with respect to the variables of interest (see also Principle 8 below).

5. Do some preliminary sampling (a pilot study) so that steps 6-9 can be done.

6. Evaluate the sampling method for consistency (lack of bias) over the entire universe that will be sampled.

7. Estimate necessary sample number (or adequacy of feasible sample number), and optimum sample unit size.

8. If there is a large scale spatial pattern, consider a stratified sampling design. To estimate spatial distribution allocate samples evenly over the area; to estimate abundance allocate samples proportional to estimated abundance.

9. Decide how to handle problems in data: transform it? use nonparametric statistics? use simulation, randomization or jackknife? use sequential sampling? apply corrections for bias?

10. Stick with the results (i.e. let the hypotheses be falsifiable).

56.1 Formulate Statistical Hypotheses

Statistical hypotheses will have to be formulated as a part of the definition of the analytical framework.

Example statistical hypotheses corresponding to the key questions, outlined earlier in Section 5.3, might be:

Hypothesis 1:

Ho: All fish habitat in the estuary is equally productive.
Ha: Habitats in the vicinity of the industrial effluent outfalls are less productive than habitats at greater distance.

Hypothesis 2 :

Ho: There is no change in fish population in the estuary.
Ha: The fish populations in the estuary are declining.

Hypothesis 1 implies that sampling will have to be stratified spatially; Hypothesis 2 implies that time series information will be required.

5.7 Establish Rigorous Quality Assurance Programs

The accuracy and precision of data generated by a monitoring program can only be assessed if a good quality assurance and control program is in place. The objectives of the intensive quality assurance program are to:

1. generate quality analytical data;

2. ensure complete documentation and defensibility of all data; and

3. expedite data evaluation and acceptance.

Several factors affect the results of any given sampling program. Some of these factors are:

1. high level of temporal and spatial variability;

2. analytical and sampling error;

3. sample contamination; and

4. high concentration values due to natural or special source conditions.

To successfully carry out a monitoring program requires field and laboratory staff trained in sample collection and handling procedures. If appropriately trained staff are not available, the available staff should be sent to a commercial or government laboratory for detailed instruction in the methods required.

Specific protocols for: 1) sample collection and storage; 2) sample shipments; and 3) testing laboratories should provided in the overall design.

5.8 Prepare a Cost Estimate for the Entire Monitoring Program

There are at least five major cost elements associated with monitoring programs in addition to overall administration and coordination costs:

1. program design costs;
2. field sampling programs;
3. laboratory analyses;
4. operation and maintenance costs associated with the information management system; and
5. quantitative analysis and reporting.

A cost estimate for each of these program elements should be provided in detail at the outset of the monitoring program.

5.9 Practice Adaptive Management

The monitoring program should continue over a number of years. The program will benefit greatly from a periodic review to ensure that the data being collected and information being provided to decision makers is still relevant. In most cases, a systematic review of the program will allow for new scientific understanding to be incorporated into the program. This will likely lead to modifications of hypotheses and sampling programs.

It is necessary to review the program after one field season to make necessary corrections in the sampling design, and field and laboratory protocols.

6.0 Environmental Effects Monitoring in Practice

In the preparation of this manual, some of the past experience with environmental effects monitoring in Canada was reviewed and summarized in the case examples provided in Appendix 1. The experience of these programs provide some practical lessons that can benefit future programs. Many of these lessons have been directly incorporated into the general principles (Section 3) and the recommended approach to design of environmental effects monitoring programs (Section 5). This section provides a synthesis of the key findings of the case studies.

6.1 Environmental Effects Monitoring Programs are Issue Driven

Invariably there is a specific set of issues that must be addressed by the monitoring program. For example, the Beaufort Sea Environmental Monitoring Project arose because many concerns persisted after the EARP Panel completed its review. Monitoring was deemed necessary because of the difficulties and uncertainties associated with the environmental impact assessment including the inability to reliably predict the impacts of development, in part because of the limited understanding of Arctic ecosystems. This problem was compounded by uncertainties about the innovative technologies proposed by industry and the limited experience of the petroleum industry in the offshore Arctic. The environmental issues that were considered by BEMP were summarized in approximately twenty-one carefully stated and reviewed impact hypotheses (see Appendix 1, Table Al. 1).

The Working Group that oversaw the Norman Wells Environmental Monitoring Program also established a set of priority environmental issues (see Appendix 1, Table A3.1). These issues covered a broad range of terrestrial, aquatic, air quality, and socioeconomic concerns.

The issues considered by pulp and paper aquatic monitoring programs were fewer in number and more focused (see Appendix 1, Table A2.1). The concerns at pulp mills include:

1. reduction in dissolved oxygen concentrations due to increased BOD;
2. contamination from chlorinated organics (including dioxins and furans); and
3. contamination from metals.

Monitoring with respect to pulp mills include monitoring in each of four major ecosystem components: 1) effluent; 2) water; 3) sediment; and 4) biota. The Athabasca River Pulp Mill Effects Monitoring Program appeared to be directed towards resolving specific issues with respect to:

1. permit drafting;
2. assessment of assimilative capacity (BOD capacity) of the river in anticipation of more mills; and

3. uncertainty in the understanding of river processes and ecosystem processes.

Similarly, the metal mining monitoring program was focused on a small set of issues. The concerns associated with metals mines are:

1. acid mine drainage and its effects on fish and other aquatic biota; and

2. mill effluent outfalls and potential for metal contamination.

The guidelines for metal mines discharging to the aquatic environment also provide a rationale for each of the parameters suggested for monitoring (Appendix 1, Table A5.1).

The Lower Columbia monitoring program integrated a number of issues and concerns of different agencies associated with different industries. The Lower Columbia has a pulp mill, a smelter and mill complex, hydroelectric dams and generating facilities, and municipal sewage outfalls. As such the environmental issues associated with the pulp mills and metal mines apply as well as those specifically related to hydroelectric dams. With respect to proposed hydroelectric development, issues of particular interest are: total gas pressure and dissolved oxygen in the Columbia River as well as fish movements in the Lower Columbia.

While there appears to be a wide range of questions being addressed, there are many similarities among the aquatic monitoring programs reviewed with respect to the variables chosen for monitoring. The Columbia Integrated Monitoring program provides an excellent example of how the needs of a number of agencies and industries can be accommodated with one common data set, though differences of course do exist. Usually the differences in monitoring programs result from different contaminants being present in waste streams of different industrial effluents.

6.2 Environmental Effect Monitoring Programs Require Focused Objectives

It appears that monitoring program objectives can be stated by a number of levels of generality:

1. general objectives related to evaluating and improving environmental protection measures and our capabilities in environmental assessment;

2. general objectives relating to assessing effects (e.g. to assess the present state of the reach of the Columbia River from and environmental point of view) and mitigation measures (e.g. evaluate the long term of mitigation measures associated with Norman Wells Pipeline) for the specific case;

3. well stated objectives directed at assessing the effects of a given activity or stressor on a specific part of the ecosystem (e.g. to assess the effects of mine effluent on fish and other aquatic organisms and their habitat); and

4. objectives related to specific data collection and information management tasks (e.g. to define a baseline for present winter water quality conditions).

The Beaufort Sea and Norman Wells projects had almost identical objectives related to evaluating and improving the environmental assessment process that led to development approval. These programs were concerned with: 1) determining and quantifying environmental impacts and to examine the recovery process; 2) comparing actual and predicted impacts; 3) evaluating long-term effectiveness of mitigative measures; and 4) preparing environmental recommendations applicable to future northern pipeline and oilfield developments.

The pulp mill and metal mines monitoring guidelines suggested by Environmental Protection, Environment Canada also had similar objectives to determine:

1. the effects of effluent on fish and other aquatic organisms and their habitat;

2. the extent that deleterious substances have damaged or are likely to damage fish and other aquatic organisms and their habitat;

3. the adequacy of any remedial action taken after any unauthorized deposit of a deleterious substance; and

4. the adequacy of existing control requirements and the need for more stringent or site-specific measures.

The specific case of the pulp mills on the Athabasca and Equity Silver Mines, had more limited objectives generally focusing on gathering and compiling data and make a crude assessment of the effects to date. The information in the Equity Silver Mines was used in permit negotiations; and the information on the Athabasca system was used both in setting permit requirements and for assessing the assimilative capacity (in terms of BOD) of the Athabasca River for pulp mill effluent.

6.3 Environmental Effects Monitoring Programs Require a Coordinated Effort

BEMP was especially challenging because of the large spatial scale and the magnitude of the proposed development. This, combined with the limited understanding of Arctic ecosystems, untied technologies, inexperience of the petroleum industry, and a large number of agencies and interest parties required an innovative approach to the development, coordination, and conduct of the monitoring program.

The Beaufort Sea Environmental Monitoring Project, the Norman Wells Environmental Monitoring Program and the proposed Columbia River Integrated Monitoring Program are examples of sets of monitoring studies coordinated under a single umbrella. Coordination is achieved through a multiple agency steering committee that sets program direction and priorities.

The pulp mills and the metal mines are discreet and in general require smaller monitoring efforts. These appear to be coordinated by industry and federal and provincial governments agencies. However, in the Equity Silver Mines case a broader range of interests was involved.

The pulp mill monitoring has a strong element of coordination within the program. The specific guidelines, protocols (currently under development) and requirements for an interpretative report should lead to greater consistency between monitoring programs within the industry. Greater consistency will lead to better understanding of regional and national effects of pulp mills.

6.4 Conceptual Models of Environmental Effects Should be Formulated

It is desirable to have simple conceptual models of the mechanisms by which impact might occur. In addition to being useful in determining which variables to monitor, these models are extremely valuable in communicating the rationale for monitoring.

Both the Beaufort Environmental Monitoring Project (BEMP) and the Norman Wells Environmental Monitoring Programs used simple conceptual models represented in the form of impact hypotheses. Impact hypotheses are statements of the causal relationships between human activities and an ecosystem (Section 3.3). Some impact hypotheses are long causal chains emphasizing the interrelationships between the various biophysical components in the ecosystem. In BEMP valued ecosystem components represented the assessment endpoints of the causal chain. However in many cases, it'was important and necessary to monitor other components lower down in the causal chain.

The generic guidelines for pulp mill monitoring fall short of specifying impact hypotheses but recommend that the details of all mill activities which have the potential to affect the environment need to be documented for both the design of the monitoring program and interpretation of results. Information required includes: 1) process and treatment systems; 2) production and flow rates; 3) chemical used; 4) existing environmental information; 5) habitat inventory; 6) effluent plume delineation; and 7) sediment transport and deposition. In the development of the generic guidelines there was consideration of the effects of the various mill activities on the receiving environment. The Humber Arm pilot study (Environment Canada 1989) provides a rationale for each variable to be monitored. However, the actual effects of concern of these are not explicitly stated. It seems desirable that the basic questions which each specific monitoring program is trying to address should be clearly stated and be translated into testable hypotheses. The specific case studies on the Athabasca River did not clearly specify the effects being addressed and would likely have benefited by formulation of hypotheses.

The Columbia River Integrated Monitoring Program developed four clearly stated falsifiable hypotheses:

1. the ambient water quality in each reach is identical;

2. the quality of the sediment bed in each reach is identical;

3. **the** body burden of contaminants in the aquatic biota in each reach is identical; and

4. the annual mean concentration of a substance in sediment is identical in each reach.

Similar hypotheses were suggested to test variability in water, sediment, and biota quality among stations within each reach, among sites within each sampling station, and temporal variability at sites.

The generic guidelines for metal mines recommend that the details of all mine activities that have potential to affect the environment need to be documented for both the design of the monitoring program and interpretation of results. Information required includes: 1) mine geology; 2) local climatology and hydrology; 3) mining methods; 4) milling and smelting systems; 5) chemicals used; 6) existing environmental information; 7) habitat inventory; and in certain instances 8) sediment transport and deposition (EVS Consultants 1990). In the development of the generic guidelines there was consideration of the effects of the various mine activities on the receiving environment. While a short rationale is given, it seems desirable that the basic questions which each specific monitoring program is trying to address should be clearly stated and these questions translated into testable hypotheses.

6.5 Variables for Monitoring Should be Chosen Based on Specific Criteria

The Columbia Integrated Monitoring Program provided a rationale for the choice of monitoring variables. In addition to the water quality concerns addressed by the existing monitoring network the effects of concerns related to: 1) the Ministry of Environment's objectives for development monitoring; 2) the Dioxin/Furan Baseline Sampling Program for the Columbia River; 3) Environment Canada's data needs to review the Celgar Expansion project; 4) B.C. Hydro's interest in monitoring total gas pressure; and 5) the toxic organic and heavy metal survey of the sewage treatment plants. The fish component of the integrated program is focused on the assessment of the distribution and abundance of fish, fish migration and movement patterns, habitat utilization by sportfish species, and contaminant burdens in fish tissues. An assessment of the suitability of various fish species for inclusion in the biomonitoring program was made based on the following combination of ecological, economic and social criteria: 1) use; 2) residency time; 3) spawning time; 4) food source; 5) sediment exposure; 6) abundance; and 7) fecundity.

Both the pulp and paper mill and the metal mine generic guidelines recommend a specific core set of variables to be monitored at every site. In addition, a suggested set is provided from which variables to be monitored would be chosen based on type of operation and receiving environment. The suggested ecological indicators are based on professional judgement embodying our current understanding of impacts.

BEMP made its choice of variables through a systematic evaluation of the impact hypotheses. A major task in the evaluation was the documentation of existing knowledge including evidence for, evidence against, and uncertainties in the statements in the hypothesis. In designing the test of the impact hypotheses a number of linked questions were addressed --

what do we monitor? what do we want to know? what do we actually measure? what information do we get from these measurements? how will this information help us achieve what we want to know?

6.6 Frameworks for Analyzing Data and Reporting Must be Designed Prior to Data Collection

In most of the monitoring programs reviewed it appeared there was a lack of a systematic approach of analysis for monitoring results. Analytical frameworks were seldom worked out in advance. Because of this it was difficult to undertake rigorous quantitative analyses to determine significant effects. As a consequence, most of the results presented in monitoring reports are descriptive in nature.

In the case of pulp mills and metal mines generic guidelines, the data reporting is to centralized databases (e.g. NAQUADAT). In the case of pulp mills EEM, interpretative guidance will be provided at the generic and parameter specific levels. This is a step in the right direction and should provide meaningful reports to managers and decision makers.

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Appendix 1: Case Study Analysis

Case Study Analysis

Five case studies were undertaken to analyze the design, planning, management, and scientific basis of environmental effects monitoring programs. The pulp and paper, metal mining, and oil and gas sectors were addressed. Along with specific case histories, proposed generic guidelines developed by Environment Canada for the pulp and paper sector as well as metal mines discharging to the aquatic environment were reviewed. In addition, an integrated monitoring program for the Columbia River was reviewed. Four major sources of contaminants are part of the Columbia River program: 1) a pulp mill; 2) a smelter; 3) hydroelectric dams and generating facilities; and 4) municipal sewage outfalls.

The analysis of the case studies are presented in summary form. Many of the important observations of the case studies have been summarized in Section 6 or incorporated into other parts of the manual.

Al Beaufort Environmental Monitoring Project

Al.1 Background

The Beaufort Sea Region has seen considerable hydrocarbon exploration activity and some production during the 1970's and 1980's. The broad range of planned activities (Dome Petroleum Limited et. al. 1982, Vol. 1) includes:

1. exploration activities and drilling to identify and delineate oil reserves;

2. construction of development platforms, drilling of wells and assembly of oil production facilities;

3. installation of subsea pipelines and onshore gathering systems to connect production and transportation facilities; and

4. development of a means of transporting oil to markets either by marine vessels, or through an overland pipeline, or some combination of both.

The Beaufort Sea - Mackenzie Delta region extends from the Yukon and Alaska border in the west to Cape Bathurst in the east, and from Inuvik in south (68 degrees latitude) to the edge of the continental shelf in the north (72 degrees latitude).

The potential development activities were submitted for review to the Federal Environmental Assessment and Review Office in 1980. A comprehensive environmental impact statement (EIS) was produced and extensive public hearings were held under the Environmental Assessment Review Process (EARP) in both northern and southern Canada. In 1984, the EARP Panel released its report with a recommendation that a phased development of Beaufort Sea hydrocarbons could be compatible with sound environmental management subject to implementation of a substantial number of mitigative measures (Everitt et al. 1986).

In spite of the comprehensive EIS and long period of review many concerns persisted because of the difficulties and uncertainties associated with the environmental impact assessment, including the inability to reliably predict the impacts of development. This problem was compounded by uncertainties about the innovative technologies proposed by industry and the limited experience of the petroleum industry in the offshore Arctic. These concerns and uncertainties pointed to a clear need for an environmental monitoring program that was fully integrated with the scenario of planned exploration and development activities. In response to this need, Indian and Northern Affairs Canada (INAC) and Environment Canada initiated the Beaufort Environmental Monitoring Project (BEMP).

BEMP was especially challenging because of the large spatial scale and the magnitude of the proposed development. This, combined with the limited understanding of Arctic ecosystems, untried technologies, inexperience of the petroleum industry, and large number of agencies and interest parties required an innovative approach to the development, coordination, and conduct of the monitoring program.

Al.2 Effects Monitoring Defined

In BEMP, effects monitoring was defined as a test of an impact hypothesis designed to:

1. measure environmental impacts; and

2. analyze cause-effect relationships.

Monitoring is the repetitive measurement of variables to detect changes directly or indirectly attributable to a specific development activity. The primary purpose of monitoring is to determine the causal relationships between development activities and environmental effects. Understanding the causes of these effects can then be used to plan appropriate mitigation responses. In the context of BEMP, monitoring was not part of the regulatory process to ensure that industry meets the terms and conditions associated with permits and licenses. Monitoring is a scientific process designed to test specific hypotheses linking actions (sources of environmental impact) to their effects as expressed by various ecological indicators.

Al.3 0 bjectives

The long term objective of BEMP was to provide INAC and Environment Canada with the technical basis for design, operation and evaluation of comprehensive environmental research and monitoring program to accompany hydrocarbon development in the Beaufort Sea region.

To meet its objectives, it was recognized that the monitoring program must include the following features:

1. determination of the most significant environmental resources and features likely to be affected by development;

2. formulation and testing of impact hypotheses and predictions;

3. recommendation of mitigative measures and continual evaluation of their success; and

4. adaptability of future research and monitoring to reflect new information, identified data gaps, and changes in the development scenario.

Al.4 Operational Considerations

BEMP was designed using an approach based on the development of impact hypotheses. This approach based on the development of a conceptual model of the Beaufort Sea ecosystem and the human potential impact on the ecosystem consisted of eight steps:

1. identification of valued ecosystem components (VEC);
2. identification of development activities;
3. identification of temporal considerations;
4. identification of spatial considerations;
5. identification of impact hypotheses that casually relate development activities to VECs;
6. screening of impact hypotheses for validity, relevance and credibility;
7. evaluation of impact hypotheses; and
8. design of specific data collection programs.

A1.4.1 Identifications of Effects

BEMP developed simple conceptual models of the mechanisms by which impact might occur. These models were used in determining which variables to monitor. Impact hypotheses are statements of the causal relationships between human activities and an ecosystem. Some impact hypotheses are long causal chains emphasizing the interrelationships between the various biophysical components in the ecosystem. In BEMP, valued ecosystem components represented the endpoints of the causal chain. However, in many cases, it was important and necessary to choose other components lower down in the causal chain. The impact hypotheses were carefully formulated to specify the environmental effects considered by the monitoring program. The environmental issues that were considered by BEMP were summarized in approximately twenty-one carefully stated and reviewed impact hypotheses (see Table Al. 1).

Al.4.2 Spatial and Temporal Considerations

The Beaufort region encompasses a very large geographic area. Each individual impact hypothesis has different spatial and temporal considerations.

Table Al.l: Impact hypotheses used to guide Beaufort Environmental Monitoring Project.

Hypothesis 1:	The effects of ship traffic, seismic exploration and active offshore structures on the western arctic population of bowhead whales.
Hypothesis 2:	The effects of various facilities and activities associated with offshore hydrocarbon development on white whale harvest.
Hypothesis 3:	The effects of marine vessel traffic, seismic activities, dredging operations, aircraft overflights and active offshore platforms/islands on the size of the Beaufort Sea populations of ringed seals and bearded seals.
Hypothesis 4:	The effects of increased frequency of icebreaker traffic through the landfast ice and through Amundsen Gulf on ringed seal pup production.
Hypothesis 5:	The effects of icebreaker traffic in the transition (shear) zone on bearded seal pup production.
Hypothesis 6:	The effects of icebreaker traffic in Amundsen Gulf on the ringed seal and polar bear populations.
Hypothesis 7:	The effects of active facilities on polar bears.
Hypothesis 8:	The effects of offshore development activities on polar bear harvest.
Hypothesis 9:	The effects of chronic/episodic oil spills resulting from normal petroleum hydrocarbon development activities within and adjacent to the marine environment on polar bears.
Hypothesis 10:	The effects of chronic (episodic) oil spills resulting from normal petroleum development activities on birds.
Hypothesis 11:	The effects of oil in open water areas around offshore structures during periods of ice cover on eiders and diving ducks.
Hypothesis 12:	The effects of low altitude aircraft flights on staging brant.
Hypothesis 13:	The effects of hydrocarbons and heavy metals on fish harvest.
Hypothesis 14:	The effects of nearshore structures on broad whitefish populations.
Hypothesis 15:	The effects of nearshore structures on the alaskan population of arctic cisco.
Hypothesis 16:	The effects of production fields and discharge of pollutants on arctic cisco and broad whitefish populations.
Hypothesis 17:	The effects of water intake on broad whitefish and arctic cisco populations.
Hypothesis 18:	The effects of air emissions associated with the operation of aircraft, marine vessels, drill rigs, offshore platforms and shorebases on air quality.
Hypothesis 19:	The effects of dredging on bearded seals.
Hypothesis 20:	The discharge of drill cuttings contaminated with oil based drilling muds during hydrocarbon exploration or production will reduce the populations of fish, birds, or mammals or will decrease the harvest of these resources due to hydrocarbon accumulation in tissue.
Hypothesis 21:	Tanker traffic and minor oil spills associated with the westward transport of Canadian Beaufort oil will cause reductions in the Western Arctic population of bowhead whales and the harvest of this population by Alaskan Inupiat.

A1.4.3 Choice of Variables to be Sampled

BEMP made its choice of variables through a systematic evaluation of the impact hypotheses. **A** major task in the evaluation was the documentation of existing knowledge including evidence for, evidence against, and uncertainties in the statements in the hypothesis. In designing the test of the impact hypothesis a number of linked questions were addressed:

1. what do we monitor?;
2. what do we want to know?;
3. what do we actually measure?;
4. what information do we get from these measurements?;
5. how will this information help us achieve what we want to know?

A1.4.4 Sampling Frequency, Sample Size, Data Collected

This task was left to the individual research managers and scientists whose charge is to manage and execute individual monitoring projects.

Al.5 Program Management

Al.51 Program Planning and Coordination

The first two years of BEMP were planned and coordinated through a series of major workshops where participants formulated and discussed all the impact hypotheses that guided the project. These workshops fostered interdisciplinary communication and served to integrate the entire monitoring efforts in the Beaufort Sea region. During the first years the basic approach outlined above was used. In subsequent years, focused workshops were held to review individual monitoring projects conducted under the auspices of BEMP to assess the relevance of their results in the context a specific BEMP hypothesis. Based on these reviews, monitoring efforts was redirected.

A1.5.2 Lessons

Three lessons related to organizing and managing people participating in monitoring programs arose out of BEMP (Everitt et al. **1986):**

1. interdisciplinary groups are more likely to be successful at developing integrated plans if conceptual models are used as a framework to guide discussions and information gathering;

2. model building designed to facilitate integrated monitoring must start from the' ideas of those individuals who will be involved in the management and execution of the monitoring program; and

3. the problem definition phase of designing monitoring programs is characterized by subjective decisions about what to include and what to exclude from the program.

Al.53 Statistical Principles of Research and Monitoring Design

Some of the guiding principles for the research and monitoring design used during BEMP were (Green 1987):

1. Clearly formulate the question. Rephrase as a null hypothesis and an alternative hypothesis.

2. There should be a control. If it is an observational study over space and time, try to have both a spatial and temporal control.

3. Have replicate samples within treatments, areas, etc.

4. There should be a balanced (equal) and random (or at least unbiased) allocation of samples with respect to the variables of interest (but see Principle 8 below).

5. Do some preliminary sampling (a pilot study) so that 6-9 can be done.

6. Evaluate the sampling method for consistency (lack of bias) over the entire universe that will be sampled.

7. Estimate necessary sample number (or adequacy of feasible sample number), and optimum sample unit size.

8. If there is a large scale spatial pattern, consider a stratified sampling design. To estimate spatial distribution allocate samples evenly over the area; to estimate abundance allocate samples proportional to estimated abundance.

9. Decide how to handle problems in data: transform it? use nonparametric statistics? use simulation, randomization or jackknife? use sequential sampling? apply corrections for bias?

10. Stick with the results (i.e. let the hypotheses be falsifiable).

Al.6 References

Dome Petroleum Limited, Esso Resources Canada Limited, and Gulf Canada Resources Inc. 1982. Environmental Impact Statement for hydrocarbon development in the Beaufort Sea - Mackenzie Delta region. Vol. 1. Summary. Calgary, Alberta.

Everitt, R.R., D.A. Birdsall, and D. Stone. 1986. The Beaufort Environmental Monitoring Program. In: R. Lang (ed.). Integrated Approaches to Resource Planning and Management. University of Calgary Press, Calgary Alberta.

Green, R. 1987. The Fundamental Principals of Research and Monitoring Program Design in Relation to the BEMP Process and the Design of Systematic Aerial Surveys for Whales. Appendix B. In: Beaufort Environmental Monitoring Project 1986-87 Final Report. Northern Affairs Program Environmental Studies Report No. 52. Indian and Northern Affairs Canada, Ottawa Ontario.

A2 Pulp Mill Environmental Effects Monitoring

A2.1 Background

Over the past few years Environmental Protection of Environment Canada has sought to develop a generic program that could be applied consistently and systematically for environmental effects monitoring associated with new mills and for existing mills undergoing modemization **or** expansion (Environment Canada 1989). The recently released "Guidelines for Environmental Effects Monitoring at Pulp and Paper Mills" in October 1990 outline a program that has three interrelated activities: 1) design features which include an assessment of the mill's potential to impact on the receiving environment; 2) the EEM monitoring program which consists of a set of Core components which will be collected by all mills; and **3)** a list of mill specific components that may be collected depending on the mill processes, treatment, and features of the receiving environment (Environment Canada 1990).

These guidelines grew out of a review of West Coast pulp and paper mill monitoring programs (Bernard et al. 1987) which identified lack of consistency amongst programs. A subsequent national federal- provincial workshop (Bernard and Everitt 1987) developed a more consistent approach to EEM which was evaluated in two pilot studies at mills discharging into the marine environment. One in Newfoundland (LeDrew, Fudge and Associates Ltd. 1989) and one in British Columbia (Colodey in prep.). Results of these two pilot studies were discussed at a national workshop (Environment Canada 1989) and later evaluated for two freshwater systems - Fraser River in British Columbia and the Saint Maurice River in Quebec. The pilot freshwater studies were reviewed at a workshop in March 1990 and their results along with those of the marine studies, led to the development of the guidelines.

A2.2 Rationale for Environmental Effects Monitoring

Effects monitoring is defined (Bernard and Everitt 1987, Environment Canada 1989) as

"routine measurements undertaken to:

determine changes in environmental conditions at a site;

2. test environmental assessment predictions; or

3. evaluate the effectiveness of mitigation measures."

A2.3 0 bjectives

The objectives of the environmental effects monitoring are to determine the:

1. effects of effluent on fish and fish habitat;
2. extent that deleterious substances have damaged or are likely to damage fish and fish habitat;

3. adequacy of any remedial action taken after any unauthorized deposit of a deleterious substance; and

4. adequacy of existing control requirements and the need for more stringent or site-specific measures.

It is significant to note that these objectives do not make any direct reference to water quality.

A2.4 Operational Considerations

A2.4.1 Identification of Effects

The generic guidelines recommend that the details of all mill activities that have potential to effect the environment need to be documented for both the design of the monitoring program and interpretation of results. Information required includes: 1) process and treatment systems; 2) production and flow rates; 3) chemical used; 4) existing environmental information; 5) habitat inventory; 6) effluent plume delineation; and 7) sediment transport and deposition.

In the development of the generic guidelines there was consideration of the effects of the various mill activities on the receiving environment. The concerns at pulp mills include:

1. reduction in dissolved oxygen concentrations due to increased BOD;

2. contamination from chlorinated organics (including dioxins and furans); and

3. contamination from metals.

Monitoring with respect to pulp mills include monitoring in each of four components: 1) effluent; 2) water; 3) sediment; and 4) biota. The pilot study at Humber Arm (Environment Canada 1989) provided objectives for the parameters monitored (Table A2.1).

A2.4.2 Spatial and Temporal Considerations

The guidelines make provisions for specific protocols. Presumably these protocols will provide guidance on how to handle the spatial and temporal aspects of the monitoring programs.

A2.4.3 Variables to Be Sampled

The guidelines provide for a core set of variables and for mill specific parameters to be sampled.

Table A2.1: Core and site specific components of pulp mill monitoring programs used in the Humber Arm case study. (Source: Environment Canada 1989)

Core Components

Component	Parameter	Objective
Effluent	TSS BOD	Estimate loading Required to develop dissolved oxygen (DO) budget
	Resin Acids pH Colour	Define toxic nature of effluent function as effluent tag
Water	DO concentration and saturation	Establish suitability for aquatic life, develop DO budget
	Temperature Salinity	Required to calculate DO saturation and develop DO budget
	Colour	Function as effluent tag
Sediments	Particle size	Required to interpret benthic invertebrate and contaminant data
	SVR	Effluent solids dispersion/settlement tracer, evaluate contaminant data, benthic infauna data and habitat suitability
	Resin Acids	Effluent dispersion/settlement tracer, evaluate sediment toxicity tests.
Biota	Benthic infauna/macro fauna • species presence/absence	Evaluate effluent impact on benthic habitat
	Intertidal photographic survey, shoreline community structure	Evaluation of general mill impact on shoreline habitat
	Sediment bioassay • acute tests using clams, and/or amphipods	Evaluate sediment toxicity

Table **A2.1:(continued)**

Site Specific Modules

Component	Parameter	Objective
Effluent	Chlorophenols Chloroguaiacols Chlorocatechols TOC AOX Chloroform Fish bioassay-acute	Establish organochlorine constituents to use as effluent tag
Water	Chlorophenols Chloroguaiacols Chlorocatechols TOC AOX Chloroform	Determine concentrations in the water column for tracing effluent
	NFR/FR Turbidity Fish bioassay-acute and chronic	Evaluate effect of TSS loading Determine toxicity
Sediments	Chloroguaiacols Chlorocatechols Metals	Determine concentrations' and compare to known effects levels
	Redox potential H_2S	Determine effect of settlement of effluent solids
	Bioassay-acute, chronic using clams, amphipods	Determine toxicity
Biota	Tissue analyses (bile, liver, muscle) • resin acids • chlorophenols • chloroguaiacols • chlorocatechols • metals	Determine exposure to effluent and evaluate level of effect
	Histopathology • gill, liver, external	Determine long term sublethal exposure effects
	Behavioral tests • preference/avoidance	Effluent tracer

A2.4.4 Sampling Frequency and Size

Protocols again.

A2.5 Program Management

Program design, data collection, data analysis, and data management protocols are provided by Environment Canada Environmental Protection Regional Offices. All monitoring data will be stored in regional and centralized database established by Environment Canada.

The actual management of individual monitoring programs will be done by the environmental managers at the mills or in the provincial or federal governments.

A2.6 Effects Monitoring at Pulp Mills: Athabasca River Experience

A2.6.1 Background

This case study is based on the results of: 1) two survey programs carried out between 1984 and 1986 on the upper Athabasca River (Anderson 1989); 2) winter water quality monitoring (Norton and Shaw 1989); and 3) a report on dissolved oxygen modelling (HydroQual 1989).

Licenses for mills are normally conditional on flow and oxygen criteria.

A2.6.2 Rationale for Monitoring

The 1984 and 1986 monitoring had two objectives:

1. determine the effect of the combined effluent on water quality of the Athabasca River, and

2. evaluate the effect of combined effluent on the zoobenthos in the Athabasca River.

The objectives of the 1988 and 1989 winter water quality monitoring had three objectives:

1. obtain additional data for water quality protection planning;

2. define a baseline for present winter water quality conditions; and

3. better assess the impacts of existing effluents on river water quality.

The 1988 and 1989 monitoring data was also used to calibrate and validate the dissolved oxygen model. It also appears the monitoring was undertaken:

1. in support of permit drafting;
2. to assess the assimilative capacity (BOD capacity) of the river in anticipation of more mills; and
3. to gain an understanding of river processes and ecosystem processes.

A2.6.3 **Operational and Environmental Considerations of Program Design**

Identification of Effects

The 1985 - 86 water quality surveys seemed to be based on concerns that had arisen during the lifetime of the mill. There is no specific mention of the effects assessed.

The 1984 - 85 zoobenthic surveys seemed to be concerned with determining significant differences in zoobenthic community composition between sample sites at various distances from the effluent discharge point to determine whether the combined effluent from Hinton induced changes in the Athabasca River. It is assumed that these surveys are looking for long term changes and not the short term response to existing water quality conditions.

The 1988 and 1989 winter water quality surveys were directed primarily at providing a baseline for assessment of future pulp mill developments on the Athabasca River. Based on previous monitoring (Andersen 1989), the surveys were concerned with effluent effects on dissolved oxygen, phenolic compounds, trace organic compounds, colour, odour, phosphorus, and manganese. The surveys were also concerned with the effects associated with sewage treatment plants along the river and, in particular, changes in nitrogen, phosphorus, and bacteria.

Spatial and Temporal Considerations

The zoobenthic surveys were under taken in the spring of 1984 and the fall of 1985. One site upstream and five sites downstream at different distances (5, 10, 20, 30, 50 km) were sampled. Samples were taken at the left and right banks at all sites except for the 30km site.

The water quality surveys were undertaken during periods of low flow in October of 1985 and February of 1986. One site upstream and eight sites downstream at different distances (1, 6, 12, 20, 30, 40, 50, 60 km) were sampled. Samples were taken at the right bank at the upstream site. Samples were taken at the left bank, centre channel, and right bank at the 1, 6, and 12 km sites. Composite samples (equal parts from left, right, and centre) were taken at all other sites.

The five winter water quality surveys were undertaken on the Athabasca River system during 1988 and 1989:

Survey 88-l: 1 - 11 February 1988; Hinton to Town of Athabasca

Survey 88-2: 4 - 9 March 1998; Hinton to Town of Athabasca

Survey 89-l: 9 January - 15 February, 1989; Hinton to Lake Athabasca

Survey 89-2: 26 January - 6 February, 1998; Hinton to Town of Athabasca

Survey 89-l: 13 February - 16 March, 1989; Hinton to Lake Athabasca.

In all there were over seventy possible stations spread over approximately 1240 km of river from near Hinton to the Lake Athabasca.

Sampling was designed to follow a parcel " a volume" of water downstream. Sampling tended to be during a period of low flow (i.e. minimum dilution).

Variables Sampled

There is no clear explanation of how the water quality parameters were chosen in either of the 1985-85 studies or the 1988 and 1989 studies. The analysis tended to focus on water quality variables that are indicative of pulp mill effluent. A number of routine water quality parameters were included.

Sampling Frequency and Size

The water quality monitoring was done during periods of historically low flows and hence low dilution.

Program Management

The current monitoring program on the Athabasca is composed of four elements:

1. a long term network of sites that are monitored monthly;
2. winter low flow synoptic surveys on the Athabasca and Wapiti-Smoky;
3. continuous oxygen recorders; and
4. near field assessments associated with new mills done preoperation and post operation.

Quality Control

In 1988 and 1989 winter water quality surveys specific field and laboratory quality control procedures were used including the use of field blanks and blind replicate samples.

Data Management

All data were inspected by the person undertaking the sampling and project manager. Questionable values were checked with lab and/or field personnel. Values were only discarded if a reason for the aberration could be identified. After inspection and verification, lab data were transferred electronically to the NAQUADAT computer data base of EQMB. To avoid re-entry errors, the data were downloaded electronically from NAQUADAT to an IBM-AT personal computer for manipulation.

A2.7 References

Anderson, A.M. 1989. An assessment of the effects of combined pulp mill and municipal effluents at Hinton on the water quality and zoobenthos of the Athabasca River. Report. Environmental Quality Monitoring Branch, Environmental Assessment Division, Alberta Environment. Edmonton, Alberta.

Bernard, D.P. and R.R. Everitt. 1987. Pulpmill Environmental Effects Monitoring: Towards a More Consistent Approach. Proceedings of a Workshop, Kamloops, Oct. 1987. Environment Canada, Environmental Protection, Environmental Impact Systems Division. Ottawa

Bernard, D.P. Marmorek, D.R., Sutherland, G.D., and S. Groves. 1987. Marine Environmental Effects Monitoring Program: Design and Evaluation for Pacific Coastal Pulp Mills, Environment Canada, Environmental Protection, Vancouver, B.C.

Colodey, A. (in prep). Environmental Monitoring of Pulpmill Discharges into Alberni Inlet 1984, 1986, and 1988. Environment Canada, Environmental Protection Regional Report, Vancouver, B.C.

Environment Canada. 1989. Proceeding of the Second Workshop on Pulp Mill Environmental Effects Monitoring: Towards a consistent approach. Report. Environmental Protection, Environment Canada. Ottawa Ontario.

Environment Canada 1990. Guidelines for Environmental Effects Monitoring and Pulp and Paper Mills. Pamphlet. Environmental Protection, Environment Canada: Ottawa Ontario.

HydroQual Consultants Inc. 1989. Model Calibration and Receiving Water Evaluation for Pulp Mill Development on the Athabasca River: I. Dissolved Oxygen. Report for Alberta Environment Standards and Approvals Division. Edmonton, Alberta

LeDrew, Fudge and Associates Ltd. 1989. Humber Arm Monitoring Program 1988 Sampling. Report prepared for Comerbrook Pulp and Paper Ltd. Comerbrook, Newfoundland.

Norton, L.R. and R.D. **Shaw.** 1989. Winter water quality in the Athabasca River System, 1988 and 1989. Report. Environmental Quality Monitoring Branch, Environmental Assessment Division, Alberta Environment. Edmonton, Alberta.

A3 Norman Wells Pipeline Monitoring Program

A3.1 Background

In the early 1980s, the proposal to expand the Norman Wells oilfield and build an associated petroleum pipeline down to Alberta was scrutinized by a federal Environmental Review Panel. The Norman Wells Research and Monitoring Program was initiated to follow up on the many recommendations by the Panel for research and monitoring relating to potential effects of oilfield and pipeline construction and operation. In August of 1981, the projects were approved contingent on the submission of further information by the proponents. In August of 1982, the Deputy Minister of the Government of the Northwest Territories Department of Renewable Resources, Mr. James Bourque, proposed the development and implementation of an intergovernmental research and monitoring program. A Working Group was formed to design and direct the program.

A3.2 Rationale for Environmental Effects Monitoring

The purpose of the program was to test the validity of impact predictions identified during the environmental assessment and review process and to test the effectiveness of mitigative measures identified during the regulatory process (Environment Canada 1988 a,b).

A3.3 Program Objectives

The program had four specific objectives:

1. determine and quantify environmental impacts and to examine the recovery process;
2. compare actual and predicted impacts;
3. evaluate long-term effectiveness of mitigative measures; and
4. prepare environmental recommendations applicable to future northern pipeline and oilfield developments.

A3.4 Operational Considerations

A3.4.1 Identification of Effects

The initial task of the Working Group was to identify all environmental issues and concerns related to northern pipeline and oilfield developments. The working group began with a review of:

1. reports of the Berger Commission;

2. report of Norman Wells EARP Panel;

3. report of Alaska Highway Gas Pipeline EARP Panel;

4. transcripts of NWT Water Board hearings;

5. reports of NEB Hearings on Norman Wells Oilfield Expansion and Pipeline; and

6. consultation with U.S. Federal and State of Alaska officials experienced in the construction of the Trans-Alaska Pipeline System.

Out of this review the Working Group established a set of priority environmental issues (Table A3.1) which was latter added to and refined.

Table A3.1: Priority environmental issues that guided the Norman Wells Environmental Monitoring Program.

1.	revegetation of and restoration;
2.	artificial island integrity during Mackenzie River break-up;
3.	oilfield emissions and air quality;
4.	terrain performance along pipelines;
5.	effects and effectiveness of wood chip insulation;
6.	thermal regime and ground stability along the pipeline;
7.	soil temperatures;
a.	forest ecosystem disturbances;
9.	contaminant pathways in the Mackenzie River;
10.	fish quality and physiological condition downstream of the Norman Wells Refinery;
11.	aquatic impacts from the construction of pipeline stream crossings;
12.	snow geese and their habitat use;
13.	disturbance to raptors;
14.	disturbances to terrestrial wildlife; and
15.	renewable resource harvesting.

A3.5 Program Management

The Working Group of the Norman Wells Research and Monitoring Program met formally at a northern location in the Fall of each year. At these meetings, members of the Working Group discussed the results of individual projects, coordination between studies, requirements for further research and monitoring, and the preparation of environmental recommendations for future northern pipelines and oilfield developments. The working group was committed to the concept of community based environmental effects monitoring and welcomed the participation of public, both at its regular meetings and in its field projects.

In November of 1987, a workshop was held to prepare environmental recommendations applicable to future northern pipeline and oilfield development. The workshop used the impact hypothesis approach used in BEMP (Everitt et al. 1986) and proceeded in three sequential steps:

1. statement of hypothesis addressed by the monitoring;
2. testing through evaluation of research results; and
3. proposing defendable environmental recommendations supported by studies.

Because the hypotheses were formed at the end of the program (i.e. identifying the questions that should have been addressed; instead of the questions that were addressed), this process is somewhat flawed. However, as a result of this workshop a number of specific recommendations regarding new mitigation measures and needed research in support of environmental assessment were made.

A3.6 References

Environment Canada, Conservation and Protection. 1988a. Norman Wells Research and Monitoring Program Fifth Annual Summary Report. Report CP(EP) WNR88/89-2C prepared by Boreal Ecology Services. Environment Canada, Conservation and Protection, Yellowknife, NWT.

Environment Canada, Conservation and Protection. 1988b. Proceedings 1987 Norman Wells Research and Monitoring Workshop 18-20 November 1987. Report CP (EP) WNR88/89-1C prepared by Boreal Ecology Services. Environment Canada, Conservation and Protection, Yellowknife, NWT.

Everitt, R.R., D.A. Birdsall, and D. Stone. 1986. The Beaufort Environmental Monitoring Program. In: R. Lang (ed.). Integrated Approaches to Resource Planning and Management. University of Calgary Press, Calgary Alberta.

A4 Columbia Integrated Environmental Monitoring Program

A4.1 Background

The Lower Columbia is one of the most intensely developed and carefully monitored river reaches in British Columbia. It is an international river with a number of major developments in progress or proposed. Environmental data on the Lower Columbia River have been collected over the years by several groups, including large industrial water users such as Celgar (pulp mill), Cominico (smelter), and B.C. Hydro as well as B.C. provincial government agencies. To address growing concerns over the environmental quality in the Lower Columbia, a committee of agency and industrial users was formed in 1989 to discuss common monitoring requirements. This committee was responsible for the design of an integrated monitoring program (Sigma 1990).

The Lower Columbia has a pulp mill, a smelter and mill complex, hydroelectric dams and generating facilities, and municipal sewage outfalls. Most of the environmental issues associated with the pulp mills and metal mines discussed in other cases studies apply, as well issues specifically related to hydroelectric dams. Specific issues related to the proposed hydroelectric development are: total gas pressure and dissolved oxygen in the Columbia River as well as fish movements in the Lower Columbia.

A4.2 Monitoring Program 0 bjectives

The objectives of the long term monitoring program are to:

1. assess the present state of Lower Columbia River from an environmental point of view;

2. provide baseline information that could be used to predict the impacts of industrial and hydroelectric projects;

3. assess the degree to which ambient environmental quality meets general and site specific criteria and objectives set for the river by regulatory agencies;

4. provide information that could be used for developing agency site specific water quality objectives; and

5. provide information that could be used for assessing needs for future environmental monitoring..

A4.3 Components of the Integrated Program

The program is integrated in two senses:

1. sampling of different media to assess trends in environmental quality and to determine the overall health of the ecosystem; and

2. integration of study requirements of a large number of participants with an interest in water quality of the lower Columbia.

The program consists of three major components:

1. Water;
2. Sediment and Biota; and
3. Fish.

A4.3.1 Program Hypotheses

The program is designed to detect changes in aquatic environmental quality and to determine the significance of these changes with respect to sustainable uses of the river. The program developed four clearly stated falsifiable hypotheses:

1. the ambient water quality in each reach is identical;
2. the quality of the sediment bed in each reach is identical;
3. the body burden of contaminants in the aquatic biota in each reach is identical; and
4. the annual mean concentration of a substance in sediment is identical in each reach.

Similar hypotheses were suggested to test variability in water, sediment, and biota quality among stations within each reach, among sites within each sampling station, and temporal variability at sites.

A4.3.2 Spatial and Temporal Variability

The Lower Columbia was divided was divided into four stream reaches with three potential sampling stations in each reach. Reach 1, Lower Arrow Lake, upstream of the Hugh Keenlyside Dam, was chosen as a control as this part of the river is above the major sources of contamination. The reaches were chosen based on the sources of contaminants and the location of major tributary flows into the Columbia.

The sampling frequency varies from station to station (from weekly to monthly). The overall design is directed towards fixed interval sampling.

A4.3.3 Water Quality Variables

In addition to the water quality concerns addressed by the existing monitoring network, the program is designed to address concerns related to: 1) the Ministry of Environment objectives for development monitoring; 2) the Dioxin/Furan Baseline Sampling Program for the Columbia River; 3) Environment Canada's data needs to review the Celgar Expansion project; 4) B.C. Hydro's interest in monitoring total gas pressure; and 5) the toxic organic and heavy metal survey of the sewage treatment plants.

A4.3.4 Sediment and Biota

Because insufficient information currently exists to define the essential components of a long term biomonitoring program the Lower Columbia River, a comprehensive biomonitoring reconnaissance study has been recommended for the first year. This program will provide information required to develop the trend assessment component of the overall monitoring program. The bed sediment and biota monitoring should be designed to detect shifts in environmental quality that may result from contaminants due to changes in waste loadings to the system.

The results of the reconnaissance study will be used to select future sampling stations and biological organisms for sampling.

A4.3.5 Fish

The fish component of the integrated program is focused on the assessment of the distribution and abundance of fish, of fish migration and movement patterns, of habitat utilization by sportfish species, and of contaminant burdens in fish tissues.

An assessment of the suitability of various fish species for inclusion in the biomonitoring program was made based on the following combination of ecological, economic and social criteria: 1) use; 2) residency time; 3) spawning time; 4) food source; 5) sediment exposure; 6) abundance; and 7) fecundity.

A4.4 Program Management

The overall design of the program was undertaken under the auspices of a committee. It is assumed that the same committee is responsible for coordination of the study.

A4.4.1 Quality Assurance and Quality Control

The accuracy and precision of data generated by a monitoring program can only be assessed if a good quality assurance and control program is in place. The objectives of the program's intensive quality assurance program are to:

1. generate quality analytical data;

2. ensure complete documentation and defensibility of all data; and
3. expedite data evaluation and acceptance.

Several factors affect the results of any given sampling program. Some of these factors are:

1. high level of temporal and spatial variability;
2. analytical and sampling error;
3. sample contamination; and
4. high concentration values due to natural or special source conditions.

Recognizing that the successful undertaking of a monitoring program requires field and laboratory staff trained in sample collection and handling procedures, specific protocols for: 1) sample collection and storage; 2) sample shipments; and 3) laboratory testing are provided in the overall program design.

A4.4.2 **Program Costs**

The monitoring program design has a complete cost estimate provided including data collection and analytical costs.

A4.5 References

Sigma Engineering Ltd. 1990. Columbia River Integrated Environmental Monitoring Program. Report to B.C. Ministry of Environment, Cominco Metals, Celgar Pulp, and B.C. Hydro.

A5 Metal Mining - Proposed Guidelines for Effects Monitoring for Metal Mines Discharging to the Aquatic Environment

A5.1 Background

Recently Environmental Protection, Environment Canada has sought to develop a generic program that could be applied consistently and systematically for environmental effects monitoring associated with metals discharging to the aquatic environment. Metal mines pose a number of challenges for EEM, primarily because of the site specificity of each mine. Potentially deleterious substances can move to water bodies not only from point sources (i.e. mill effluent outfalls) but also from a number of nonpoint sources, including surface runoff, leachate, shallow groundwater flow and atmospheric deposition. Environment effects monitoring needs to acknowledge these sources. Also, since temporal variation in natural factors (e.g. climate) and in methods of mining and milling occur, the amount and type of materials form a mine can vary significantly throughout the year (EVS Consultants 1990).

The concerns associated with metals mines are:

1. acid mine drainage and its effects on fish and other aquatic biota; and

2. mill effluent outfalls and potential for metal contamination.

The metal mine generic guidelines recommend a specific core set of variables to be monitored at every site and a suggested set to be monitored from which variables would be chosen based on type of operation and receiving environment. The guidelines for metal mines discharging to the aquatic environment provide a rationale for each of the parameters suggested for monitoring (Table A5.1).

A5.2 Objectives for Environmental Effects Monitoring

The objectives for environmental effects monitoring are:

1. effects of mine effluent on fish and other aquatic organisms and their habitat;

2. extent that deleterious substances have been damaged or are likely to damage fish and other aquatic organisms and their habitat;

3. adequacy of any remedial action taken after any unauthorized deposit of a deleterious substance; and

4. adequacy of existing control requirements and the need for more stringent or mine specific measures.

Table A5.1: **Core** and mine specific monitoring components for metal mines discharging to aquatic environment. (Source: EVS 1990)

a. Core monitoring **components.**

	Parameter	**Rationale**
Background Information	• Type of operation (open pit, underground, placer, etc.	Establish background conditions and guidance for sampling locations and site-specific parameters for monitoring
	• Mine activities potentially impacting on the environment	
	• Mill activities potentially impacting on the environment	"
	• Smelter activities potentially impacting on the environment	
	• Any other activities potentially impacting on the environment	"
	• Reclamation plan for mine decommissioning	"
	• Existing biological, chemical and physical data for the receiving environment	
	• Habitat inventory - aquatic and riparian	
	• Hydrology	
	• Mine an regional geology	
	• Sediment transport and deposition	Guidance for selecting contaminants for monitoring
	• Chemical operations used in mine/mill operations and processing	
Effluent (final and bypasses*)	• Residues (total and non-filterable)	Estimates for solids loadings/bioavailability
	• PH	Basic water quality measurement
	• Colour	"
	• Temperature	"
	• Flow rate	Effluent dispersion patterns
	• Sublethal/lethal toxicity tests (fish, invertebrate, algae)	Evaluates toxicitv of whole effluent
Receiving Environment Water (effluent, leachate related, and ambient)	• Total organic carbon (TOC)	Related to bioavailability
	• Alkalinity	"
	• Acidity	
	• Hardness	
	• Sulphate	
	• Dissolved oxygen concentration and saturation	Establish suitability for aquatic life, dissolved 0, budgets
	• PH	Basic water quality measurement
	• Temperature	"
	• Colour	"
	• Total suspended solids	Estimates for solids loadings
	• Total dissolved solids	"
	• Flow rate (rivers)	Site characteristics
	• Secchi depth (lake)	
Sediment	• Particle size	Basic sediment quality characteristic
	• Sediment volatile residue	
Indigenous Biota	• Quantitative benthic invertebrate survey	Characterization of community
	• Fish population survey (growth, recruitment)	
	. Algae - quantitative survey: periphyton (river), phytoplankton (lake)	

*Bypasses - i.e. any mine or mill discharge not originating from an outfall

Table A5.1: (continued)

b. Mine-specific monitoring components.

	Parameter	Rationale
Effluent (final and bypasses*)	• Sulphate (SO,	Related to bioavailability
	• Alkalinity	Effluent quality measurement
	• Acidity	
	• Chlorine	Potentially toxic
	• Electrical conductance	Basic water quality measurement
	• Total organic carbon (TOC)	Provides a measure of bioavailability
	• Nutrients (total N, NO,, NO_2-N, PO_4-P)	Effluent quality measurement
	• Major cations (Ca, Mg, Na, Al)	"
	• Major anions (Cl, F)	
	• Other metals (As, Cu, Pb, Ni, Rn-226, Cd, Cr, Co, F, Fe, Mn, Hg, MO, Se, Ag)	Potentially toxic
	• Cyanide (total, weak acid dissociable, thiocyanate, cyanate)	
	• Chronic toxicity assessment (bacteria, invertebrates, fish, aquatic plants)	Evaluates toxicity of effluent
	• Genotoxicity testing	Evaluates genotoxicity
	• Process-specific bacteria	Indication of bacteria associated with deleterious effects
Receiving Environment Water (effluent, leachate related, and ambient)	• Nutrients	Basic water quality measurement
	• Process-specific bacteria	Indication of bacteria associated with deleterious effects
	• Velocity (rivers)	Effluent dispersion patterns
	• Turbidity	Basic water quality measure
	• Other metals (as above)	Potentially toxic
	• Cyanide (total, weak acid dissociable, thiocyanate, cyanate)	
	• Wet and dry atmospheric deposition	
	• Bioaccumulation	Provides a measure of bioavailability
	• Sublethal/lethal toxicity assessment	Evaluates toxicity of ambient environment
	• Chronic toxicity assessment	Evaluates toxicity of ambient waters
Sediment	• Other metals (as above)	Potentially toxic
	• Sulphate	Related to bioavailability
	• Sedimentation rate	Basic sediment characteristic
	• Bioaccumulation	Provides a measure of bioavailability
	• Sublethal/lethal toxicity assessment	Evaluates toxicity of sediment
	• Chronic toxicity assessment	
Indigenous Biota (fish and invertebrates)	Physical	
	• age, weight, length	Determine effect of contaminants and provide a measure of population level effects
	• morphological anomalies	
	• somatic index (fish)	
	• reproductive state	
	Tissue analyses (muscle, liver, bone, gill, kidney)	Measure of bioaccumulation in field populations
	• metals	

*Bypasses - i.e. any mine or mill discharge not originating from an outfall

A5.3 Program Elements

The EEM program for metal mines has four interrelated activities:

1. identification of goals and intent of each mine's monitoring program;
2. background information associated with the design of the monitoring program;
3. the monitoring program itself; and
4. data management and reporting.

A5.4 Operational Considerations

A5.4.1 Identification of Effects

The generic guidelines recommend that the details of all mine activities that have potential to affect the environment need to be documented for both the design of the monitoring program and interpretation of results. Information required includes: 1) mine geology; 2) local climatology and hydrology; 3) mining methods, milling and smelting systems; 4) chemicals used; 5) existing environmental information; 6) habitat inventory; and in certain instances, 7) sediment transport and deposition (EVS Consultants 1990).

In the development of the generic guidelines there was consideration of the effects of the various mine activities on the receiving environment. The actual effects of concern are explicitly stated. While a short rationale is given, it seems desirable the basic questions that each specific monitoring program is trying to address should be clearly stated and that these questions be translated into testable hypotheses.

A5.4.2 Spatial and Temporal Considerations

The guidelines make provisions for specific protocols. Presumably these protocols provide guidance on how to handle the spatial and temporal aspects of the monitoring programs.

A5.4.3 Variables to be Sampled

The guidelines provide for a core set of variables and for mine specific parameters to be sampled.

A5.4.4 Sampling Frequency and Size

Protocols again.

A5.5 Program Management

Program design, data collection, data analysis, and data management protocols are provided by Environment Canada Environmental Protection Regional Offices. All monitoring data will be stored in regional and centralized database established by Environment Canada.

Data generated by the EEM program will be used for several purposes, including:

1. characterization of environments under the potential influence of metal mining activities (e.g. parameter mean, maximum, minimum, standard deviation and variation under the influence of seasons);

2. time series analysis to examine variation in conditions over time;

3. comparison of differences in environmental quality in areas exposed to metal mining discharges (e.g. downstream of mine) vs. areas outside to the area of possible influence (e.g. upstream of mine);

4. verify the success of best management practices being utilized by the metal mining industry during exploration, mining, processing and decommissioning; and

5. document environmental conditions and their inherent variability so that sound management decisions can be made.

The actual management of individual monitoring programs will be done by the environmental managers at the mines or in the provincial or federal governments.

A5.6 Equity Silver Mines Case Study

The report on the monitoring associated with the Equity Silver mine was prepared in support of B.C. provincial government permit requirements (Equity Silver Mines 1986) in direct response to a letter from the B.C. Ministry of Environment Waste Management Branch. The major environmental issues associated with the mine is acid mine drainage which is the focus of environmental control measures. In July of 1982, Equity prepared a report directed towards solution of water quality problems over short, medium, and long term. A Technical Review Committee consisting of Equity Silver, Waste Management Branch, Ministry of Energy, Mines and Petroleum Resources, and the Environmental Protection Service personnel was formed to periodically review Equity's compliance status. A second committee, Equity Silver Public Surveillance Committee, was formed in July 1982 to serve as a communication forum for parties interested in acid mine drainage issues associate with Equity's operations (Equity Silver Mines 1986). This committee consists of representatives from Equity, Waste Management Branch, Buckflats Residents, Environmental Protection Service, Ministry of Energy, Mines & Petroleum Resources, Department of Federal Fisheries and Houston Municipality (Equity Silver Mines 1986). From various pieces of correspondence, the representative(s) from the Buckflats Resident Association appears very knowledgable and informed on the environmental issues associated with the mine. The representative was highly critical of some of the monitoring work completed and pointed out a number of inaccuracies and unsupportable conclusions in the report.

The objectives of report (Equity Silver Mines 1986) on 1980-85 monitoring studies appear to be to:

1. provide annual summaries of monthly data collections;

2. provide a database for assessment of environmental trends with respect to biological and water quality; and

3. recommend modifications to existing monitoring programs.

Specific objectives associated with the component of the study directed towards fisheries and benthic invertebrate concerns (Norecol 1986) were:

1. summarize existing fisheries information for potentially affected streams to identify the fish resources in mine area drainage and evaluate their significance;

2. compare fish densities to other streams in the upper Bulkley River system;

3. tabulate and evaluate all existing fish tissue metal data related to mine development;

4. assess the fish tissue data with respect to water quality data;

5. recommend future fisheries monitoring programs;

6. summarize the various benthic invertebrate collection and analysis programs;

7. assess the results of invertebrate studies and relate these the water quality; and

8. evaluate this monitoring technique and its use as a tool for future monitoring.

A5.6.1 Fish Tissue Analysis Studies

The metals of concern were: copper, lead, zinc, cadmium, arsenic, and antimony. It appears there were at least three questions being addressed:

1. were metal concentrations within acceptable limits?;

2. were concentrations at downstream sites different than those at upstream sites?; and

3. was there a trend through time?.

AS.7 References

EVS **Consultants.** 1990. Proposed Guidelines for Effects Monitoring At Metal Mines Discharging to the Aquatic Environment. Draft Report prepared for Environment Canada, Environment Assessment Division, Inland Waters Directorate. Ottawa.

Equity Silver Mines Limited. 1986. Assessment of Acid Mine Drainage Control Measures and Resultant Impacts on Streams Draining the Equity Silver Minesite. Report Period 1980 - 1985. Equity Silver Mines Limited. Houston, B.C.

Norecol Environmental Consultants. 1986. Assessment of Fish and Benthic Invertebrate Populations in Streams Draining the Equity Silver Mine near Houston, B.C. prepared for Equity Silver Mines. Houston, B.C.