Ecosystem Health and Integrated Monitoring in the Northern River Basins

10

Synthesis Report

Canada Alberta Northwest Territories

Northern River Basins Study

NORTHERN RIVER BASINS STUDY
SYNTHESIS REPORT NO. 10

ECOSYSTEM HEALTH AND INTEGRATED MONITORING IN THE NORTHERN RIVER BASINS

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Executive Summary

As one of the eight study components under the Northern River Basins Study (NRBS), the Synthesis and Modelling Component was established to address two primary objectives:

1) to integrate the scientific planning and findings of all the components; and
2) to provide answers to the Study Board Question 13:
    a) *What predictive tools are required to determine the cumulative effects of man made discharges on the water and aquatic environment?*
    b) *What are the cumulative effects of man made discharges on the water and aquatic environment?*

    and to the Board's guiding question No. 14:

    What long term monitoring programs and predictive models are required to provide an ongoing assessment of the state of the aquatic ecosystems?

The general purpose of this report was thus to take an integrated approach to the challenges described above in order to provide an answer to Study Board Questions 13a and 14 (Question 13b is addressed in Wrona *et al.* (1996)). More specifically, the report had three primary objectives:

1) To provide an overview and critical analysis of concepts such as "ecosystem health", "cumulative effects assessment" and "ecological risk assessment" and to define the "ecosystem approach" used by the NRBS science program. In other words, to provide a conceptual approach for monitoring and assessment within these basins
2) To provide a pragmatic approach to the choice of ecological indicators that are ecologically and socially relevant and which can be used effectively in basin management decision-making.
3) To provide a northern basins framework approach that could be used to develop an integrated monitoring and assessment program that is ecosystem-based.

The authors recommend that the NRBS take an "ecosystem approach" to environmental management in these basins. This approach represents a major shift away from the abiotic-based approach toward one that recognizes: 1) the complex and dynamic interactions (physical, chemical and biological) that occur at a variety of scales (spatial, temporal, and organizational) within an ecosystem; 2) the fact that human populations (and their activities) constitute an important component of that environment and that they cannot be viewed as being separate and apart from it; and 3) the need for human populations to make use of natural resources in a more sustainable fashion.

While the value of the ecosystem approach to environmental management has now been widely recognized there remain significant challenges in translating the stated objectives of the approach into

practical management tools that can be used to assess and monitor the state of ecosystems. We recommended a practical approach to ecosystem management that combines the best available scientific knowledge with societal expectations of the ecosystem to develop a pragmatic, operational view of the desired structure and function of the ecosystem being managed. The development of an effective monitoring and assessment program is dependent on an explicit statement of management goals and objectives (reflecting stakeholder input) that provide a framework for the establishment of the program and a means by which its success can be measured. Development of specific ecosystem goals and objectives also represents a process by which all stakeholders (informed by the best available scientific knowledge) determine the nature of the world in which they want to live. Clearly, this is a societal decision and not a scientific issue. Science plays a role in refining general goals and in developing specific monitoring objectives that will help satisfy those goals, but the goals themselves must first be determined by society.

In addition to reviewing current monitoring practices and identifying issues and ecological indicators that could be incorporated in future monitoring and assessment programs, we recommend the development of an Integrated Ecosystem Monitoring (IEM) program for these basins. Such a program would serve to identify and prioritize environmental issues, participate in the development of ecosystem goals and the development of ecological indicators, coordinate monitoring activities, and provide a forum for stakeholder input to ecosystem management. Key recommendations include:

A basins' Integrated Ecosystem Monitoring Committee (IEMC) should be established to coordinate all ecosystem monitoring in the northern river basins.

Governments, industries, some municipalities and to a lesser extent other organizations conduct various types of monitoring. This committee should play a key role in overseeing all aspects of monitoring within these basins (e.g., scientific implementation and assessment of societal goals/objectives, evaluate protocols for design, data collection, analyses, quality assurance and data management).

We recommend that the IEMC adopt the ecosystem approach to environmental monitoring and the Integrated Ecosystem Monitoring framework described in this report.

This synthesis report has provided in some detail the basis for the design and implementation of a holistic and integrated ecosystem monitoring program and should be considered at the starting point for future monitoring in the basins.

A panel of scientific experts (including representatives of Traditional Knowledge) should be established to advise the IEMC.

A scientifically rigorous IEM program requires expert advice on its design, implementation, data interpretation, and scientific recommendations. Similar to the Science Advisory Committee of the NRBS, this committee would serve as an independent and objective reviewer of the IEM program.

Current and future monitoring activities within the basins should be integrated following the framework developed in this report. Particular attention must be given to standardization of monitoring activities and the adoption of appropriate quality assurance / quality control protocols.

There is a need to ensure that monitoring within the basins is coordinated and avoids duplication. Appropriate priority needs and scientifically acceptable protocols must be identified and applied across agencies. Quality assurance and quality control practices as well as procedural standardization must incorporated into all aspects of monitoring activities.

An IEM database for the basins should be established and maintained.

A critical component to an effective integration of monitoring data is the existence of a standardized database that will allow for interpretation of monitoring information at a variety of scales (spatial and temporal). A process is required by which this database can monitored, updated and made publicly available.

A process must be established whereby the integration of monitoring data collected in the basins be subject to scientific interpretation by an independent group.

The individual agencies contributing to the IEM database are responsible for the interpretation of their own monitoring data. However, there is also a need for interpretation of the integrated data. Such an interpretation should be scientifically-based and consider a broader range of issues that would any single monitoring agency. It is also necessary that the scientific validity of monitoring activity be assessed by independent experts.

Volunteer organizations and individuals should be incorporated into the IEM implementation strategies.

Community involvement in the implementation of basin-wide monitoring provides a unique opportunity. The involvement of volunteers (including schools) in monitoring results in a more holistic consideration of ecosystem health. A major challenge will be to adapt community-based monitoring to the scale of the northern river basins. Paramount in any decision to introduce community-based participation in monitoring will be the development of appropriate manuals, other educational material and the adoption of an ongoing training plan.

An IEM recognizes that the aquatic ecosystem is directly related to the adjacent terrestrial ecosystem and that evaluation of aquatic ecosystem health must include considerations of land use activities (forestry, agriculture, urban development, mining, etc.).

The Study Board deliberated at length about the inclusion of terrestrial components within the research program of the NRBS. Due to its restricted mandate and limited budget, NRBS was unable to incorporate such issues as forestry management and other land uses, climate change and biodiversity. The science components responsible for the design and implementation of the NRBS science program also recognized the need to focus primarily on the aquatic ecosystem, but expressed concerned over the limited research pertaining to terrestrial issues. Future IEM in these basins should extend beyond the mainstems of the major rivers and tributaries to consider importance of terrestrial activities and processes.

As process of public consultation should be undertaken every 3-5 years to assess and re-evaluate societal priorities and to identify emerging issues.

As essential component of an effective IEM is the requirement to assess periodically and re-evaluate societal priorities, goals, and objectives for these basins and to incorporate this information in the refinement of monitoring activities. As discussed in this synthesis report, the identification of appropriate ecosystem indicators is dependent on the development of precise statements of ecosystem goals and objectives.

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1.0 GENERAL INTRODUCTION

As one of the eight study components under the Northern River Basins Study (NRBS), the Synthesis and Modelling Component was established to address two primary objectives:

1) to integrate the scientific planning and findings of all the components; and
2) to provide answers to the Study Board Question 13:
   a) *What predictive tools are required to determine the cumulative effects of man made discharges on the water and aquatic environment?*
   b) *What are the cumulative effects of man made discharges on the water and aquatic environment?*

   and to the Board's guiding question No. 14:

   What long term monitoring programs and predictive models are required to provide an ongoing assessment of the state of the aquatic ecosystems?

The Study Board has embraced an "ecosystem approach" (see below) to integrated resource planning. This approach depends on the development of an ecosystem management framework within which: (1) sustainable development goals can be developed and pursued; (2) specific problems considered and priorities established; (3) objectives and indicators necessary for focussing monitoring activity and data interpretation developed; (4) monitoring, research and assessment conducted; and from which actions (regulatory and non-regulatory) for ecosystem preservation and remediation would result. Figure 1 illustrates the essential elements of such a framework that has at its heart, the involvement of stakeholders (all levels of government, special interest groups and the general public). This representation of an ecosystem management framework highlights two key components explored in depth within this report: ecosystem indicators and integrated monitoring and assessment.

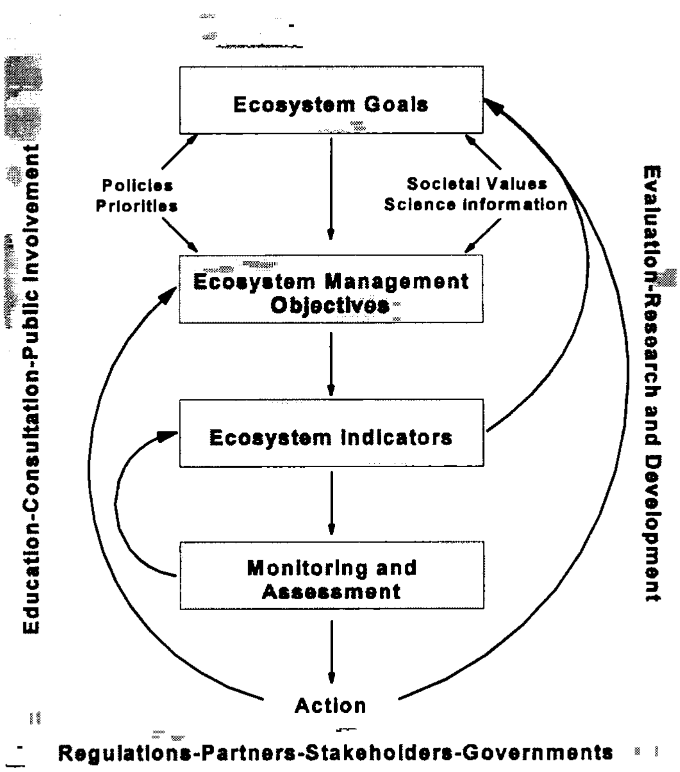

Figure 1. Integrated Monitoring Framework.

While appearing straightforward, the questions set by the Study Board actually raise complex issues and challenges to be addressed by the NRBS science program before recommendations for an integrated ecological monitoring and assessment framework could be set out.

Existing Knowledge

The first of these challenges was posed by the limited understanding of the ways in which specific point- and non-point- source physical, chemical and biological stressors affect the structure and function of these large, cold-regions rivers at various temporal (e.g., immediate, seasonal, inter-annual) and spatial (e.g., local, reach-specific, basin-wide) scales (discussed further in Section 4). While earlier and contemporary monitoring programs and research studies of these rivers (e.g., Alberta Environmental Protection Monitoring Programs, Alberta Oil Sands Environmental Research Program, Prairie & Northern Region (Environment Canada) Monitoring Programs, Arctic Environmental Strategy (Environment Canada), Slave River Monitoring Program (Government of the North West Territories (GNWT), Department of Indian and Northern Affairs (DIAND), Peace-Athabasca-Technical Studies and programs conducted by industry) provided important background and complementary data to the NRBS science program, it became apparent that a better understanding of the complex inter-relationships among key societal values, hydrologic, chemical and ecological processes occurring in these large river systems was required to assess the state of the ecosystem.

Much of our current understanding of the hydrology and ecology of lotic (i.e., flowing water) ecosystems and their response to anthropogenic stressors is based on research and monitoring of smaller watersheds, in which hydrologic, chemical, and biologic parameters have been more thoroughly analyzed (Likens 1992). This observation had two important implications for NRBS in general, and for attempts to develop an effective monitoring and assessment program in particular. First, it was necessary to adapt available information and theory to issues unique to large northern rivers such as these. Secondly, and more importantly, it was necessary to develop a monitoring and management framework for the system while *simultaneously* attempting to gain an understanding of the basic structure and function of the system itself. The need to develop effective monitoring tools in the absence of a complete understanding of the ecosystem is not unique, indeed it is a characteristic of every exercise of this type. However, the constraint acting on the NRBS was particularly extreme given the gaps in knowledge about the system, the tremendous spatial scale involved and the theoretical and logistical difficulties associated with research in large northern rivers.

Societal Concerns and Priorities

A second challenge to ecosystem management was to recognize and incorporate local, regional and basin-wide societal concerns and priorities regarding the: (1) perceived present state of these river systems, (2) historical changes that have taken place and, (3) future desired state of these systems. Appropriate feedback was obtained through an extensive Study Board community consultative process in which local and regional concerns were documented and from a series of questionnaires and surveys conducted by the Other Uses (NRBS Other Uses Synthesis Report No. 7) and Traditional Knowledge (NRBS Traditional Knowledge Synthesis Report No. 12) components of the science program. As will be discussed below, a variety of point- and non-point-source anthropogenic stresses have, and continue to, influence the Athabasca, Peace and Slave river systems. In light of these influences the goal of pristine waters is untenable and is replaced by an attempt to protect current quality and define what constitutes "acceptable impact". Under this scenario, reach- and region-specific water resource goals for the basins are based on societal priorities and ecological understanding.

Ecosystem Indicators

A third challenge was to identify and assess the appropriateness of various indicators to determine their continued use, or potential for future application, in environmental monitoring and assessment of these basins. The selection of indicators forms the foundation of any monitoring and assessment program and the success of any such program will be largely determined by this crucial step.

As will be discussed below, the NRBS has chosen to emphasize an integrated approach to environmental monitoring and before providing details of the monitoring program itself it is necessary to explore more fully the concept of an integrated approach and its implications for the NRBS.

Traditionally, integrated monitoring has referred to the simultaneous consideration of both chemical and biological data in the evaluation of potential impacts (Chapman 1986). However, the ecosystem approach recognizes that the process of integration must be broadened to include virtually all aspects of ecosystem management (Box 1).

Box 1. Types of integration required for integrated ecosystem monitoring.

1. Integration of concerns forwarded by different stakeholders within the basins (i.e., all levels of government, general public, interest groups, industry).
2. Integration of societal concerns with scientific information in the development of ecosystem goals.
3. Integration and coordination of monitoring efforts among the different agencies and groups working within these basins. (i.e., standardization of techniques, QA/QC protocols).
4. Integration of all monitoring data into a standardized and accessible database.
5. Integration of research with ongoing monitoring programs.
6. Integration of monitoring results with ongoing ecosystem goal and priority refinement.

Integration of stakeholder concerns does not represent a scientific process but is nevertheless essential in providing a starting point for the scientific management of these basins. In the context of the NRBS, there is a need to represent adequately all interests and for those interests to reach a consensus as to their general concerns. Clearly this is a complicated and challenging process since it must accommodate a variety of different views and priorities and must, in some cases, reconcile antagonistic objectives (e.g., the desire for continued economic development *vs.* the desire to maintain the *status quo*, or even reduce current levels of development).

Integration of societal concerns and scientific knowledge will be discussed in detail in the next section of this report. It is this integration that defines what constitutes an adequate level of ecosystem structure and function and begins the development of ecosystem goals, management objectives and specific ecological indicators. Integration of this type is essential to both the definition and the success of any ecosystem management program.

Integration and coordination of efforts among groups and agencies currently responsible for monitoring within these basins is a key element of this approach. There is a great and growing need for these agencies to coordinate their activities so as to provide the maximal amount of useful information. This argument recognizes that different agencies collect different types of monitoring data for different purposes (e.g., regulatory *vs.* ambient monitoring) and does not suggest that the ability of any agency to satisfy its own objectives would be compromised by the integration process. However, it is also clear that such integration has the potential to provide insights not available from the activities of any single agency (e.g., basin-wide trends) and may even improve overall efficiency of monitoring by decreasing duplication and providing a better focus for monitoring activities. This integration should extend beyond monitoring activities to administrative responsibilities, should recognize that different agencies all contribute to an assessment of the ecosystem and that their efforts should be complimentary and co-ordinated.

Essential to integration of this type is the need to standardize techniques associated with study design, data collection and analyses, and to develop appropriate quality assurance/quality control (QA/QC) protocols to ensure the accuracy of collected data. Standardization of technique and the implementation of QA/QC protocols should already be involved in the monitoring designs of individual agencies and thus would not represent additional work or expenditure on the part of these agencies Standardization and appropriate QA/QC protocols will however, provide more comprehensive and reliable information which will ultimately lead to greater insight into ecosystem structure and function.

Integration of monitoring data into a single and accessible database is closely related to the coordination of monitoring effort. If all monitoring data were to be routinely compiled into a standardized and widely available database a variety of benefits would accrue. First, regional monitoring efforts (e.g., monitoring required under EEM) occurring in different parts of the basin could be "linked" in such a way as to provide a basin-wide perspective on ecosystem trends. Second, areas within the basins that are not currently monitored in an adequate fashion could be identified and monitoring efforts could be redirected toward those areas. Third, the ability to consider simultaneously and quantitatively the results of a variety of monitoring efforts could demonstrate important patterns not previously apparent and allow information to be synthesized over a variety of spatial, temporal and organizational scales. Finally, the ability to compare a variety of different regions within the basins will greatly assist managers in distinguishing between natural and anthropogenically induced variation at any one location. NRBS has made a substantive contribution towards these goals through the development of databases required for Global Imaging System (GIS) maps of the basins, and the standardization of benthological information in the Benthos of Northern Rivers (BONAR) database (Cash *et al.* 1996a). This type of data integration and synthesis is a prerequisite to cumulative effects assessment since such a process must consider the cumulative impacts of separate stressors occurring within the basins.

Integration of research and ongoing monitoring represents an important feedback loop within an integrated monitoring framework. Monitoring data are essential to the documentation of trends within the environment and in the generation of hypotheses that could provide explanations for such trends. However, monitoring itself is incapable of testing these hypotheses or determining the underlying cause of observed trends or patterns. Only properly designed experiments are capable of determining causal mechanisms with statistical rigour. Such experiments also provide new insight into ecological structure and function which can help to focus monitoring activity and ultimately lead to new experiments. In addition to the testing of specific hypotheses, research should be directed toward specific needs (e.g., improvements in data collection techniques, enhancement of predictive models) identified by routine monitoring.

Finally, *integration of monitoring results with the process of setting ecosystem goals and priorities* serves to inform stakeholders as to the results of the monitoring activity and provide them with the knowledge required to modify further the monitoring program. It is important to note that the role of stakeholders does not consist of merely establishing ecosystem goals and then removing themselves from the process. Rather, stakeholders must play an ongoing role in the setting of management priorities, and in the interpretation of monitoring results.

The general purpose of this report was thus to take an integrated approach to the challenges described above in order to provide an answer to Study Board Questions 13a and 14 (Question 13b is addressed in Wrona *et al.* (1996)). More specifically, the report had three primary objectives:

1) To provide an overview and critical analysis of concepts such as "ecosystem health", "cumulative effects assessment" and "ecological risk assessment" and to define the "ecosystem approach" used by the NRBS science program. In other words, to provide a conceptual approach for monitoring and assessment within these basins
2) To provide a pragmatic approach to the choice of ecological indicators that are ecologically and socially relevant and which can be used effectively in basin management decision-making.
3) To provide a northern basins framework approach that could be used to develop an integrated monitoring and assessment program that is ecosystem-based.

Each of these objectives will be dealt with in the following sections of this report.

2.0 CONCEPTUAL APPROACH TO ECOSYSTEM MANAGEMENT

2.1 Introduction

The purpose of this section is to provide the conceptual and theoretical background that forms a basis for the proposed approach to assessment and monitoring of cumulative anthropogenic impacts within the Northern River Basins. Before providing details of any assessment framework it is necessary that underlying concepts such as ecosystem approach and ecosystem health be explicitly defined and their theoretical implications carefully considered. There is not always general agreement as to what these concepts refer to and this disagreement can constrain and confuse the development of an appropriate assessment and monitoring program. In the following sections the concepts listed above will be defined and explored in the context of the NRBS. The final part of this section will then provide a general overview of how these concepts have been applied in the development of a program designed to assess and monitor cumulative anthropogenic impacts.

2.2 Ecosystem Approach to Environmental Management

The most common approach to setting environmental regulations, particularly in North America, has been based largely on the assessment of physical and chemical attributes of anthropogenic inputs (e.g., effluent, or "end-of-pipe" analyses) and the distribution of those inputs within the receiving environments. Consequently, most traditional designs of environmental assessment have focused on developing and refining field and laboratory methods to assess and predict changes in the concentration and distribution of chemicals within the environment (e.g., quantifying and evaluating the types of stressors and their environmental fate and distribution) while paying less attention to the consequences for biological or ecological structure and function (Reynoldson and Metcalfe-Smith 1992; Loeb 1994).

Box 2. Key traits of the "ecosystem approach" to environmental assessment and management (after Christie *et al.* 1986).

1. an emphasis on the collection and synthesis of integrated knowledge of ecosystem structure and function
2. a holistic perspective, inter-relating systems at different organizational levels within the ecosystem
3. an attempt to develop management strategies that are ecological, anticipatory and ethical
4. recognition that human populations are part of, and not separate from, the ecosystem

An alternative approach to environmental assessment involves identifying physical and chemical stressors and their potential impacts on biological communities from a more holistic, ecosystem-based perspective. This approach represents a major shift away from the abiotic-based approach toward one that recognizes: 1) the complex and dynamic interactions (physical, chemical and biological) that occur at a variety of scales (spatial, temporal, and organizational) within an ecosystem; 2) the fact that human populations (and their activities) constitute an important component of that environment and that they cannot be viewed as being separate and apart from it; and 3) the need for human populations to make use of natural resources in a more sustainable fashion (Marmorek *et al.* 1992). More recently, this approach has been embraced by policy makers and has come to be known as the "ecosystem approach" to environmental assessment. Although specific definitions of the "ecosystem approach" may vary, most contain four key traits: (1) an emphasis on the collection of integrated data, (2) a holistic perspective, (3) ethical management strategies and, (4) a recognition that humans are part of the ecosystem (Box 2). Although these traits have not been explicitly identified by the NRBS Study Board, all elements of the "ecosystem approach" are contained within the NRBS Vision Statement and Guiding Questions (NRBS 1994). Thus the "ecosystem approach" forms the foundation for the research conducted within this program.

2.3 Ecosystem Health

2.3.1 Definition of Ecosystem

Implicit in the concept of an "ecosystem approach" is the desire to maintain the ecosystem at some adequate level of function, or health. Unfortunately, both "ecosystem" and "health" are difficult to define. An ecosystem can be considered as a collection of interacting populations (microbes, plants, animals (including humans), etc.) and their abiotic (non-living) environment. While there is little disagreement as to what constitutes an ecosystem, there is often considerable uncertainty as to what bounds it. Ecosystems are not closed systems; energy, nutrients, and organisms move among ecosystems at a variety of spatial and temporal scales. Traditional ecology has defined ecosystem boundaries as regions of reduced ecological interaction or energy transfer (e.g., a river versus adjacent terrestrial habitat), but has also recognized that even these boundaries are arbitrary, albeit necessary, conveniences. In other words, ecosystems are not self-contained. Superimposed on this definition of ecosystem boundary is the need to consider the context (spatial, organizational and temporal scales; political, economic and societal concerns) in which the system is being studied.

Because true ecosystem boundaries cannot be objectively determined, it is important that researchers and environmental managers explicitly define the boundaries of the system they are assessing and yet recognize any such boundaries are largely arbitrary and that processes occurring outside of these boundaries may have important consequences for the structure and function of the ecosystem under study. For example, global climate change affects all ecosystems, but is not a property of any one.

In the context of the NRBS, the ecosystem being studied has been defined as those sections of the Peace, Athabasca and Slave river basins that occur within the Province of Alberta and the North West Territories. Clearly this definition does not include those sections of the basins that are found in British Columbia or Saskatchewan. However, it is nevertheless important to recognize that activities (e.g., hydro-electric development in British Columbia, long-range-aerial transport of contaminants from other regions) that occur outside these boundaries may have important consequences for the NRBS study area and that activities within the NRBS study area (e.g., pulp mill activity) may have impacts on other ecosystems (e.g., Great Slave Lake, the MacKenzie River). Similarly, most of the research conducted by the NRBS has focused on the mainstem and major tributaries of these rivers while considerably less attention has been devoted to smaller tributaries or to terrestrial habitat within these systems. This focus is a reflection of (1) priorities established by the NRBS Study Board, (2) available information and, (3) financial and time constraints acting on the study. As with the geographic boundaries discussed above, a focus on the mainstem rivers within the study area does not suggest that processes occurring in smaller tributaries or in terrestrial habitat are unimportant to overall ecosystem structure and function. Rather, it merely illustrates that all ecosystem studies must, to some extent, involve rather arbitrary boundaries but that the choice of boundaries will have important implications for both the understanding and management of the ecosystem.

2.3.2 Definition of Ecosystem Health

The concept of ecosystem health, and its obvious analogy with human health, has broad intuitive appeal and has come to be widely used by managers, certain researchers, and members of the general public (Rapport 1992a,b). Consequently, there now exists a considerable literature exploring the philosophical, economic and scientific implications of the concept of ecosystem health (Costanza *et al.* 1992; Callicott 1995; Calow 1995).

Unfortunately, the concept of health is itself, difficult to define (Calow 1992, 1995), and the development of precise definitions of ecosystem health and ecosystem integrity is particularly problematic (Haskell *et al.* 1992; Suter 1993a; Ramonde 1995; Rapport 1995; Wicklum and Davies 1995). At the First International Symposium on Ecosystem Health and Medicine held in Ottawa, Canada (June 1994) and at other workshops (e.g., Costanza *et al.* 1992; Rapport 1995) leading ecologists, philosophers, economists, sociologists, physicians, resource managers and decision makers examined and debated the philosophical, theoretical and applied aspects of ecosystem health as well as its general utility and implications for society and for ecosystem management. Although workers have recognized difficulties in defining ecosystem health, several operational definitions have emerged. One proposed definition of ecosystem health is as follows: "An ecological system is healthy and free from 'distress syndrome' if it is stable and sustainable - that is, if it is active and maintains its organization and autonomy over time and is resilient to stress." (Haskell *et al.* 1992, p. 9). This definition is applicable to all complex systems and identifies four key traits that must be possessed by a healthy ecosystem: (1) sustainability, (2) activity, (3) organization and, (4) resilience. The definition is not intended to serve as a final definition of ecosystem health, rather its purpose is to state more explicitly the current understanding of the concept and to serve as a starting point for future research and discussion in this emerging and multi-disciplinary field.

Other proposed properties that "healthy" ecosystems should display are the ability to maintain desirable vital signs, the ability to display vigour, the absence of disease, and the ability to maintain a balance between system components, and recover to equilibrium after perturbations (Rapport 1989; Costanza 1992). Costanza (1992) went as far as suggesting an overall system health index, defined as HI (ecosystem health) = V*O*R, where; V refers to a measure of system vigour, that incorporates measures of system activity, metabolism, and productivity; O represents a system organization index (ranging from 0-1) that incorporates concepts of diversity and food web connectivity; and R quantifies system resilience to perturbations (also ranging from 0-1).

Such broad operational definitions have the apparent appeal of formalizing and incorporating several ecological concepts key to the notion of ecosystem health and provide a conceptual starting point for the development of a long-term strategy for the study of ecosystem health. However, while they recognize the importance of ecosystem characteristics such as sustainability, resilience and autonomy, these characteristics are themselves, difficult to define in a practical context. Therefore, while such operational definitions provide a first step on a multi-disciplinary research program, they provide no direct, immediate utility to those charged with the task of managing ecosystems.

Some researchers (e.g., Suter 1993a) have argued that because the term ecosystem health possesses so little direct utility and has the potential to be misleading it should be abandoned all together. While we agree with many of Suter's arguments we also argue that the term does have value and is now widely used and entrenched in the scientific lexicon (witness the creation of new scientific journals such as *The Journal of Aquatic Ecosystem Health* and *Ecosystem Health*). Instead of replacing ecosystem health with an equally difficult to define term such as ecosystem quality we favour an approach that seeks to develop an adequate operational understanding of what constitutes a healthy ecosystem and have found the work of Calow (1995) helpful in this regard.

Rather than concentrate on specific definitions, Calow (1995) identified four general approaches within which, researchers have attempted to develop the concept of ecosystem health (Table 1). In the first approach, ecosystems are viewed as super-organisms or as single creatures with many different components (e.g., the GAIA Hypothesis as expounded by Lovelock (1987)). This view of ecosystems as organisms is, however, flawed. Ecosystems are not organismic in the sense that they can be conceived of as a single unit. They do not reproduce as individuals, they do not compete amongst themselves for limited resources, and importantly they do not possess a genotype on which natural selection can act. These criticisms recognize that different ecosystem components are highly interconnected and dependent on one another but that ecosystems cannot be managed as if they were single organisms.

Table 1. Current Approaches to the Study of Ecosystem Health.

Approach	Key Assumptions	Relative Utility
Super-organism	ecosystems are subject to natural selection	low: assumptions are logically flawed
Holistic	healthy ecosystems attain stable equilibrium states	low: assumptions not supported by evidence
Anthropocentric	healthy ecosystems are those that meet economic and aesthetic expectations of society	low: restrictive definition, not sustainable
Pragmatic	healthy ecosystems defined by combination of scientific and societal criteria	high: flexible, practical, facilitates development of appropriate indicators

The second approach considers ecosystems as systems that maintain an optimum or steady equilibrium state. Among the general public this view is best represented by the "balance of nature" arguments. The view of ecosystems as stable states also presents difficulties (Suter 1993a; Calow 1995). Because stable states are context dependent, measures of how stable an ecosystem (or components within that ecosystem) is cannot be used to determine the state of ecosystem health. For example, the Northern River Basins study area is characterized by a considerable degree of natural variation. The timing and extent of flooding varies from year to year and events such as ice scour and flooding often destroy benthic aquatic communities established in the previous months thereby "resetting" the process each year. However, the presence of this natural variation cannot be used to argue that the Northern River Basins represent an inherently unstable, and thus unhealthy ecosystem.

There is also considerable theoretical and empirical evidence for intrinsic and extrinsic processes that would prevent ecosystems from maintaining long-term stable states (e.g., naturally occurring population cycles). Finally, this approach fails to recognize the importance of stochastic or random events that disrupt community or ecosystem structure and allow for reinvasion. Indeed disturbance, particularly at intermediate levels, is widely recognized as an important determinate of ecosystem structure and function (Connell 1978; Sousa 1979; Resh *et al.* 1988).

In the third approach, healthy ecosystems are defined in an anthropocentric sense in which the health of an ecosystem is determined by its ability to provide the services demanded of it by human populations. Under this scenario, an ecosystem capable of satisfying the economic and aesthetic demands of a human society is deemed healthy. Drawbacks of a reliance on this approach include: 1) given the contrasting requirements of different segments of society it may not be possible to maximize simultaneously the ecosystem's ability to supply all desired services; 2) even if a consensus emerges on a suite of services required of the ecosystem it may not be possible to manage the ecosystem so as to maintain such a state; and, 3) managing an entire ecosystem solely from the perspective of human goals raises clear ethical concerns and is a direct contradiction of the "ecosystem approach".

In the final approach, ecosystem health and integrity is defined in a pragmatic sense. This approach does not seek to develop a general definition of ecosystem health but rather, combines the best available scientific knowledge with societal expectations of the ecosystem to develop a pragmatic, operational view of the desired structure and function of the ecosystem being managed (Box 3). We would argue that the pragmatic approach to ecosystem health provides the greatest utility to those tasked with managing ecosystems. This approach does not attempt to develop a precise and general definition of ecosystem health, and thus avoids the very real problems and challenges faced by those that do (Costanza *et al.* 1992; Suter 1993a). Rather, it makes full use of the best scientific information available but is also capable of making subjective assessments of ecosystem health based on this information. Importantly, the pragmatic approach is sufficiently flexible to allow for the incorporation of new information, changes in societal priorities, improvements in monitoring techniques and/or refinements in theoretical understanding as they become available.

Box 3. Key traits of a pragmatic approach to ecosystem health.

1. Ecosystem health is defined by incorporating the best available scientific knowledge with societal expectations.
2. Ecosystem health is defined on an ecosystem-specific basis.
3. Our understanding of ecosystem health can readily change to accommodate new scientific information or changes in public priorities.

Because the pragmatic approach to ecosystem health relies on societal input and scientific information, the expectations of what any particular ecosystem should look like may change as societal priorities and the state of scientific knowledge change. As a consequence, the basis on which an ecosystem is judged to be either healthy or unhealthy may change from region to region and may change within a region over time. Implicit in this approach, is the recognition that the management of ecosystems and the development of specific indicators of ecosystem health must be considered on a case by case basis (Box 4). This in no way suggests that approaches and indicators developed in one region are not applicable to other locations. Rather, it argues that the issues of concern for a given ecosystem will be a consequence of the nature of that system and of the specific stresses acting upon it. In other words, it is not possible to *a priori* determine what indicators will prove most valuable in a particular ecosystem, nor is it feasible to attempt to develop indicators that are applicable to all regions and ecosystems.

Box 4. Implications of the pragmatic approach to ecosystem health for the development of ecological indicators.

- The criteria/endpoints used to define ecosystem health will be ecosystem dependent and will vary both spatially and temporally.
- The process of indicator selection and employment must adapt to changes in societal priorities and scientific understanding.

The pragmatic approach incorporates societal priorities but not to the exclusion of scientific understanding of ecosystem structure and function. Ultimately, issues of "acceptable impact" involve political rather than scientific decisions; however the pragmatic approach allows for a more explicit statement of the ecological consequences of those decisions and at the same time allows general statements concerning society's desire to live in a "clean" world to be refined into specific management objectives.

The Synthesis and Modelling Component of NRBS has recommended a pragmatic approach to the assessment of ecosystem health and have used this approach as the basis for the development of a proposed integrated assessment and monitoring framework and for the development of specific indicators of ecosystem health (Cash 1995; Cash *et al.* 1996b). In this way we hope to provide an appropriate context in which to view the proposed NRBS monitoring program. In the following sections we describe a process where by the practical approach to ecosystem health assessment can be used in the establishment of ecosystem goals and ecological indicators.

2.4 Development of Ecosystem Goals and Indicators

This section illustrates how concepts discussed earlier can be applied in developing general ecosystem goals, management objectives and ecosystem indicators. While the value of the ecosystem approach to environmental management has now been widely recognized there remain significant challenges in translating the stated objectives of the approach into practical management tools that can be used to assess and monitor the state of ecosystems. Advantage should be taken of existing guidelines (e.g., Alberta's Surface Water Quality Objectives, Canadian Water Quality Guidelines and Canadian Drinking Water Quality Guidelines, Environmental Effects Monitoring) when developing ecosystem management objectives (Figure 2). What follows is a more detailed description of the development of general ecosystem goals and the refinement of those goals into management objectives and, eventually, specific ecological indicators.

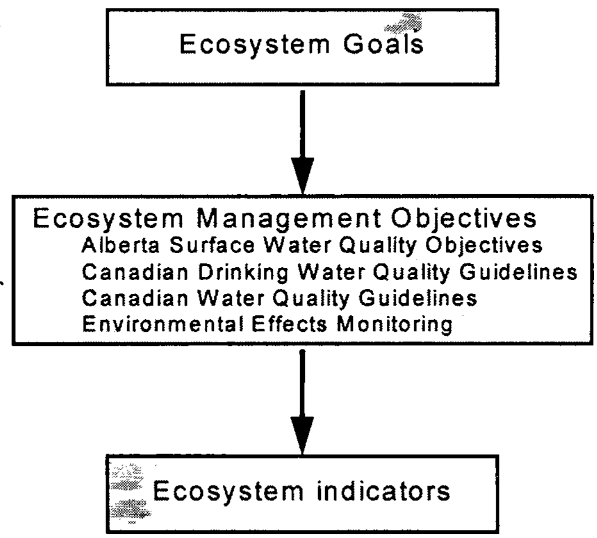

Figure 2. Relationship Between Indicators, Goals Objectives and Guidelines.

2.4.1 Ecosystem Goals and Management Strategies

Monitoring and assessment programs, particularly those operating on the scale required by the NRBS, are both expensive and labour intensive. The development of an effective program is dependent on an explicit statement of management goals and objectives (reflecting stakeholder input) that provide a framework for the establishment of a monitoring program and a means by which its success can be measured. Development of specific ecosystem goals and objectives also represents a process by which all stakeholders (informed by the best available scientific knowledge) determine the nature of the world in which they want to live. Clearly, this is a societal decision and not a scientific issue. Science plays a role in refining general goals and in developing specific monitoring objectives that will help satisfy those goals, but the goals themselves must first be determined by society. Any monitoring program developed solely on scientific priorities could prove unpopular with the public at large and would be very unlikely to receive legislative approval and support.

The development of ecosystem goals and their refinement into more specific management strategies represents a complicated and at times, daunting, process; however such a process is necessary to the development of appropriate management strategies. The Synthesis and Modelling component envisions this process of objective development as consisting of two phases (Figure 3). In the first phase, a group of stakeholders begin to develop general ecosystem goals; that is, they begin to define ecosystem health according to the pragmatic approach described above. Note that general ecosystem goals are generated by a group of stakeholders representing the public at large, special interest groups, industry and all levels of government and that they are assisted in that process by scientific explanations as to the current and predicted state of the ecosystem. It is also important to note that this phase also includes a feedback loop indicating that once preliminary ecosystem goals are established they may be further refined (with stakeholder assent) by the scientific information available.

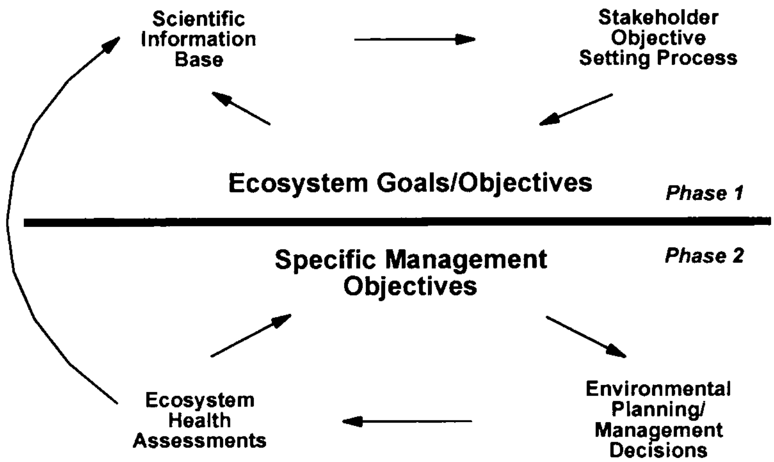

Figure 3. Development of Ecosystem Management Objectives.

In the second phase general ecosystem goals are modified into specific management strategies that are used to assess ecosystem health and develop specific ecological indicators. It is important that the specific management strategies developed in this phase relate directly to the general goals articulated in the first phase. An example of such a relationship is that between specific technical studies conducted within the NRBS and the 16 Guiding Questions developed by the Study Board.

Finally, information generated through the assessment of ecosystem health influences both environmental planning/management decisions and, through additions to the scientific information base, the process of setting ecosystem goals. Indeed, the process of setting ecosystems goals should be viewed as an iterative one, subject to changes resulting from shifts in societal priorities, scientific information and/or the results of monitoring activities.

2.4.2 Ecological Indicators

Following the development of ecosystem goals and specific management strategies potential indicators must be evaluated in terms of their ability to fulfil these objectives in an efficient and cost-effective manner. Figure 4 describes the process of indicator development proposed by the Synthesis and Modelling Component. The process begins with an explicit statement of the problem based on

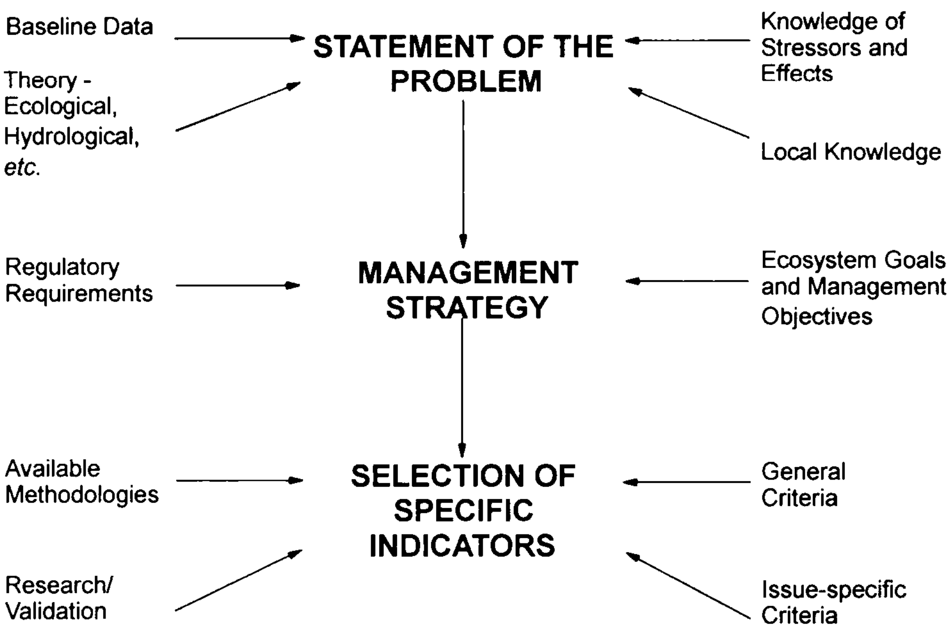

Figure 4. Development of Ecosystem Indicators.

stakeholder input (local knowledge), knowledge of the specific ecosystem under study (baseline data, information on stressors and effects) and general scientific theory (e.g., ecological, hydrological). The problem statement, in conjunction with stated ecosystem goals and regulatory requirements is then used to develop a management strategy. Finally the management strategy along with certain practical constraints (available methodologies, validation, general and issue specific criteria for indicator selection) is used to evaluate potential indicators.

The key to this approach rests with the direct link between a statement of the problem and the selection of an indicator. As Cairns *et al.* (1992) have pointed out, everything is an indicator of something. In other words, there is a danger of developing a series of answers for which there are no questions; it is thus not simply a matter of selecting indicators but of selecting indicators that address specific questions and do so in the most cost-effective manner possible. This challenge is complicated by the fact our current understanding of ecological systems is typically insufficient to identify what needs to be measured and what components are most in need of protection and by the need to determine the ecological relevance of many indicators currently in development. A clear and explicit statement of the specific problem under consideration and a continual reference to that statement during indicator development will greatly increase the probability of getting the data required to address the specific question.

The management strategy, and the evaluation of candidate indicators, will be further influenced by the perceived state of the ecosystem (Figure 5). Perceived ecosystem condition is an important consideration because it helps to determine specific indicators independent of ecosystem goals and objectives. For example, stakeholders, in consultation with scientists and managers, might develop an ecosystem goal that

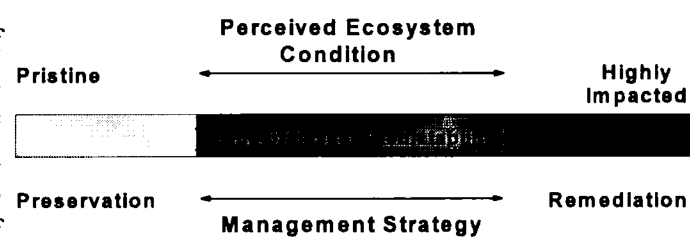

Figure 5. Relationship of Management Strategy to Perceived Ecosystem Condition.

involved maintaining populations of a given fish species at a level that allowed for fishing and consumption. In a pristine environment an appropriate management strategy might involve the preservation of critical (spawning and rearing) habitat and the monitoring of fishing effort. However, in an ecosystem thought to be heavily impacted, the management strategy might involve contaminant studies to assess whether the fish can be eaten or the remediation of lost habitat. Thus, while the ultimate ecosystem goal is the same in both cases, the management strategy and tools employed varies as a function of perceived ecosystem condition. This example is a simple one and compares extreme situations; in many cases the perceived condition of the ecosystem will be much more intermediate in nature. In these cases, the ability of managers to predict the consequences of their actions is much lower and the need to consider carefully the details of their management strategy much greater (Figure 5).

To illustrate the process of indicator selection and development described above we present a specific example of indicator development within the NRBS.

2.4.3 Indicator Development in the NRBS: An Example

One of the pronounced concerns for people using the Athabasca-Peace-Slave river basins is the potential ecological and human health-related risks associated with environmentally persistent contaminants in resident fish and wildlife populations. Many people living in these basins still attempt to maintain traditional lifestyles and rely on the river systems for drinking water, fish and other game, and use the rivers as a means of transportation. These river systems also form a fundamental basis of their culture and spirituality (NRBS Traditional Knowledge Synthesis Report No. 12). Non-indigenous users of these river basins have also placed a great deal of aesthetic and ecological value on these systems (NRBS Other Uses Synthesis Report No. 7). The challenge for NRBS was thus to incorporate environmental, societal, industrial and regulatory concerns in the development of an appropriate set of indicators that provide the necessary information to assess and predict whether key food webs are being adversely affected by toxic contaminants, particularly those associated with pulp-mill effluents.

Historically, a primary source of environmentally persistent organochlorine compounds to these river ecosystems is from bleach-kraft pulp-mills. Compounds of greatest concern are the highly toxic chlorinated isomers 2,3,7,8-TCDD (tetrachlorodibenzo-*p*-dioxin) and 2,3,7,8-TCDF (tetrachlorodibenzofuran), both known mutagens and teratogens (Ramonde 1987). Over the past few years, the remaining bleached-kraft pulp mills on these river systems have upgraded their technology eliminating the use of free elemental chlorine in their bleaching process (NRBS Contaminant Synthesis Report No. 3). Thus, environmental levels of chlorinated compounds, such as dioxins and furans, are expected to decline within these ecosystems. Any selected indicator(s) of contaminants must be sufficiently sensitive to detect and predict any such changes.

In addition, the exposure of fish to pulp-mill effluents has been associated with physiological changes, including increased activity of liver detoxification enzymes and decreased production of steroid hormones that control reproduction (Gagnon *et al.* 1994; Munkittrick *et al.* 1994). Recent findings have shown these changes can be correlated with organismic effects such as delayed sexual maturity, reduced gonadal size, and depressed secondary sexual characteristics in certain fish species (e.g., Munkittrick *et al.* 1991, 1994). Other studies have suggested an association with exposure to endocrine-disrupting compounds and reproductive impairment in birds and mammals, including humans (e.g., Colborn *et al.* 1993; Bortone and Davis 1994; Cotton 1994). Perhaps what is of greatest concern is that many of these observed physiological changes have been associated with a wide range of pulp-mill effluents, including effluents from mills with secondary treatment and mills that do not use chlorine in their bleaching process (e.g., thermal-mechanical pulp mills). Consequently, although environmental levels of chlorinated organic compounds are expected to decline within these basins, other potentially toxic effects from pulp-mills and other industrial and municipal effluents remain to be understood and monitored.

Finally, the monitoring of wild fish populations is also a regulatory requirement under the Environmental Effects Monitoring (EEM) program for Canada's pulp and paper industry (Environment Canada and Department of Fisheries and Oceans 1991). One of EEM's key components involves a biological assessment using sentinel fish species to determine the potential effects of mill effluents. The program specifies a comparison of various measures of fish health (e.g., tissue body burdens, liver enzyme bioassays (e.g., Mixed-Function Oxidase (MFO) activity)) between upstream (reference) and specified downstream (potentially impacted) locations. An underlying, but seldom tested assumption of this approach is that the behaviour, physiology, and movement patterns of the sentinel species accommodates such a comparison.

The challenge was therefore to identify a set of indicators that could be used to address several issues simultaneously. We chose several criteria by which to evaluate the appropriateness of potential indicator(s) of contaminants levels in fish tissues (Box 5). Based on these criteria, three different, but complimentary approaches were selected and tested as potential indicators of contaminant fate and effects on aquatic food chains. Together these indicators provided information on contaminants and biomagnification at a basin-wide (Burbot (*Lota lota*)) and local scales (small, resident cyprinid species) and indication of bioavailable contaminant concentrations at selected sites throughout the basins (semi-permeable membrane devices (SPMDs)).

Box 5. Selection criteria for indicators of contaminant loadings in fish.

1. The indicator(s) must be known to bioaccumulate organochlorine compounds in specified tissues.
2. For specific individual taxa, general information was available on distribution, life history, and feeding habits and they occurred in densities sufficient to allow appropriate sample sizes for statistical analyses.
3. The scale (basin-wide versus localized) of applicability is known.
4. The information derived from the indicator(s) (not necessarily the indicator itself) has relevance to identified public concerns.
5. The indicator(s) are cost-effective.
6. The information derived from the indicator(s) has relevance regulatory requirements.

Burbot was chosen since, of all the fish species occurring within these river basins, it best met the general criteria; more particularly, although individuals possess relatively restricted distributions, the species occurs throughout basins, it is a known bioaccumulator of contaminants (Hakkari 1992) and is an important food source to people within the basins.

While burbot serve as indicators of food web contaminant levels on a basin-wide or reach-wide scale, an additional concern was that no species currently being used as biomonitors within these basins (e.g., rocky mountain whitefish, long-nosed suckers, northern pike) were representative of localized effects. NRBS fish movement studies have shown these species regularly move upstream and downstream of specific effluent exposure areas and may thus not reflect conditions in the area in which they were collected (R.L.& L. Environmental Services Ltd. 1994). Field evidence suggests these species have more limited mobility and possess smaller home ranges, making them better indicators of environmental stressors in localized environments. Moreover, because of their small body size, they are amenable to validation of their field responses using laboratory bioassay approaches in which biochemical disruptions can be directly related to changes in growth, survival and fecundity (Gibbons *et al.* 1995). To address this problem, a new bioindicator approach is being refined examining biochemical disruptions in smaller fish species, primarily members of the Families Cyprinidae and Cottidae.

The third indicator uses a semipermeable membrane (SPMD) as a passive measures of the average concentrations and bioavailability of organic contaminants in water. These devices, comprised of thin-walled, low-density polyethylene tubing filled with a neutral lipid such as triolen, passively accumulate organic compounds (Huckins *et al.* 1993). Accumulated organics are extracted and added to cell culture to test for physiological effects such as MFO induction. Relative to fish collections, the use of SPMDs allows information to be collected in a standard manner at specific locations and permits control of the exposure period. Conversely, SPMDs cannot be directly related to ecologically relevant endpoints, but along with the fish indicators discussed above provide a more complete understanding of the distribution, availability and ecological consequences of certain contaminants.

The preceding discussion demonstrates how a careful consideration of the local ecology, public concerns and the nature of stresses acting on the system was used to develop the proposed indicators. The approach taken by NRBS in developing an indicator framework was based on four basic components; 1) identification of public concerns and priorities, 2) pursuit of the best available scientific understanding of ecosystem structure and function, 3) incorporation of public concerns and scientific knowledge in the development of ecosystem-specific indicators, and 4) recognition that managing ecosystems is a dynamic process and must maintain maximum flexibility to incorporate advances in scientific understanding and changes in societal concerns. The process emphasizes the need for ecosystem-specific input into the development of appropriate indicators. Indicators developed in one system may be applicable to others but their ultimate utility must be assessed on a case by case basis. In this case, indicators were selected based on their ability to satisfy management objectives and societal concerns within the northern river basins study area.

3.0 INTEGRATED MONITORING AND ASSESSMENT CONSIDERATIONS

3.1 Integrated Monitoring

As the extent and complexity of anthropogenic impact on the environment increases so does the need to develop effective management criteria that can be used to maintain current levels of ecosystem structure and function and, where necessary and possible, take remedial action in systems deemed to have been unacceptably impacted. Essential to the development of any effective management strategy is the development and implementation of a suite of appropriate monitoring techniques. A properly designed monitoring program would be based on, and contribute to, the existing data base describing the general nature (i.e., structure and function) of the ecosystem being managed. Such a program would also provide early warning of changes to that system, and ultimately provide information as to the causes of those changes and the steps required to restore the ecosystem to some acceptable level of structure and/or function (i.e., ecosystem health) (Box 6).

Box 6. Primary functions of a monitoring and assessment program.

1. To provide basic information as to the nature (structure and function) of the ecosystem.
2. To identify and monitor long-term trends or cycles within the ecosystem.
3. To provide early (or at least timely) warning of changes to that system.
4. To provide the information required to determine the underlying causes of observed changes in the ecosystem.
5. To provide the information required to predict the ecological consequences that future levels of development would have on the ecosystem.

3.1.1 General Issues for Scientific Design of an Integrated Monitoring Program

The last several decades have witnessed a tremendous increase in the number and types of monitoring techniques available to ecosystem scientists and managers. Current research in monitoring aquatic systems is being conducted by academic institutions as well by various levels of government and industry. Specific research projects span fields as diverse as genetics, paleolimnology, biochemistry, physiology, toxicology, taxonomy, multivariate statistics, and genetics as well as basic ecology and systematics (Burton 1992a,b; Johnson *et al.* 1993; Rosenberg and Resh 1993).

Box 7. General issues in the development of a monitoring program.

1. Basic Ecology
2. Study Design
3. Scale
4. Research
5. Cumulative Effects

The specific design of any monitoring program will be contingent upon the ecosystem goals and objectives of the program itself, as well as on inevitable financial and logistic limitations. There are, nevertheless, basic issues that should be considered in the development of any monitoring program designed to assess ecosystem health, cumulative impacts and environmental risk assessment. What follows is an identification and brief discussion of several of these general issues (Box 7). An awareness of these issues will aid in the design of an effective monitoring program and will assist in the identification of knowledge gaps in our current understanding of the ecosystem.

Basic Ecology

An explicit objective of the NRBS is to acquire a baseline data set pertaining to the basic ecology (i.e., structure and function) of the Peace, Athabasca, and Slave river basins. Such information is essential, because it provides an understanding of the ecosystem structure and function as it currently exists and because it provides a reference point for future comparisons. As pointed out by Johnson *et al.* (1993) it is impossible to apply knowledge that one does not have and the success of any monitoring program or ecosystem management strategy will be largely constrained by the understanding of the basic ecology of the system under study.

Unfortunately, there are considerable gaps in our current knowledge of the ecology of the northern basins. These knowledge gaps are reflective of the difficulties associated with working in these systems and of a general lack of information on the ecology of large rivers, particularly large northern rivers. Knowledge gaps relating to the basic ecology of these systems greatly complicate the development of a monitoring framework required to assess ecosystem health and cumulative effects within these basins. It should however, be possible to provide a general approach to the development of such a framework even if certain might change as new information becomes available.

The importance of understanding the basic ecology of the ecosystem cannot be over emphasized. It is this understanding which determines our view of the system and provides a context within which all management priorities and objectives are developed. Gaps in this understanding could result in a failure to identify key issues or in the misdirection of time and effort.

At a more pragmatic level, an adequate understanding of ecosystem structure and function is essential in order to (1) accurately trace the fate of contaminants once introduced to the system, (2) identify those components of the ecosystem most likely to be affected by such an introduction, and (3) predict the overall effect of contaminants or groups of contaminants on the nature of individuals, populations, communities and the ecosystem. An understanding of the basic ecology of the system will also be important in (1) predicting long term consequences of observed change in community structure or function; (2) determining underlying mechanisms responsible for observed changes; and (3) identifying those species that play an important role in the maintenance of the community and/or ecosystem.

Information relating to basic ecology may also be a prerequisite for the successful application of commonly used monitoring techniques. Several community-based monitoring techniques require all individuals collected be identified to the level of family genus, and in several cases species. Such an approach presupposes a detailed taxonomic knowledge of species collected and can (particularly in the case of benthic macroinvertebrates) entail considerable costs. Similarly, knowledge of the ecology of individual species is required before they can be employed as bioindicators within the monitoring program, their taxonomy and distribution must be understood, as must their response to perturbation (IJC 1991; Cairns *et al.* 1992; Johnson *et al.* 1993). Knowledge of movements, ecology, and population structure of potential bioindicators is also important in the development of techniques relating to the locating and sampling of such species. Finally, the utility of chronic toxicity tests and bioassays that predict environmental effects is dependent on the selection of ecologically relevant endpoints (survival, growth, fecundity, performance), and a knowledge of the ecological roles and trophic interactions of the test species (Burton *et al.* 1992b; La Point and Fairchild 1992; Buikema and Voshell 1993).

Ideally, environmental monitoring programs would have at their disposal, accurate and complete information as to the basic ecology of the ecosystems being monitored. Such a database could be used to clearly identify the most appropriate ecological indicators, and identify those components most sensitive to perturbation. Unfortunately, limitations on resources as well as on our ability to understand complex ecological processes inevitably preclude this possibility. In reality, programs such as the NRBS face the challenge of having to synthesize available knowledge and fill large information gaps in baseline data, while at the same time determining the impact of anthropogenic activities on the system and developing a framework for ongoing ecosystem health and cumulative effects monitoring.

Despite these limitations a carefully designed monitoring program will be capable of generating a database providing information on the basic ecology of the system under study. The existence of such a database has several important advantages: (1) An understanding of the basic ecology provides the context within which ecosystem goals and objectives are formulated. (2) An adequate and accessible database provides researchers and managers with the flexibility required to apply different interpretative techniques to the same data set and to select those that best meets their objectives. (3) Improvements in monitoring techniques could be retroactively applied to "quality" data already collected and synthesized. (4) The existence of a long-term, carefully constructed database will facilitate the detection of important ecological trends, may provide early warnings of changes to the ecosystem and will provide a background against which the progress of remediation efforts can be judged.

Study Design

One of the major goals of any monitoring program is to use patterns of distribution and abundance of organisms to determine the state of the ecosystem and to detect change. The extent to which this goal is met is dependent on the ability to (1) identify those components that require measurement; (2) properly measure and describe those components; (3) compare and contrast those measures at a variety of spatial and temporal scales; and (4) relate these observed patterns to corresponding patterns in physicochemical variables. The development of appropriate study designs is critical to this process and will facilitate management objectives by assuring the proper collection of relevant data, the elimination of confounding effects and the selection of appropriate analyses (Norris and Georges 1993).

Spatial and temporal variation in the distribution and abundance of organisms is often considerable, even in the absence of any disturbance. It is therefore important that environmental variability and its effects on sampling accuracy and precision be accounted for both in study design and in data analyses. The past two decades have witnessed considerable improvements in, and greater standardization of, field sampling and collection techniques (Downing 1979; Cuffney *et al.* 1993a,b; Gibbons *et al.* 1993; Meador *et al.* 1993a,b; Porter *et al.* 1993; Resh and McElravy 1993). It is also now generally recognized that even small habitat differences among sites can be a major source of natural variation in biological communities. Sampling protocols should thus include habitat characterization and measurements of all important and relevant physicochemical variables (Norris and Georges 1993).

Improvements in study design such as the development of the BACI (Before After Control Impact) approach (Green 1979), a recognition of the importance of sample replication and statistical power, and the development of Quality Assurance/Quality Control (QA/QC) protocols have helped to ensure that appropriate, accurate and precise data are collected and properly handled. The increased use of powerful statistical techniques will permit researchers and managers to identify pattern within the data set and to discriminate between natural and stress induced variation (Green 1979; Dixon and Newman 1991; Jackson 1993; McBride *et al.* 1993; Norris and Reynoldson 1993). These techniques are also useful in the generation and rigorous testing of hypotheses relating to the underlying causal mechanisms responsible for the observed variation (Norris and Georges 1993).

In the NRBS, an additional aspect of study design is important. Given that monitoring data are likely to be collected by a variety of groups or agencies and for a variety of purposes (e.g., Environmental Effects Monitoring legislation, Provincial Regulations, academic research, etc.) there is a particular need to ensure that data are collected in a consistent and comparable fashion. In this way it will be possible to integrate monitoring data over large spatial and temporal scales.

Scale

Issues of scale (spatial, temporal and organizational) in the design of monitoring programs are closely related to those of appropriate sampling design. Scale is an important consideration, not only from the perspective of adequately sampling a system as large the Peace, Athabasca and Slave river basins, but also from the perspective of interpreting and identifying spatial and temporal pattern in the data once collected. Indeed, a number of researchers have argued the problem of pattern and scale is rapidly emerging as a central problem in population ecology and ecosystem science (Fox 1992; O'Neill *et al.* 1992); and that it represents an important bridge between theoretical and applied ecology (Levin 1992), and should play an important role in the development of monitoring programs.

In the first instance, large-scale monitoring programs such as that required for the northern river basins presents considerable logistic and theoretical challenges (O'Neill *et al.* 1992). Questions include (1) What is the extent and intensity of sampling effort at different scales required to describe these system? (2) Are there specific ecosystem components that are particularly vulnerable to anthropogenic stresses, or are key to ecosystem function? (3) Can managers extrapolate from patterns observed in one area, time, or level of organization to other areas, times, or levels of organization within the same system?

In many cases determining the scale most relevant to the question being asked can be addressed using available background data on physical, chemical, and biological parameters and on the nature, source, and timing of stresses. If such information is not available, then monitoring programs should be designed in such a way as to begin to construct such a database. The problem of deciding the most relevant scale is further complicated by the effect of scale on the interpretation of pattern once observed. Because each species or group of species experiences the environment at a unique range of scales, the scale of observation chosen will influence the description of pattern. It is thus necessary to ensure that researchers are careful to chose a scale of observation appropriate to the question being asked since specific patterns observed within the environment will be largely a function of the scale at which workers choose to make observations (Levin 1992).

This observation has important consequences for the design of monitoring programs. Measurements collected at the level of the individual (or in single species toxicity tests) may be appropriate for examining the short-term behaviours of individuals but may not be appropriate for examining populations, communities or whole ecosystems (Buikema and Voshell 1993). Similarly, patterns observed within communities may contain little information on the response of individual species or of the entire system (Cooper and Barmuta 1993). Finally, in long-term studies of whole lake ecosystems, Schindler (1987, 1988, 1990) has demonstrated that significant changes in species composition and community structure may not be reflected by changes in ecosystem level processes. This suggests that monitoring at the level of the ecosystem itself may not provide the data required to assess properly ecosystem condition or to detect changes in ecosystem structure and function.

Issues of scale and pattern will continue to complicate the interpretation of monitoring data and are deserving of further investigation. Problems arising from misinterpretation of monitoring data can be minimized if issues relating to scale are explicitly recognized both in the design of studies and in the interpretation of results. Confusion resulting from scale-related problems may also be minimized by: (1) carefully considering the scale or scales of relevance for a particular question, (2) collecting observations from a variety of different spatial, temporal, and organizational scales, (3) being sensitive to the difficulties in extrapolating between scales (Cooper and Barmuta 1993), and (4) being aware of the fact that the causal mechanisms producing the observed pattern often occur at a scale below that at which the pattern is observed (Levin 1992). In addition to these general issues, there are particular concerns of direct relevance to the NRBS including the need to: (1) develop monitoring tools for use at point source discharges as well as at reach-specific and basin-wide levels; (2) to account for the variability in a system as large and diverse as the Peace, Athabasca and Slave river basins; (3) identify and reconcile the different scales impacted by a single point or non-point source discharge.

Research

A well designed monitoring program is capable of detecting pattern within the environment, identifying trends in the state or condition of the ecosystem, and can provide inferences as to the cause or causes of observed trends. However, in the absence of controlled experiments properly and rigorously designed to test specific hypotheses, monitoring programs cannot determine the underlying causes of observed patterns (Clements 1991; Rose and Smith 1992). In the past, the limitations of monitoring alone have not always been fully appreciated. For example, differences in measurements from locations obtained immediately above and below a point source discharge may be properly collected and analyzed but only served to demonstrate differences and could provide no explanation as to the cause of those differences. Differences of this type have traditionally been misinterpreted as evidence of a causal link between the presence of a point source discharge and some presumed downstream effect. In reality, additional information relating changes in measures taken to differences in the relevant environmental variables and the use of properly designed and rigorous experiments would be necessary to demonstrate any causal link between the presence of the point source discharge and the observed downstream changes.

Properly designed and executed field and laboratory experiments should play an integral role in the development and operation of monitoring programs. A well designed experimental approach will allow managers to: (1) investigate, under replicated and controlled conditions, important aspects of field conditions; (2) better interpret observed ecological response; (3) calibrate and validate existing or proposed monitoring programs; (4) identify ecological indicators; (5) predict responses to perturbations; (6) disentangle the direct and indirect effects of perturbations; and (7) determine the direct and interactive effects of a variety of variables on ecological systems (Cooper and Barmuta 1993).

As discussed above, extrapolation from experimental results to phenomena observed at other scales is often complicated. However, rigorous, controlled experiments designed to test specific and relevant hypotheses will increase understanding of the interaction between scale and pattern. Clearly, all experiments involve some sacrifice of reality and accuracy in favour of an increase in precision, but they also provide the best opportunity to test rigorously hypotheses generated from an examination of monitoring data and to identify the causal mechanisms responsible for environmental change.

Cumulative Effects

A recognition of the importance of cumulative effects influences the design of an appropriate monitoring program. What follows are several examples of the way in which cumulative effects must be accounted for in a monitoring program. Traditional aquatic monitoring programs were largely developed to examine the effects of organic pollutants (i.e., sewage) on the environment (Metcalfe-Smith 1994). However, aquatic organisms in nature are routinely exposed to a great variety of different stresses, both organic and inorganic, simultaneously. Common stressors include organic pollution (including sewage, dioxins, furans, and organochlorines) and heavy metals (Costan *et al.* 1993) and in some cases (e.g., pulp mill effluent) some of the most important contaminants are thought to be as yet unidentified. Monitoring programs must therefore be sensitive to a variety of perturbation types as well as to the additive and synergistic effects of exposure to several different types of stress simultaneously. Similarly, lower dissolved oxygen levels under winter ice conditions represents a stress but the interaction between this and other stresses such as contaminant exposure may produce additional and unexpected cumulative effects.

3.1.2 Summary of Existing Monitoring

Introduction

This section provides an overview of selected monitoring programs within the study area. It does not deal with all monitoring only that which concerns water quality and is related to fisheries. This information will serve as a backdrop to monitoring recommendations that follow however, the reader should be aware that current monitoring practices are undergoing change and the overview presented here may be subject to change.

Ambient Aquatic Ecosystems

Most of the ambient aquatic monitoring within the basins is undertaken by provincial, federal and municipal governments (Alberta Environmental Protection 1995; NRBS Drinking Water Synthesis Report No. 9; Carson and Hudson 1995; Sentar 1994) and to a lesser extent by industries (McCubbin and Folke 1993). Spatially extensive and temporally intensive monitoring is not undertaken except as related to water flow and lake levels.

Traditional knowledge provides improved awareness of the how the ecosystems have changed in response to development and other factors (NRBS Traditional Knowledge Synthesis Report No. 12). This knowledge has been derived from a "human monitoring protocol" involving the passing of knowledge down from one generation to the next and from the direct knowledge of those individuals who have experienced changes first hand over time and across the lands where they live. This form of monitoring has not historically been well received by the conventional European-type communities;

however, NRBS has demonstrated the value of such traditional information not only on the basis of its own merits but also through its coupling with the knowledge gained through the conventional European approaches to monitoring.

Existing ambient aquatic ecosystem monitoring within the northern river basins involves the collection of information concerning the following: (1) water demand and use, (2) water licensing and allocation, (3) water supply, forecasting and availability (i.e., hydrology), (4) water quality of river systems (near and far field) and lakes, (5) fisheries, and (6) drinking water quality. An overview of existing statistics and monitoring related to water demand, use, licensing, allocation, and hydrology can be found in several other NRBS reports (NRBS Other Uses Synthesis Report No. 8; Reicher and Thompson 1995; NRBS Traditional Knowledge Synthesis Report No. 12; NRBS Nutrients Synthesis Report No. 4 and 5; McCubbin and Folke 1993; Sentar 1995a,b,c,d,e; NRBS Hydraulics / Hydrology Synthesis Report No. 1; Aitken *et al.* 1995; Hudson 1995; Carson and Hudson 1995; Alberta Environmental Protection 1995). An overview of the drinking water quality monitoring programs conducted by the Province of Alberta and its municipal agencies is described elsewhere (NRBS Drinking Water Synthesis Report No. 9; Prince *et al.* 1994).

Active ambient water quality monitoring in the basins is summarized in Table 2 and indicates that comprehensive monitoring is spatially and temporally limited, and that the choice of variables, methodology, and sampling are not consistent with the recommendations of NRBS studies (Carson and Hudson 1995), or the need to monitor and assess the health of the aquatic ecosystem (Cash 1995). For example, federal monitoring programs on the Peace and Athabasca rivers continues to focus on water chemistry and does not include biological attributes of the ecosystem. Specific details about the water quality (chemistry) parameters investigated, the period of record and trends have been reported for the Peace River (Shaw *et al.* 1990), Athabasca River (Noton and Saffran 1995; Noton and Shaw 1992), Smoky and Wapiti Rivers (Noton 1992; Swanson *et al.* 1992) and Slave River (MacDonald Environmental Sciences Ltd. 1993; and Grey *et al.* 1995). More recent programs, such as the Pulp Mill Liquid Effluent Environmental Effects Monitoring (EEM) required under the federal Fisheries Act (Environment Canada and Department of Fisheries and Oceans 1992) includes an assessment of the state of the ambient environment. The EEM approach is discussed in more detail below; Table 3 provides a summary of the EEM requirements for each mill in Alberta. The EEM approach places the cost of monitoring in the hands of those industries who harvest the natural resources. Should other industries (e.g., hydrocarbon recovery, agriculture and forestry management) adopt the same "ecological" assessment protocols, the basins will have a strong science basis for dealing with cumulative effects assessments and the foundation for an ecosystem approach to water management.

With regard to government conducted surveys and water quality assessments, they are, and will likely continue to be, mission-oriented with a clearly defined purpose or hypothesis to test. These surveys tend to be ecosystemic (multi-media) in approach and are responsive to new and evolving assessment technologies and findings from the scientific literature. As with the EEM approach these assessments should be designed in a fully integrated manner drawing upon the value of monitoring investments made by the industry monitoring programs within the basins.

Table 2. Overview of Active Ambient River Water Quality Monitoring in Northern Basins.

Provincial	Federal	Industry
Upper Athabasca River to town of Athabasca		
One long term water station monthly; Four winter oxygen recording monitors one of which is on Lesser Slave River; Nine medium term water stations 6x per year; all for general chemistry (ions and nutrients) and conventional contaminants--chlorinated organics, heavy metals, pulp mill contaminants	Two mainstem sites monthly for general water chemistry, heavy metals, nutrients	4 Pulp mills monitor according to EEM regulations: general water chemistry; toxicity; bioaccumulation; benthic community
Middle Athabasca River from Athabasca to Ft. McMurray		
Two mid term water stations 6x per year; two winter oxygen recording monitors; for variables as noted above	None	1 pulp mill monitors according to EEM regulations: general water chemistry; toxicity; bioaccumulation; benthic community Oil Sands industries (Syncrude): seasonal sampling at 9 surface sites within operations for ions, carbons, suspended solids, Oil and Grease, phenols and heavy metals
Lower Athabasca River from Ft. McMurray to Lake Athabasca		
None	One long term site monthly for general water chemistry, heavy metals, nutrients and organics substances	None
Upper Peace River from B.C.-Alberta Boundary to Peace River		
One long term mainstem monthly; three tributary sites mid term x6 per year; for general chemistry, oxygen, heavy metals, pesticides and other pulp mill related organics	Two long term sites monthly for general chemistry and periodic for contaminants (metals, pesticides)	3 Pulp mills monitor according to EEM regulations: general water chemistry; toxicity; bioaccumulation; benthic community
Mid Peace River from town of Peace River to Fort Vermillion		
One long term monthly for variables as described above	None	None
Lower Peace River from Fort Vermillion to Lake Athabasca		
None	One long term time of visit for general chemistry, heavy metals and nutrients	None
Slave River from confluence with Peace to Great Slave Lake		
None	One long term site now part of Slave River Study for general chemistry, nutrients, heavy metals and bioaccumulation of contaminants in fish	None

Table 3. Pulp and Paper - Environmental Effects Monitoring.

MILL	CONSULTANT	RECEIVING ENVIRONMENT	PLUME DELINEATION	MILL START-UP	RECENT SIGNIFICANT OPERATIONAL CHANGE	SENTINEL SPECIES	INVERTEBRATE SURVEY	TISSUE ANALYSIS	TAINTING EVALUATION	WATER TRACER	FISH TRACER
Alberta Newsprint, Whitecourt	SENTAR	Athabasca River, Alberta	RWT	1990	1992	Lake chub, Longnose dace	Intensive	No	No	No (Klebsiella for benthic)	No
Weyerhaueser, Grande Prairie	GOLDER	Wapiti River, Alberta	Modelling	1972	1995	Longnose sucker, Mountain whitefish	Intensive	Yes	Yes	Colour, Dioxin Conductivity, Na RFA(sediments)	No
Daishowa, Peace River	SENTAR	Peace River, Alberta	RWT	1990	1990	Longnose sucker, Burbot	Intensive	Yes	No	Na	TCG in bile/liver/muscle
Slave Lake Pulp, Slave Lake	EVS	Lesser Slave River, Alberta	RWT, modelling	1990	1990	Longnose sucker, White sucker	Intensive	No	No	Na	Resin acids
Millar Western, Whitecourt	SENTAR	Athabasca River, Alberta	RWT	1988	1988	Longnose sucker, Lake chub	Intensive	No	No	Na	RFA in bile/liver
Weldwood, Hinton	GOLDER	Athabasca River, Alberta	RWT	1957	1993	Mountain whitefish, Longnose sucker	Intensive	Yes	Yes	Phenol, Na, pH, Conductivity	RFA in bile/liver, chlorophenols
Alberta Pacific, Boyle*	SENTAR	Athabasca River, Alberta		1993	1993	N/A	N/A	N/A	N/A	N/A	N/A
British Columbia Pulp Mills on the Peace River											
Fletcher Challenge, Mackenzie	G3	Williston Lake, B.C.	Conductivity, Colour	1973	1993	Chub, Longnose Sucker, Lake Whitefish	Extensive	Yes	No	Conductivity, Colour	________
Fiberco Pulp, Taylor	EVS, PLA	Peace River, B.C.	Modelling, Na tracer	1988	1994	Longnose Sucker, Largescale sucker	Intensive	No	No	Na, Conductivity	DHA in bile
Finley Forest Industries, Mackenzie	G3	Williston Lake, Peace River, B.C.	Conductivity, Colour	1970	1989/90, 1993	Mountain whitefish, Longnose sucker, Chub	Extensive	Yes	No	Conductivity, Colour	D/F

* - NEW MILL - EEM study to be completed 09/96
N/A - Not available, Study design not approved

Industrial and Municipal Effluents

Within the northern river basins, effluents from industry and municipalities are, for the most part, licensed under provincial (Alberta, British Columbia and Saskatchewan) and Northwest Territories legislation. Federal regulatory requirements (e.g., Fisheries Act) for effluents relate to the Pulp and Paper Mill Regulations and uranium mine discharges. These statutes have been discussed elsewhere (Kennett and Saunders 1995; Wagner 1995; McCubbin and Folke 1993; Sentar 1994).

Alberta Environmental Protection (1995) provides a description of the regulatory standards and monitoring requirements for industries in Alberta. Table 4 is taken from this government report and summarizes these general liquid effluent monitoring requirements. The report states: "The frequency that a facility is required to monitor a substance is a dynamic variable and must consider a number of factors, including the type of treatment process, retention time, the environmental significance and nature of the substance, the need for baseline river information, the cost of monitoring relative to the dischargers capabilities and benefit obtained, and the compliance history."

The report also argues monitoring frequencies can change on the basis of scientific and monitoring finds. In 1992, the Pulp and Paper Effluent Regulations of the Fisheries Act were amended, to bring all mills in Canada under a body of regulations that prescribed limits for the discharge of biochemical oxygen demand, total suspended solids in effluent, and acute lethality of effluent to rainbow trout. In acknowledgment of the fact that a single set of uniform effluent standards may not adequately protect aquatic life and receiving environments, the amended regulations called for an EEM study from each mill every three years. The purpose of EEM is to assess the adequacy of effluent regulations, and evaluate the need for further control measures and/or formulation of site-specific control measures.

The specific requirements for first cycle EEM activities are outlined in Environment Canada and Department of Fisheries and Oceans (1992). Reporting requirements for the first EEM cycle include submission of a pre-design document and a study design proposal for review by a Technical Advisory Panel (TAP), made up of qualified representatives from Environment Canada, Department of Fisheries and Oceans and provincial environmental departments. The TAP is required to review the first cycle documents and subsequent interpretive reports for adequacy of information, validity of scientific design and conclusions, and compliance with EEM regulations and procedures. The first cycle study design is used both to establish a baseline against which data from future cycles can be compared, and to provide a preliminary assessment of what, if any effects are evident in the receiving environment. The study design must include a scientifically defensible (statistically valid) adult fish survey, invertebrate community survey (both must include supporting physical, chemical, sediment, and effluent tracer measurements), tissue analyses (for mills employing chlorine bleaching), a tainting evaluation if required, and effluent toxicity measurements. The first cycle experimental design must be replicable, and all mills must, at minimum, repeat the monitoring requirements of the first cycle in their second cycle.

Table 4. Liquid Effluent Monitoring Requirements.

Parameter \ Category	Chemical Plants	Coal Processing	Concrete & Cement	Fertilizers	Fish Farms/Hatcheries	Food Processing	Foundry	Gas Processing	Meat Processing	Municipal Wastewater	Potato Processing	Power Plants	Pulp & Paper mills	Rapeseed	Refineries	Rendering Plants	Salt Caverns	Sand & Gravel	Tar Sands	Wood Processing
Alkyl Benzenes	X																			
Aluminum		X					X												X	
AOX													X							
Arsenic		X																		X
BOD1													X							
BOD5	X	X		X	X	X			X	X	X		X	X						X
BODu													X							
Chloride	X					X		X									X			
Chlorinated Phenolics													X							
Chlorine Residual			X					X				X								
Chromium			X										X							X
COD	X	X	X	X			X	X				X	X	X	X				X	
Coliform		X								X			X							
Colour		X											X							
Copper		X																		X
Dioxins & Furans													X							
Dissolved Oxygen		X										X	X							
DOC	X			X				X					X							
EC (specific Conductance)	X							X					X							
EDTA													X							
Fecal Coliform									X	X			X							
Flouride		X					X													
Flow	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Gross-alpha				X																
Gross-beta				X																
Heavy Metals	X		X				X	X				X	X		X				X	
Hydrogen Peroxide	X																			
Iron		X	X				X				X	X								
Major Ions													X			X				
NH3-N	X		X	X	X	X		X	X				X	X	X				X	
NO2-N		X												X						
NO3-N		X	X		X									X						X
Nutrients													X			X				
Oil & Grease	X	X	X	X			X	X	X			X	X	X	X				X	
Organic Priority Pollutants													X							
Organic-Nitrogen	X			X															X	X
PCP																				X
pH	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	
Phenols		X											X		X				X	X
Phosphate				X	X			X											X	X
Phosphorous (total)	X	X			X	X				X		X			X					
Reactive Phosphorous												X								
Resin & Fatty Acids													X							
SAR																X				
Settleable Solids		X																		
Sulphate	X							X					X							
Sodium		X											X							
Sulphide		X											X		X				X	
Total Dissolved Solids	X	X	X					X				X	X							
Temperature	X		X									X	X						X	
Total Kjedahl Nitrogen					X									X						
Total Organic Carbon	X		X			X														
Total Organc Nitrogen						X		X					X							
Total and Dissolved Phosphorous					X									X						
Total Chlorine									X											
Total Hardness								X												
Total Nitrogen		X										X								
Toxicity: Cenodaphnia													X							
Toxicity: Daphnia magna	X					X						X	X	X	X				X	
Toxicity: Fathead Minnow													X							
Toxicity: Microtox								X												
Toxicity: Rainbow Trout	X			X		X	X	X				X	X	X	X				X	
Toxicity: Solonastrum													X							
Total Phosphorous - PO4					X															
Total Suspnded Solids	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X			X	X	X
Turbidity		X										X								
Uranium (238)				X																
Urea				X																
Vinyl Chloride	X																			
Zinc		X													X					

Fisheries Monitoring

Fisheries monitoring efforts in the northern river basins are presently conducted mainly by government fisheries management agency programs administered by Alberta Environmental Protection and by Fisheries and Oceans Canada (DFO). Additional monitoring is performed by Crown corporations (Freshwater Fish Marketing Corporation) or non-government organizations (Trout Unlimited, Western Walleye Council, local communities, etc.). These monitoring activities are summarized in Table 5.

Table 5. Existing Fish Monitoring Activities in the Northern River Basins Study Area.

Monitoring Agency	Location of Effort	Focus of Monitoring	Program Delivery
Alberta Environmental Protection	All lakes and rivers within Alberta	Fisheries management: fish populations, fish habitat maintenance and enhancement, quota administration, licensing, economic value, client satisfaction	Fisheries Management Division and Enforcement, Field Services Division of the Natural Resources Service
Department of Fisheries and Oceans Canada	Slave River and Great Slave Lake, NWT; fishery waters in Alberta and NWT	Fish stocks in NWT, contaminants (mainly mercury),marketing of commercial fish in AB and NWT, fish habitat management in AB and NWT	DFO Central and Arctic Region, Freshwater Institute, Winnipeg, and District Offices in Edmonton, Hay River and Yellowknife
Government of North West Territories	Slave River near Fitzgerald	Contaminants in fish monitored annually	
Industry and private organizations	In vicinity of pulp mills; upper reaches of selected tributaries in bull trout habitat;	Regulatory requirements under Fisheries Act and Alberta Environmental Protection Act; sports fishery preservation	Individual pulp mills on river systems; Non-government organizations (Trout Unlimited)
Freshwater Fish Marketing Corporation	Scheduled commercial fishing lakes in Alberta and NWT	Fish harvest marketing, pricing and parasite/mercury contamination and periodic organochlorine compounds	FFMC Fish Processing Plant Transcona, Winnipeg and Edmonton; cooperative/private Fish Processing plants at Edmonton, Faust, Joussard, Lac La Biche and Fort Chipewyan, Alberta and Hay River, NWT
Community	Various (e.g. fort Resolution fisherman)	Stock assessment and movements of commercial fishery species (e.g. inconnu)	Species management and quota administration

The Inspection Branch of DFO has had a contaminants monitoring program for commercial fisheries in this region since 1970. The purpose of the program is to ensure that contaminant levels do not exceed consumption guidelines and tolerances established by Health Canada. The initial focus of the program was, and continues to be, mercury, but monitoring is also done on an ongoing basis for a number of organochlorine pesticides and PCBs. The frequency of monitoring is dependent on the levels of contaminants in the fishery (the higher the contamination, the more frequent the monitoring) and the extent to which the fishery is active. In addition to the ongoing monitoring for mercury, pesticides and PCBs, in the late 1970's, commercial fisheries were extensively surveyed for a number of heavy metals. Since that time, Health Canada has rescinded all tolerances for metals (other than mercury) in fish. More recently, a limited number of commercial fisheries were analyzed for dioxin. The Freshwater Fish Marketing Corporation has recently begun monitoring of parasite infestation.

Alberta government fisheries monitoring activities are sectoral: recreational fisheries, commercial fisheries and domestic (subsistence) fisheries. They are monitored separately with different methods and reporting frequencies. Further subdivision of monitoring effort may occur within a fisheries sector to reflect varying objectives of interests to resource managers, policy needs or public interest. Monitoring may be conducted on stock assessment, life history (spawning, movement, feeding, habitat use) harvest, economic value of fisheries or fishing effort. Table 6 summarizes the sectoral breakdown, methods, frequency and objectives of fish monitoring activities in Alberta.

Table 6. Sectoral Breakdown of Fish Monitoring Activities in Alberta.

Sector	Methods	Frequency	Objective
Recreational Fishery	Creel Survey	Periodic (e.g. every 5-10 years or as needed)	Stock harvest management
	Client Questionnaire Survey	Periodic every 5 years since 1980	Harvest management, economic valuation public information and overall focus of fisheries program design
	Stock Assessment, habitat usage, movement studies, life history studies	As needed, usually incidental to policy initiatives or public concerns	Species management
Commercial Fishery	Quota enforcement and harvest survey	Annually	Stock management
	Harvest sub-sampling and stock assessment	Annually	Parasite and contaminants (mercury only) measurement for public health assurance and quota administration
	Marketing and processing enforcement and survey	Annually	Public health, quality assurance, business development, economic valuation
Domestic Fishery	Licensing administration	Annually	Quota allocation
	Harvest survey	Periodic	Stock management

As has been reported (Donald 1995; Westworth and Associates 1995), and as can be seen from Tables 5 and 6, fishery monitoring has been absent or minimal, particularly as related to fish health and the level of contaminants in fish consumed by humans. Future fishery monitoring efforts in the basins must provide information related to fish health, harvest management, public health and their consumption of fish (e.g. contaminants in fish), economic valuation and public information. The focus, however, should shift to include key monitoring approaches tested and tried by the NRBS. These include monitoring of fisheries to assess the long-term cumulative impacts of development on aquatic ecosystems and the monitoring of selected fish species (e.g. burbot) as ecosystem health indicators (Donald 1995). Integrating the monitoring efforts of governments, industry and private organizations could result in a more comprehensive integrated database with which regulatory authorities can more effectively manage the fishery. As well, there should be economic gains through integrated planning and implementation although these were not investigated as part of NRBS.

3.1.3 Candidate Indicators / Measures for Future Consideration

An important aspect of the development of an integrated ecosystem monitoring framework for the Northern River Basin drainages is the identification of specific physical, chemical, biological and ecological indicators. The specific indicators selected will be a reflection of the ecosystem goals and objectives established by stakeholders and will reflect their concerns and priorities. Although specific indicators have yet to be determined, the general objectives of an integrated ecosystem monitoring program will involve documenting, in a holistic perspective, the current status of the ecosystem, and assess (and where possible predict) the effects of different management and development alternatives. In order to satisfy these objectives, it is important that indicators of ecological condition be assessed with confidence, that we can distinguish between anthropogenic and natural sources of indicator variation, and that the effectiveness of the indicators in assessing the defined goals/objectives can be clearly reported to resource managers and the public. The purpose of this section is to identify potential classes or types of indicators and assess their utility within these basins. We recognize the importance of stakeholder involvement in indicator development and offer this discussion only as a starting point for the selection of assessment tools once management objectives have been clearly articulated.

For convenience, and in accordance with the US EPA Environmental Monitoring and Assessment Program (EMAP) (Hughes *et al.* 1992), three general classes of indicators of ecological condition can be defined: 1) Stressor, 2) Exposure/Habitat, and 3) Biological/Ecological response (Box 8). These general classes of indicators provide a framework to guide the process of selecting, evaluating and implementing actual measurements that will

Box 8. Candidate indicators for an Integrated Ecosystem Monitoring program for the Northern River Basins.

Stressor-
- Land use and landcover
- Chemical sources (point- and non-point loadings)
- Flow and channel modification

Exposure/Habitat -
- Physical aquatic habitat structure
- Water quality/quantity
- Sediment transport/deposition/toxicity
- Chemical contaminants in biota
- Biomarkers in biota

Biological/Ecological Response -
- Fish assemblages
- Macroinvertebrate communities
- Periphyton assemblages
- Semi-aquatic wildlife assemblage
- Sediment toxicity - (TRIAD/Deformities)

be used to assess the ecological condition. None of these categories are exclusive, since a given indicator or measure may serve more than one category and may also be applicable at several spatial and temporal scales as will be illustrated in Section 3.1.4.

The following sections elaborate on each of these indicator classes using examples and recommendations obtained from the NRBS science program. The goal of these descriptions is to illustrate the scientific rationale as to why these particular indicators should be considered as candidates for an integrated ecosystem monitoring program for these basins.

Stressors

Changes in Land Use / Land Cover

Change in land cover and land use is one of the primary factors influencing ecological systems. Impacts include habitat loss or quality reduction, increased non-point source pollution, increased atmospheric emissions and, changed regional hydrology and run-off patterns (Hunsaker *et al.* 1992). Landscape ecologists are advancing our understanding of the interactions between these changes and ecosystem processes at various temporal and spatial scales (e.g., Forman and Gordon 1986; Turner 1989; Risser 1990; Alke 1995), and several studies have shown that the proportion of different land uses within a watershed can account for the variability of certain surface water chemistry parameters such as nutrient levels, turbidity and related hydrologic characteristics (e.g., Omernik *et al.* 1981; DelRegno and Atkinson 1988; Osborne and Wiley 1988; Levine and Jones 1990; Ward and Elliott 1995).

A variety of landcover types and land use patterns have been identified by the NRBS (NRBS Other Uses Synthesis Report No. 7; NRBS Traditional Knowledge Synthesis Report No. 12; NRBS Hydrology Synthesis Report No. 1; Alke 1995). Present uses of the lands within the basin area range from forestry-related activities (clear-cutting, silviculture), agriculture, recreational-use, traditional-use by First Nations peoples, Provincial and National Parks, oil and gas exploration and recovery (conventional well sites and oil sands), mining, industrial and municipal land-fills.

As part of an integrated monitoring framework for the basins, it is recommended that the GIS database produced by NRBS be maintained and updated regularly (i.e., on a 3 year cycle). This database can document changes in land use and such changes can be correlated with changes with water quality and quantity. Although, it is difficult to measure directly the impact of non-point sources on the aquatic ecosystem, a GIS-based database coupled with *in situ* measures of response variables represents a promising approach to assessing non-point source impacts within these basins.

Point-Source Loadings

Information on point-source loadings (e.g., volumes and chemical composition) and well as their toxicity provides critical information as to the types and intensities of nutrient, chemical and hydrologic stresses impacting the riverine ecosystems and is an essential component of any integrated monitoring program (for reviews of point-source loadings in the study area refer to NRBS technical reports; McCubbin and Folke 1993; SENTAR 1995 a,b,c,d,e). Loadings and information on the chemical composition of the effluents is required as part of licensing by Alberta Environmental Protection (AEP) for industrial and municipal point source discharges in the basin area.

Acute and chronic toxicity bioassays involving algae, *Daphnia*, and fish are also being performed by pulp-mills as part of their AEP licensing and federal EEM regulatory requirements (Sentar 1995a). It is recommended that efforts should be made to link these laboratory "end-of-pipe" toxicity results to observed ambient responses in receiving waters. This type of integration will be necessary to validate whether discharge-based bioassay guidelines are adequately protecting the receiving ecosystem.

In addition, Alberta Environmental Protection maintains and updates effluent information on all licensed point-source dischargers in the Basin. It is important that this database be updated on a regular basis and verified for quality control / quality assurance.

Flow and Channel Modifications

Modifications of flow regimes and channel morphology have consequences for fish and fish habitat, riparian habitat and wildlife, (Walder 1995; NRBS Hydrology Synthesis Report No 1). The NRBS has determined that future evaluations of potential ecological impacts related to flow regulation and/or climate variability will require more detailed knowledge of the temporal and spatial variability of the flow regime (depth and velocity) and channel geometry at key reaches within the basins. Although a network of hydrometric stations exists in the basin area, many of these stations have been located to obtain a reliable flow records and not for their representativeness of reach-specific hydrologic characteristics (NRBS Hydrology Synthesis Report No. 1). Hence, to assess potential reach-specific ecological impacts of flow modifications interpolative models must be used to predict the hydrologic characteristics in river sections where no monitoring sites exist currently. The NRBS has developed a hydraulic flood-routing model of the Peace River and Slave Rivers that can calculate discharge hydrographs at intermediate locations (NRBS Hydrology Synthesis Report No. 1) and can determine requisite flow and velocity data if channel geometry information is also available. It is recommended that this model be adopted as a principal tool for evaluating changes to the flow regime, including the modelling of naturalized flow conditions being conducted by Alberta Environment.

The Hydrology and Other Uses components also tested the application of multi-spectral imaging of habitat availability on the Peace River as a potential tool to assess the affects of flow and channel modifications on aquatic habitat quantity and quality. It is further recommended that this approach be evaluated under a broader range of flows.

Exposure/Habitat

From a historical perspective, evaluation water of quality has been primarily concerned with physical and chemical characteristics of surface water. In an integrated monitoring program, these measures are used to estimate the expected natural range of ecological conditions and to identify the likely cause of impairment. Potential classes of ecological indicators for an integrated monitoring plan in these basins include: general water quantity and quality, sediment distribution, processes and associated toxicity, chemical contaminant levels in biota, physiological biomarkers, and physical habitat structure and quality. A general discussion of each indicator class follows.

Physical Aquatic Habitat

An important aspect of resource management in the northern river basins is the allocation of water among various uses, including both in-stream and out-of-stream uses. As used here, in-stream uses refers to all uses of water in the stream channel that do not involve withdrawal, diversion or impoundment of water. Such uses include those related to environmental protection issues (management of fish resources and maintenance of ecosystem health) as well as more direct human uses (recreation, navigation, waste transport and assimilation, and aesthetic considerations) (Walder 1995).

River impoundments and diversions can have dramatic effects on the physical, chemical, and biological characteristics of downstream reaches of the river, including physical habitat. Recognition of these effects, concern about the implications for fish populations, and interest in broader environmental protection issues have led to attempts to describe what is needed, in terms of stream flow regime, in order to achieve a desired level of environmental protection. In this context, in-stream flow needs (IFN) may be defined as stream flow regime characteristics, quantities of water, and water quality conditions needed to protect both the aquatic and riparian components of riverine ecosystems (Walder 1995).

NRBS has examined the issue of in-stream flow needs primarily from the perspective of addressing how flow regulation on the Peace River is influencing critical fish habitats in the mainstem and riparian habitats along the Peace River mainstem and in the Peace-Athabasca Delta (NRBS Hydrology Synthesis Report No. 1). Based on NRBS assessments, several aquatic habitat-related measures should be considered in any future integrated monitoring program; these include, classification and quantification of various habitat types under differing flow regimes, information on fish and other aquatic and semi-aquatic life habitat requirements (e.g., spawning areas), and responses of biota to habitat modifications (NRBS Other Uses Synthesis Report No. 7; NRBS Food Chain Synthesis Report No.6; NRBS Hydrology Synthesis Report No.1; NRBS Traditional Knowledge Synthesis Report No. 12).

Water Quantity

Hydrometric monitoring provides essential data for water (basin) planning, water forecasting (related to flood events, water levels and velocity, and water volume), licensing of water allocations, and development of site-specific regulations related to effluents and mixing zones. The economy within the basins relies on these data in order to optimize industrial operations either for economic reasons (e.g., related to hydroelectric power and transportation) or for meeting environmental requirements (e.g., water and dissolved oxygen levels and waste discharges). As both the Traditional Knowledge (NRBS Traditional Knowledge Synthesis Report No. 12) and House Hold Surveys (NRBS Other Uses Synthesis Report No. 7) indicate, communities as well as individuals who live off the land rely on water level/volume information in order to meet their requirements of drinking water, waste water treatment, recreation, fishing, transportation, and personal safety.

The NRBS has not reviewed the adequacy of the existing hydrometric agreements; however, by virtue its science programs, it has identified the importance of appropriate hydrometric data to: (1) compute chemical and contaminant loads, (2) assess erosion potential of various river reaches, (3) identify sediment depositional areas, (4) compute time-of-travel of contaminants, (5) adapt hydrometric, hydraulic and spill response models, and (6) to understand the dispersion of point-source pollutants in river systems (Aitken *et al* 1994; Hicks *et al.* 1995; Krishnappen *et al.* 1993; English *et al.* 1995; MacCauley 1996).

A key example of the need for a properly designed, hydrometric monitoring network in these basins is provided by the NRBS assessment of flow regulation on the Peace River and the ecology of the Peace-Athabasca Delta and the Slave River and Delta (NRBS Hydrology Synthesis Report No. 1). This assessment highlighted the requirement for decades of hydrometric data, new cross-sectional data and other geomorphological information, and the application of satellite and aerial imagery coupled with sophisticated 1-D hydraulic models (Aitken *et al.* 1994; Hicks *et al.* 1995; NRBS Hydrology Synthesis Report No. 1; MacCauley 1996). However, the hydrologic models developed from this assessment now provide a basis with which water resource managers can objectively review and optimize the hydrometric networks within the basin area.

NRBS has also identified additional information needs and questioned the value of some existing monitoring stations. For example, additional hydrologic monitoring is required in tributary watersheds to modify the operations of the Bennett Dam so as to restore the downstream ecological conditions of the Peace River mainstem and deltas (NRBS Hydrology Synthesis Report No. 1). NRBS has also questioned the value of continued monitoring at some of the hydrometric monitoring stations and the placement of others (Hicks *et al.* 1995; English *et al.* 1995; NRBS Hydrology Synthesis Report No. 1). The wide-range of ecological issues for which hydrometric data are required underscores its incorporation into an integrated monitoring program for these basins.

Water Quality

The monitoring of general water quality provides information on a suite of variables that describe water column conditions to which aquatic biota are exposed (Hughes *et al.* 1992). An important role of water quality monitoring is to provide reach-specific and basin-wide information on natural vs. anthropogenic-related differences in water quality.

We recommend four general attributes of water quality continued to be monitored on a basin-wide synoptic basis: 1) water type (i.e., ionic strength), 2) acid-base status (sources of acidity); 3) nutrient status, and 4) redox status (Box 9).

Box 9. Fundamental water chemistry variables to be monitored in the Northern River Basins.

Major Anion/Cations:	Na, K, Mg, Ca, Si, SO_4, NO_3, Cl
Acid-Base Status:	pH, total alkalinity, total hardness, Mg, hardness
Nutrient Status:	NO_3, NH_4, total N, total P, ortho P, Soluble Reactive Phosphorus (SRP)
Redox Status:	DO, pH, temperature, Mn, Fe
Other:	microbiological, suspended solids

Major anion and cation chemistry provides important information on the association between water quality, land-surface water processes, atmospheric inputs, and other point and non-point source anthropogenic disturbances (e.g., changes in downstream water quality associated with reservoirs). The acid-base status of water includes measures of pH and buffering capacity of water (e.g., alkalinity, magnesium and total hardness). pH is important in controlling the solubility and toxicity of many chemicals, while the buffering capacity describes the degree to which the system resists pH changes from acidic/alkaline inputs. Major anion chemistry also provides information on the sources of surface water acidity. Nutrient status addresses the supply of chemical compounds that limit the growth of aquatic algae and macrophytes in the system. The Nutrients component makes very-specific recommendations regarding the types of nutrient-related chemical variables that should be monitored (NRBS Nutrient Synthesis Report No. 4). The redox status of the water as measured by dissolved oxygen levels, and sediment-water interface (SOD), pH, temperature, and major metal cations such as Manganese (Mn) and Iron (Fe) provide critical information on the key controlling factors influencing the solubility, mobility, and toxicity of many chemicals including nutrients and heavy metals. Specific-recommendations have also been made regarding the types and frequency of monitoring necessary for water column and sediments from a nutrients/dissolved oxygen perspective (NRBS Nutrient Synthesis Reports No. 4 and 5). Other measures of water quality to consider related to microbiological levels and suspended solids (NRBS Drinking Water Synthesis Report No. 9) .

Biomarkers

Biomarkers can be defined as biochemical, physiological, or pathological responses measured in individual organisms, that provide information on exposures to environmental contaminants and/or sublethal effects arising from such exposures. The application of biomarkers to assess the affects of contaminants and other stressors on the health of individuals, and by extrapolation, to provide information on the potential effects on populations, communities and ecosystems, is a rapidly developing research area.

One of the primary uses of biomarkers is to obtain early-warning of biological impairments and corresponding ecological degradation from chemicals and other stressors in the environment. Biomarkers can be classified according to measures associated with; 1) biochemical aspects of contaminant biotransformation, mode of action, and adaptation, 2) specific indices of DNA damage (genotoxicity), 3) immune system response to toxicants, 4) physiological and non-specific responses; and 5) structural changes in tissues (histopathology). Most typically, biomarkers measure changes in the activity of enzymes (e.g., cytochrome P-450s/Mixed-Function Oxidase metabolism (MFO) in liver tissue) or in the level of a specific biogenic compound (e.g., blood chemistry and tissue measures of sex steroids, metallothionien, retinols) (Peakall 1992).

The NRBS used several biomarkers to assess the exposure and health of selected fish species to stress. These included measures of MFO induction, sex steroid levels, metallothionien and retinol production, and histopathology (NRBS Contaminants Synthesis Reports No. 2 and 3). Detailed treatments of the biochemical and physiological bases of these biomarkers are provided by Peakall (1992), Hoffman *et al.* (1995).

Biomarkers should be considered as organism-level indicators that complement population, community and ecosystem-level indicators in an integrated monitoring program. However, this physiological / biochemical response may not indicate an impact at an ecologically relevant level (i.e., growth, survival, reproduction). Application and interpretation of biomarkers requires further research in order to assess their ability to provide early warning of general ecological degradation.

Sediment transport / associated contaminant levels and toxicity

Knowledge of sediment processes (e.g., transport, deposition, re-suspension, flocculation) and associated contaminants is a necessary component of any integrated monitoring program within these basins. In a monitoring context, sediment refers to all detrital, inorganic, and organic particles settling on the bottom or re-suspended and transported via hydrologic processes (Burton 1992a,b).

NRBS has advanced the understanding of processes related to sediment transport, deposition and re-suspension in these basins (Carson and Hudson 1995; NRBS Hydrology Synthesis Report No. 1). Such an understanding is critical in establishing predictive models of contaminant fate and distribution within the basins and provides insight into the temporal/spatial and source/route of exposure and biomagnification of sediment-bound chemical contaminants through the food chain. Since sediments can serve as both sinks and sources of sorbed-contaminants, an important research component of any future sediment monitoring program should involve the bioavailability of contaminants associated with sediments and understanding factors influencing their bioavailability. While sediments might contain high concentrations of toxic compounds, this condition in itself does not lead directly to adverse affects to organisms living in the sediments, nor to those in higher trophic levels feeding upon then.

The fate of contaminants in a sediment-water system is highly dependent on their sorptive behaviour, which in turn affects their bioavailability and toxicity (Burton 1992b). While many factors can influence the bioavailability of contaminants (e.g., temperature, redox, feeding habits, presence of other chemicals, etc.), there are three primary sources/paths for contaminants to reach benthic organisms: (1) through the sediments themselves (e.g., ingestion), (2) uptake from the overlying water, and (3) uptake from the interstitial (pore) water (e.g., across respiratory surfaces and body walls) (Burton 1992a, Figure 6). Thus, a program that examines suspended and

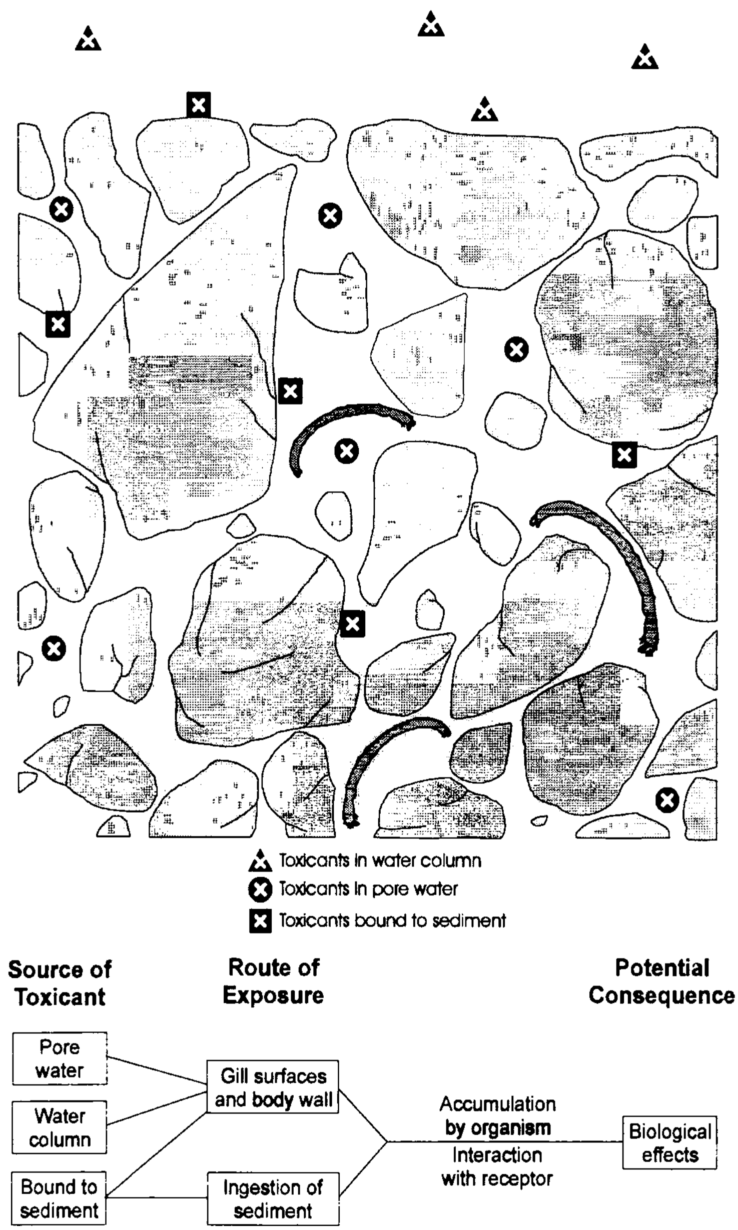

Figure 6. Contaminant Source/Pathways for Benthic Organisms.

deposited sediment and associated contaminant analyses and toxicity bioassays (e.g., TRIAD approach) should be considered on a reach-specific basis.

Contaminant levels in Biota

The NRBS has employed stable isotope techniques in an attempt to elucidate and quantify food web structure within the mainstem of the Athabasca River (NRBS Food Chain Synthesis Report No. 6). This research has allowed NRBS to understand more completely the trophic structure of these ecosystems and as a consequence, potential routes of contaminant exposure and bioaccumulation in macroinvertebrates and fish. As discussed above, semi-permeable membrane samplers further contributed to this understanding by quantifying the bioavailability of water-borne contaminants at selected sights (NRBS Contaminants Synthesis Report No. 2 and 3).

Moreover, NRBS conducted an extensive evaluation of contaminant body burden levels in fish and macroinvertebrates on a reach-specific and basin-wide basis in order to assess trends in contaminant levels in biota and to evaluate the effectiveness of changes in pulp-mill process technologies. Monitoring of this type should be considered on a 3-5 year cycle. General classes of contaminants that warrant continued assessment include; PAHs, PCBs, resin acids, Dioxins, Dibenzofurans, and heavy metals (NRBS Contaminant Synthesis Report No. 3).

Biological/Ecological Responses

Biological/ecological responses indicators describe the condition of the living components of the aquatic ecosystem, and involve assessments at a variety of biological scales (e.g., sub-organism, organism, population, community, and ecosystem). Within the Northern River Basins, monitoring and assessment has traditionally focused on fish and macroinvertebrates. We suggested that these assessments be broadened to include periphyton assemblages as well as semi-aquatic wildlife and vegetation. Each of these are considered in greater detail below.

Fish Assemblages

Although considerable time and effort has been invested by NRBS and others in the collection and analysis of data relating to fish community structure within these basins (NRBS Food Chain Synthesis Report No. 6), there still exist major information gaps, particularly with respect to quantifying fish community structure. One of the primary reasons for this lack of information is related to a historical bias in fish inventory assessments and logistical difficulties associated with comprehensively sampling fish on large rivers. In addition to logistical or practical challenges relating to the adequate sampling of a fish community in large northern rivers, there remains the considerable difficulty of defining what actually constitutes a fish community. In large rivers, such as these fish of certain species may move hundreds of river kilometres in the course of a single year while individuals of other species may live their entire lives within an area of a few square metres. These conditions complicate the delineation of community and the distinction between reference and impact communities. Given the different ecologies, habitat requirements, movement patterns and life-history strategies of the individual species that constitute fish communities within these rivers, it would clearly not be possible to describe fish community structure by sampling a restricted area during a single season. Rather, extensive and intensive sampling would have to occur over a much broader spatial and temporal scale involving long stretches of river and different seasons. If fish community structure were to be used as a biomonitoring tool the precise scale of sampling would have to be determined only after a consideration of the basic ecology of those species comprising the community. Even establishing the appropriate temporal and spatial scale of sampling required to describe adequately the fish community represents a considerable investment of time and effort and would probably be well beyond the scope of most monitoring programs. For these reasons it is recommended that measures of entire fish community structure could not be effectively used as an biomonitoring tool in the northern river basins (Cash *et al.* 1996b). It may be possible to replace measures of the entire fish community with measures of some subset of the same community (e.g., an assemblage of all species caught in a particular size of net, set for a standardized period of time). Movement patterns of species within such a subset may be more consistent and better understood, simplifying data interpretation.

It should be noted that the concerns described above relate to measures of fish community structure only, and need not apply to individuals or populations within that community. Individual- (e.g., growth, fecundity, morphometrics and meristics) and population- (e.g., distribution, age/size-class structure, rate of increase) based measures are commonly used ecological indicators and provide valuable insight into the ecological structure and integrity of riverine systems (Plafkin *et al.* 1989). Less mobile fish species within these communities may provide both reference and impact populations that could be used as effective indicators of anthropogenic impact. Given the constraints and limitations associated with using fish community structure as an indicator of biotic integrity, an alternative more practical approach is to use information on selected fish assemblages. Such an approach could be used to address, through continued monitoring, two general areas of public concern within the northern river basins; 1) the health of "selected" fish assemblages (species) and their critical habitats in these river systems, and 2) how the fishability of "selected" fish species is being impacted by environmental stressors. Fishability in this context refers to a fish assemblage containing fish that are catchable, desirable, and safe to consume by humans and wildlife (Hughes *et al.* 1992). If specific fish assemblages or populations were to be employed in a monitoring program several measures should be used to assess overall assemblage structure, including: (1) reach-specific and basin-wide relative abundance of the targeted species, (2) corresponding size/age-class distributions, (3) general external and internal appearance (condition) and pathology, and (4) contaminant body burden levels.

Fish quality for recreational and subsistence purposes has been identified as important societal values for these river systems (NRBS Other Uses Synthesis Report No. 7; NRBS Traditional Knowledge Synthesis Report No. 12). An assessment of the fish utilization for recreational and subsistence purposes should be continued, particularly in high-use areas (reaches) of the basin as identified by the Other Uses and Traditional Knowledge components. Whenever possible, these metrics should provide information on frequently asked questions - How abundant are game/subsistence fish within these systems? Are the populations reproducing? Is the rate of removal sustainable? Does the external and internal appearance of the fish make then unsuitable for consumption? Are the fish safe to eat?

Updating community concerns over fish quantity will require ongoing, periodic (e.g., 3-5 year cycle) assessments of key metrics such as the presence of external abnormalities and disease, tissue-specific concentrations of contaminants (e.g., heavy metals, persistent bioaccumulating organic toxic substances), associated fish tainting-related problems. Such a monitoring program should provide feedback to the communities on a regular basis regarding on the overall state of the fisheries. One of the ongoing challenges facing the collection of fisheries information will be to design sampling programs that adequately cover the large spatial scales and complexity of habitat conditions present in these basins in a cost/information-effective manner. Based on difficulties identified and recommendations made in the NRBS Food Chain and Contaminants synthesis reports, more attention must be given to the design of fish assessment/monitoring programs to ensure appropriate species, age-classes, sexes and sample sizes are collected for the required analyses. Public participation and local knowledge should always be sought both in the design and collection phases of the work

Finally, more general information is required on the basic ecology of those fish species identified as potential indicators or that are of particular importance to users in the basins. This information includes a further assessment of fish movement patterns (in particular a better understanding of exposure to contaminants), identification of critical fish habitat (overwintering, spawning) and food web relationships.

Benthic Macroinvertebrate Communities

Assessment of changes in benthic macroinvertebrate community structure to assess the overall health of these river basins should be continued. Macroinvertebrates play a significant role in river carbon processing and in the food web, and hence are an important component in explaining potential contaminant pathways and in describing the overall biotic integrity of these systems (Resh and Rosenburg 1989; Resh and Jackson 1993; Rosenburg and Resh 1993; Resh *et al.* 1995). Moreover, in areas of the basins where fish are rare, macroinvertebrates often provide the only information on the potential impacts of environmental stressors on aquatic ecosystem structure and function.

Biological assessments incorporating the use of macroinvertebrates have several advantages (Box 10). Macroinvertebrates are also conducive for use in broader bioassay applications such as artificial stream studies. Such controlled experimental studies provide a more comprehensive assessment of the causal mechanisms responsible for producing observed changes in population- and community-level responses of macroinvertebrates. The Nutrients component of NRBS has effectively used artificial stream studies to obtain a better understanding of: 1) synergistic/antagonistic interactions of nutrients and contaminants from complex pulp-mill effluents on observed upstream-downstream changes in macroinvertebrate community structure; 2) cumulative effects of low dissolved oxygen

Box 10. Advantages of assessing benthic macroinvertebrate assemblages in environmental monitoring (after Rosenberg & Resh 1993, Resh *et al.* 1995).

1. Integrate environmental conditions over time, rather than instantaneous measures due to relative sedentary nature.
2. Integrate the effects of multiple stressors - provide information on cumulative impacts.
3. Can provide an early warning of chronic and acute ecological effects - responses of many species to different types of pollution established.
4. Are important components in the aquatic food chain and are a vital link to bioaccumulation pathways of persistent organic contaminants and heavy metals.
5. Can be quantitatively sampled and assessed in a cost/information effective manner.
6. Many methods have been developed to analyze/interpret population / community level responses.

levels and nutrient-contaminant interactions on macroinvertebrate feeding, growth and survivorship; and 3) dose-response relationships between macroinvertebrate standing crop and species richness to pulp-mill effluent loadings (NRBS Nutrients Synthesis Reports No. 4 and 5). Culp *et al.* (1996) provides a useful framework to follow utility and application of macroinvertebrate artificial stream studies in future monitoring and assessment programs.

In addition to measuring and assessing changes in community structure, other studies within the NRBS have evaluated the potential application of the sediment-quality TRIAD analysis (Day and Reynoldson 1995) and chironomid deformities (Warwick 1995). The TRIAD concept, described in detail by Chapman (1986), comprises an effects-based approach to describing sediment quality and incorporates measures of sediment chemistry, sediment toxicity tests using benthic fauna, and observations of benthic macroinvertebrate community structure. In general, few sediment toxicity effects were observed in the NRBS samples, however, the TRIAD approach should be considered for future application in an integrated monitoring plan for these basins. The chironomid deformity assessment showed increases in the relative frequency of morphological abnormalities of certain taxa immediately downstream from the Hinton pulp-mill effluent discharge. The frequency of these abnormalities then decrease increasing river distance from Hinton and returned to levels observed at reference sites. While this study illustrates the potential for using macroinvertebrate-deformities as an early-warning biomonitoring tool, further refinement and validation of this technique is required before it can be considered for routine application in an integrated monitoring program.

Periphyton Assemblages

The measurement of the periphyton (benthic algal) assemblage should be used as an ecological indicator in the Northern River Basins. Measures of algal biomass, production and chlorophyll-*a* have several properties that make them useful ecological measures. For instance, periphyton assemblages are highly responsive to natural disturbance and to point- and non-point source nutrient additions, react both numerically and functionally to contaminant-related stresses, recover quickly from stresses, are ubiquitous and are easily sampled (Grimm and Fisher 1989; Steinman and McIntire 1990). In addition, primary producers are important in the transfer of nutrients and energy to many constituents of the aquatic food web, including benthic macroinvertebrates, fish larvae, and even adult fish (Patrick 1994).

Within the Nutrients Component of NRBS, several findings and recommendations have emerged regarding the incorporation of periphyton monitoring. For example, it has been recommended that effluent permits for municipal sewage and pulp-mill discharges be should be assessed and based on environmental endpoints (e.g., downstream levels of periphyton biomass) rather than technology design standards. This recommendation requires a proper reach-specific and basin-design for periphyton sampling to be developed.

The assessment of periphyton assemblage responses on nutrient-diffusing substrates have also provided important insight into the types of nutrient limitations occurring on a reach-specific and basin-wide basis in the study basin area (Figure 7). The integration of this type of *in situ* bioassay approach into a future

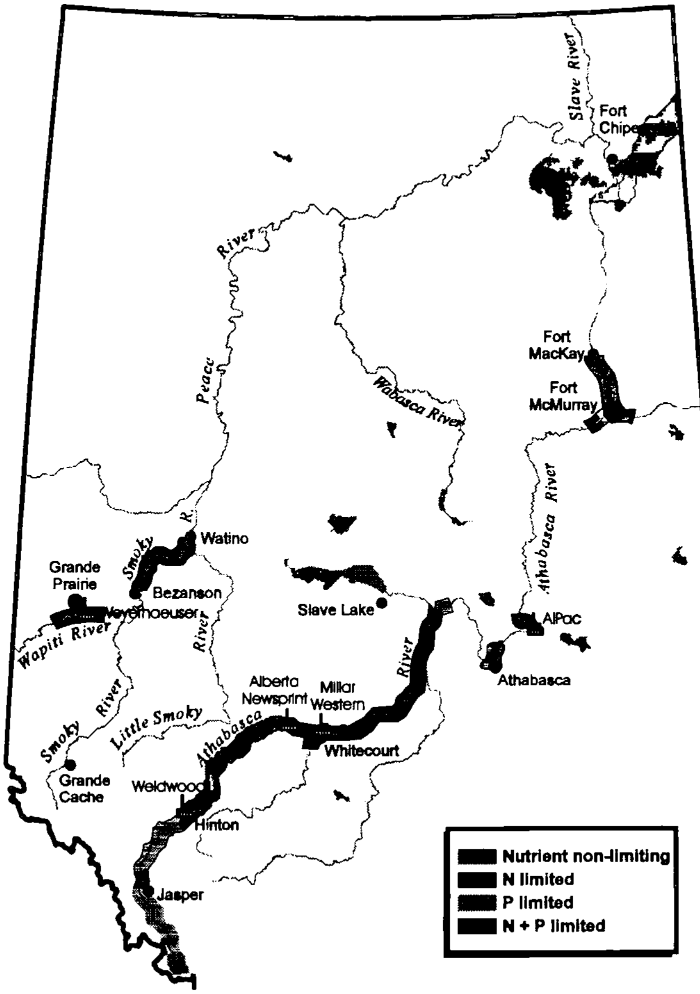

Figure 7. Nutrient Limitation Within the NRBS.

monitoring program will allow for a cost-effective assessment of patterns of nutrient limitations within the basins and also serve to test the adequacy of existing control (regulatory) guidelines in limiting the degree of eutrophication in these basins.

<u>Semi-aquatic, Riparian Wildlife and Vegetation Assemblages</u>

Only a limited number of NRBS technical studies addressed issues associated with monitoring of semi-aquatic and riparian wildlife and vegetation in the northern river basins and this is an area deserving of further attention. From a contaminants perspective, no major concerns were evident in terms of tissue body burden levels of persistent organic contaminants and heavy metals of sampled wildlife (e.g., mergansers, muskrats, mink). However these conclusions were based on small sample sizes and collections of very limited geographic range.

As highlighted in the Traditional Knowledge and Other Uses surveys, many semi-aquatic species are important recreationally (e.g., for hunting or as "watchable" wildlife), or are used for subsistence purposes (e.g., ducks, geese, muskrat, moose). Moreover, increased rates of successional changes in riparian vegetation and habitat are particularly evident in the downstream regions of the basins (e.g., lower Peace River, Peace-Athabasca-Delta, Slave River Delta) (NRBS Hydrology Synthesis Report No. 1). Given these observed changes and the associated degree of public concern on these issues, a monitoring and assessment framework should be developed to assess and predict future changes in riparian and delta wildlife, vegetation and habitat in these habitats.

3.1.4 Actual and Potential Indicators in the Northern River Basins

Having discussed in a general way, issues relating to stressors, exposure and response within these basins we now turn to a more detailed examination of the major indicator types currently being employed in the northern river basins and those potential indicators developed by the NRBS. To facilitate this examination, monitoring efforts are divided according to their spatial scale. In other words monitoring at point source (i.e., discharge), regional (i.e., reach specific) and basin-wide scales. Within each level of spatial scale indicators are identified as to their relationship to ecosystem health (Figures 8, 9 and 10) as well as the type of information provided, the current status of the indicator (required by AEP regulations, subject of NRBS research) and the particular NRBS Synthesis Report that discusses the indicator in more detail (Tables 7, 8 and 9).

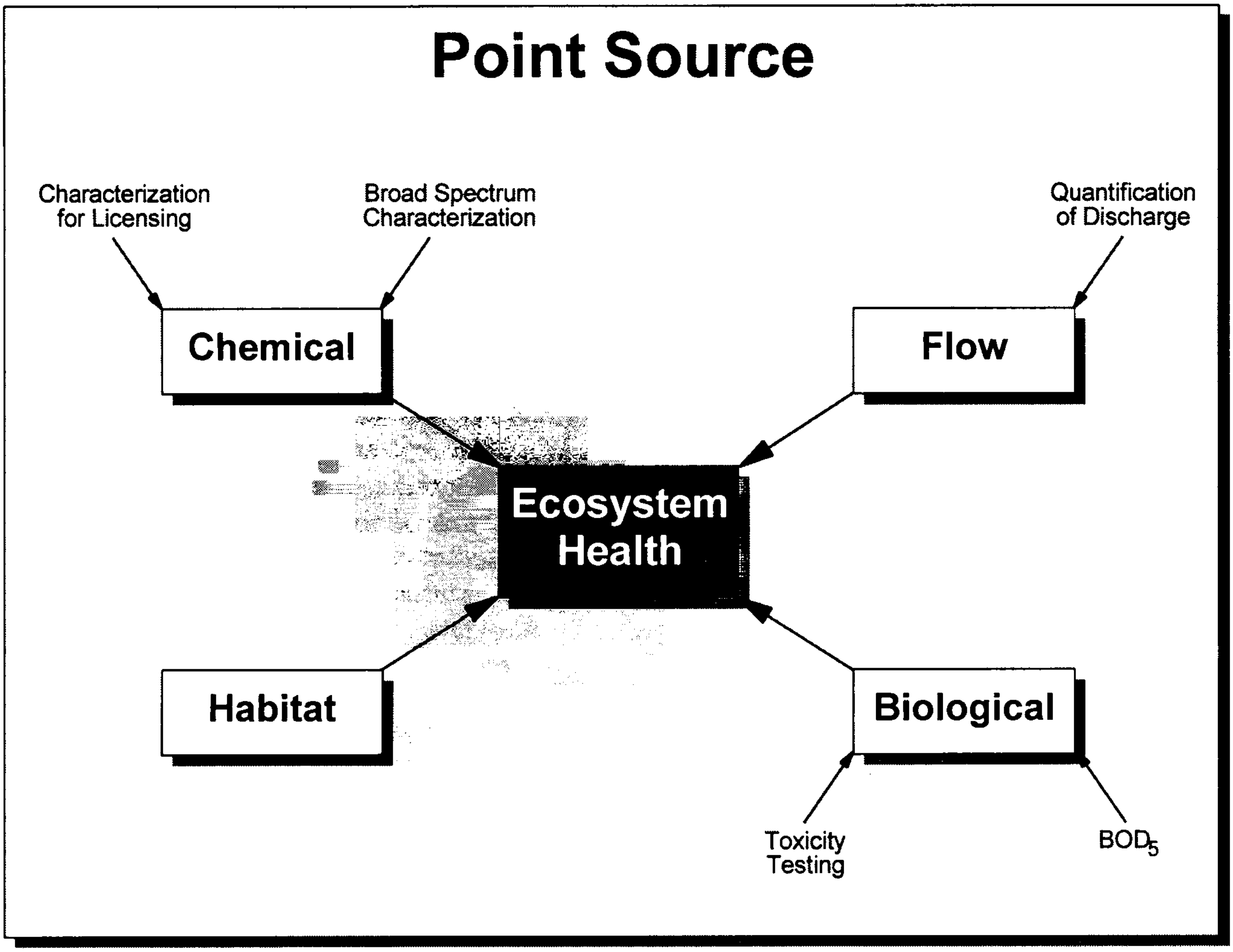

Figure 8. Point Source Determinants of Ecosystem Health.

Table 7. Types of Indicators, Information Provided and Current Status at the Point Source Scale.

	TYPE	INDICATOR	INFORMATION PROVIDED	STATUS	SOURCE (SYNTHESIS REPORT)
CHEMICAL	Pulp Mill	Characterization for licensing	Early Warning	Ongoing Monitoring†,‡	3
		Broad spectrum characterization of effluents	Early Warning Trend Analysis	NRBS Research	3
	Other Industry	Characterization for licensing	Early Warning	Ongoing Monitoring†	3
		Broad spectrum characterization of effluents	Early Warning	NRBS Research	3
	Municipality	Characterization for licensing	Early Warning	Ongoing Monitoring†	3
BIOLOGICAL	Pulp Mill		Early Warning	Ongoing Monitoring†	2,10
		BOD_5, Suspended Solids	Early Warning Trend Analysis	Ongoing Monitoring†,‡	3,10
	Other Industry	Acute/chronic toxicity tests (fish, macroinvertebrates)	Early Warning	Ongoing Monitoring†	2
	Municipality	Acute/chronic toxicity tests (fish, macroinvertebrates)	Early Warning	Ongoing Monitoring†	2
		BOD_5, Suspended Solids	Early Warning Trend Analysis	Ongoing Monitoring†	3,10
FLOW	Pulp Mill	Quantification of discharge	Early Warning	Ongoing Monitoring†,‡	3,4
	Other Industry	Quantification of discharge	Early Warning	Ongoing Monitoring†	3,10
	Municipality	Quantification of discharge	Early Warning	NRBS Research	4
HABITAT					

† under the supervision of Alberta Environmental Protection
‡ required under Environmental Effects Monitoring Legislation
* monitoring performed by municipality

2 NRBS Contaminants Synthesis Report No. 2
3 NRBS Contaminants Synthesis Report No. 3
4 NRBS Nutrients Synthesis Report No. 4
7 NRBS Synthesis and Modelling Synthesis Report No. 10

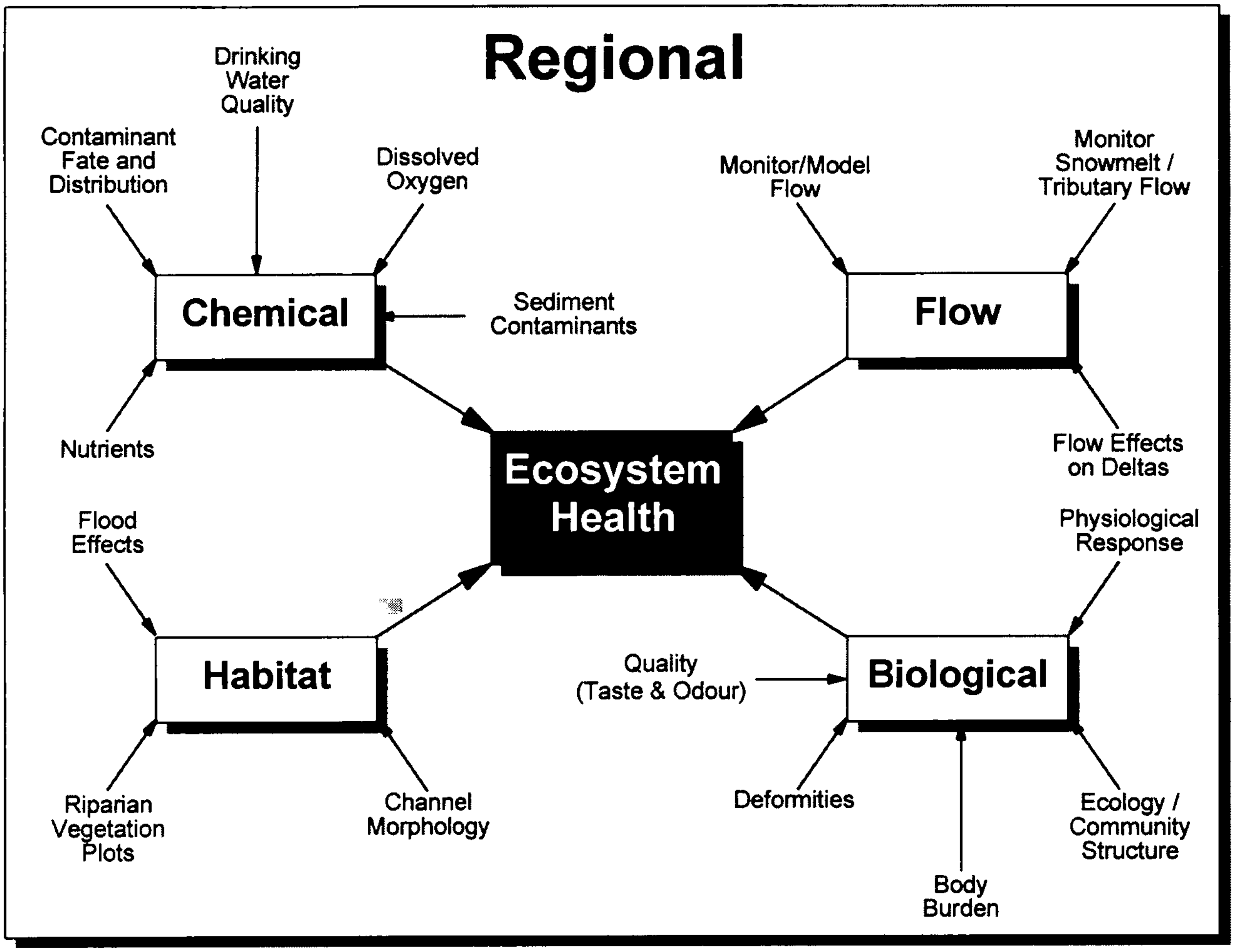

Figure 9. Regional Determinants of Ecosystem Health.

Table 8. Types of Indicators, Information Provided and Current Status at a Regional Scale.

	INDICATOR	INFORMATION SOUGHT	STATUS	SOURCE (SYNTHESIS REPORT)
CHEMICAL	Broad spectrum analysis to identify potential drinking water contaminants	Early Warning Human Health	NRBS Research	9
	Model fate and distribution of suspended sediment/contaminant	Trend Analysis Ecosystem State	NRBS/AEP Research	1,11
	Monitor suspended / depositional sediment in river main stems	Trend Analysis Ecosystem State	NRBS Research	3
	Monitor suspended / depositional sediment in lakes and PAD sediment	Trend Analysis Ecosystem State	NRBS Research	1,3
	Contaminant fate model - TOXIWASP	Early Warning Trend Analysis	NRBS Research	3,11
	Development / improvement of DO modelling capabilities - DOSTOC, WASP	Early Warning Trend Analysis	NRBS/AEP Research	5,11

	INDICATOR	INFORMATION SOUGHT	STATUS	SOURCE (SYNTHESIS REPORT)
CHEMICAL (continued)	Field monitoring of water column contaminants	Trend Analysis	AEP Research	3
	Water column nutrient levels	Trend Analysis	NRBS/AEP Research	4
	Nutrient diffusing substrates / periphyton	Trend Analysis Ecosystem State	NRBS Research	4
BIOLOGICAL	Physiological stress (MFO/EROD, sex steroid, condition, retinol, metallothionein) of consumptive fish species (Burbot, White Sucker, Mountain Whitefish, Northern Pike)	Early Warning Trend Analysis	NRBS Research, EEM	2,10
	Physiological stress (MFO/EROD, sex steroid, condition) of small non-consumptive fish	Early Warning Trend Analysis	NRBS Research, EEM	2,10
	Body burden - macroinvertebrates, fish, mammals, birds (OCs, PAHs, TCDD, TCDF, CPH, PCBs, metals, resin acids)	Early Warning Human Health Trend Analysis Ecosystem State	NRBS/AEP Research	3,10
	External/internal abnormalities (macroinvertebrate, fish, mammals, birds)	Early Warning Trend Analysis Aesthetic Values	NRBS Research, EEM	2,6,10
	Reach specific fish assemblage assessment; species composition, relative abundance, movement, critical habitat identification	Trend Analysis Ecosystem State	NRBS/AEP Research	6
	Fish tainting development of protocol for taste panel	Human Health Aesthetic Values	NRBS Research	6,7,9,12
	Membrane (SPMD) bioassays	Early Warning Trend Analysis	NRBS Research, EEM	3,10
	Multivariate benthic community analysis	Early Warning Trend Analysis Ecosystem State	NRBS/AEP Research, EEM	4,10
	Sediment toxicology - TRIAD approach	Early Warning Trend Analysis	NRBS Research	10
	Stable isotope food web analysis	Trend Analysis Ecosystem State	NRBS Research	6
	Water taste and odour assessments Athabasca, Peace Slave river basins	Human Health Aesthetic Values	NRBS Research	6,7,9,12

	INDICATOR	INFORMATION SOUGHT	STATUS	SOURCE (SYNTHESIS REPORT)
FLOW	Monitor representative flow discharge, depth and velocity	Early Warning Trend Analysis Ecosystem State	NRBS/AEP/NWT Research and Monitoring	1
	Monitor snowmelt and tributary flow	Early Warning Trend Analysis Ecosystem State	NRBS Research	1
	Model flow discharge, depth and velocity	Trend Analysis Ecosystem State	NRBS Research	1
	Spatial and temporal effects of flow on delta areas	Trend Analysis Ecosystem State	NRBS Research	1
	Remote sensing of flow-habitat interactions	Trend Analysis Ecosystem State	NRBS Research	1
HABITAT	Permanent vegetation plots Peace R., PAD	Trend Analysis Ecosystem State	NRBS Research	1
	Linkages between flow regimes and changing channel morphology and associated riparian vegetation - historical and contemporary	Trend Analysis Ecosystem State	NRBS Research	1
	Peace, Slave R., PAD riparian vegetation - landform and distributary sensitivities; satellite imagery of flooding extent	Trend Analysis Ecosystem State	NRBS Research	1

1 NRBS Hydraulics/Hydrology Synthesis Report No. 1
2 NRBS Contaminants Synthesis Report No. 2
3 NRBS Contaminants Synthesis Report No. 3
4 NRBS Nutrients Synthesis Report No. 4
5 NRBS Nutrient Synthesis Report No. 5
6 NRBS Food Chain Synthesis Report No. 6
7 NRBS Other River Uses Synthesis Report No. 7
9 NRBS Drinking Water Synthesis Report No. 9
10 NRBS Synthesis and Modelling Synthesis Report No. 10
11 MacCauley 1996
12 NRBS Traditional Knowledge Synthesis Report No. 12

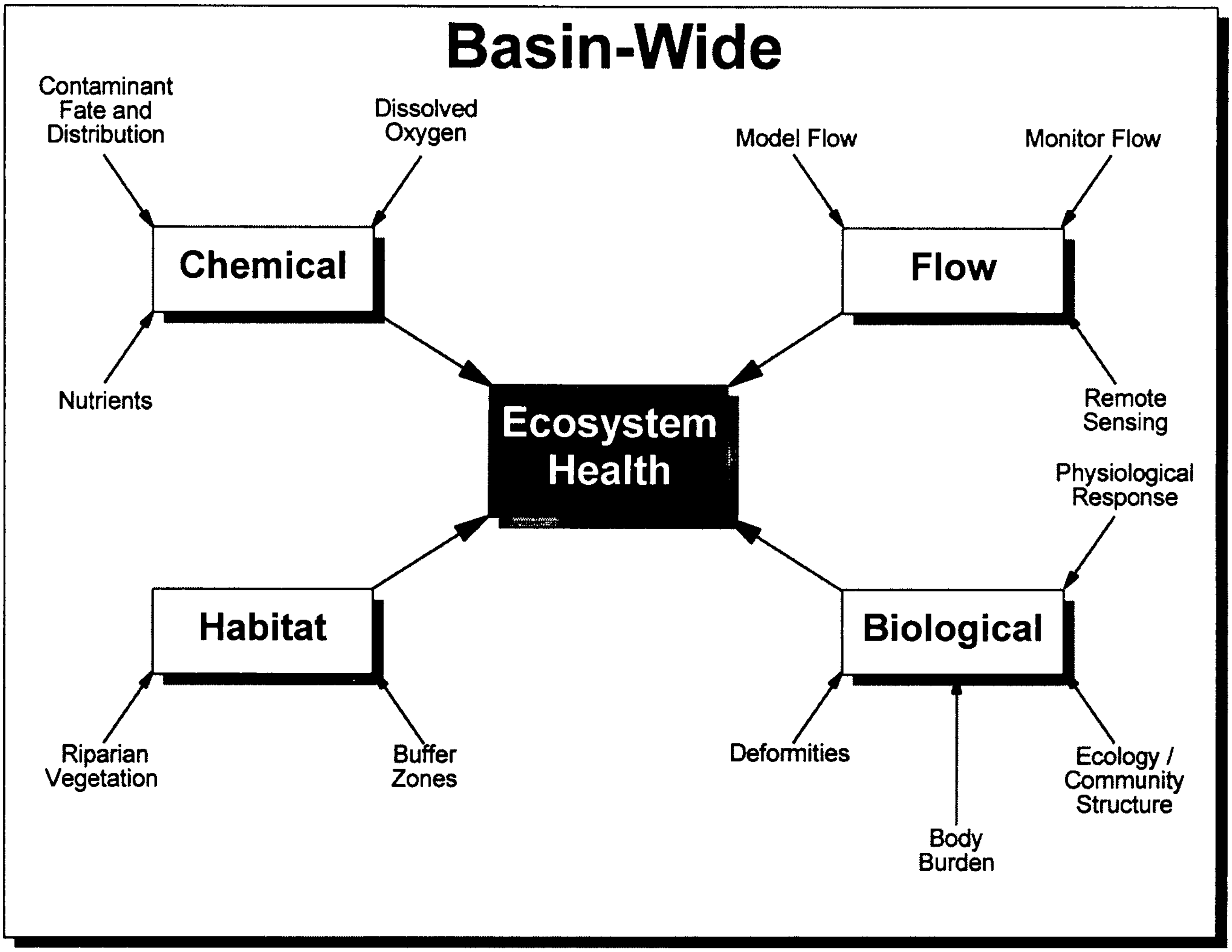

Figure 10. Basin-Wide Determinants of Ecosystem Health.

Table 9. Types of Indicators, Information Provided and Current Status at a Basin Scale.

	INDICATOR	INFORMATION PROVIDED	CURRENT STATUS	SOURCE (SYNTHESIS REPORT)
CHEMICAL	Model fate and distribution of suspended sediment/contaminant	Trend Analysis Ecosystem State	NRBS/AEP Research	1,3
	Contaminant fate model - TOXIWASP	Early Warning Trend Analysis	NRBS Research	3,11
	Development / improvement of DO modelling capabilities - DOSTOC, WASP	Early Warning Trend Analysis	NRBS/AEP Research	5,11
	Field monitoring of water column, SOD	Trend Analysis Ecosystem State	AEP Research	3,4
	Water column nutrient levels	Trend Analysis	NRBS/AEP Research	4
	Nutrient diffusing substrates / periphyton	Trend Analysis Ecosystem State	NRBS Research	4
BIOLOGICAL	Physiological stress (MFO/EROD, sex steroid, condition, retinol, metallothionein) of Burbot	Early Warning Trend Analysis	NRBS Research, EEM	2,10
	Body burden - Fish OCs, PAHs, TCDD, TCDF, CPH, PCBs, metals, resin acids	Early Warning Human Health Trend Analysis Ecosystem State	NRBS/AEP Research	2,10
	External/internal abnormalities - basin wide fish collections	Early Warning Human Health Aesthetic Values Trend Analysis	NRBS/AEP Research	2,6,10
	Basin-wide fish community assessment; species composition, relative abundance, movement, critical habitat identification	Trend Analysis Ecosystem State	NRBS/AEP Research	6
	Multivariate benthic community analysis	Early Warning Trend Analysis Ecosystem State	NRBS/AEP Research, EEM	4,10
	Stable isotope food web analysis	Trend Analysis Ecosystem State	NRBS Research	6
	Water taste and odour assessments AthabascaPeace Slave river basins	Human Health Aesthetic Values	NRBS Research	6,7,9,12

	INDICATOR	INFORMATION PROVIDED	CURRENT STATUS	SOURCE (SYNTHESIS REPORT)
FLOW	Monitor representative flow discharge, depth and velocity	Early Warning Trend Analysis Ecosystem State	NRBS/AEP/ NWT Research and Monitoring	1
	Model flow discharge, depth and velocity	Trend Analysis Ecosystem State	NRBS Research	1
	Remote sensing of flow-habitat interactions	Trend Analysis Ecosystem State	NRBS Research	1
HABITAT	Buffer zones/forestry clear cutting practices - implications for aquatic and riparian communities	Trend Analysis Ecosystem State	NRBS Research	1,10
	Riparian vegetation response modelling	Trend Analysis Ecosystem State	NRBS Research	1,10

1 NRBS Hydraulics/Hydrology Synthesis Report No. 1
2 NRBS Contaminants Synthesis Report No. 2
3 NRBS Contaminants Synthesis Report No. 3
4 NRBS Nutrients Synthesis Report No. 4
5 NRBS Nutrient Synthesis Report No. 5
6 NRBS Food Chain Synthesis Report No. 6
7 NRBS Other River Uses Synthesis Report No. 7
9 NRBS Drinking Water Synthesis Report No. 9
10 NRBS Synthesis and Modelling Synthesis Report No. 10
11 MacCauley 1996
12 NRBS Traditional Knowledge Synthesis Report No. 12

It is important to note that the some of the indicators of ecosystem health change as a function of spatial scale while others are relevant at more than one scale. Furthermore, although indicators are presented as a function of their relevant spatial scale, integration across these scales is essential to an adequate assessment of ecosystem health. Finally, in many cases individual indicators are relevant to two or more synthesis reports, demonstrating the integrated nature of many useful indicators.

3.1.5 Potential Integrated Ecosystem Monitoring (IEM) Implementation Strategy

This report has outlined factors requiring consideration in the development of a scientifically valid integrated ecosystem monitoring program. Unless an effort is made by all monitoring authorities to participate in such an endeavour, science planning will not be able to overcome the challenges discussed previously. A strategy, process and administrative structure is required that will facilitate bringing the interested parties (including all governments, industry and the public) to the same table where:

1) Societal values can be incorporated into the development and refinement of ecosystem indicators and ecosystem management objectives.
2) Agency monitoring can be reviewed and tested against science principles.
3) Parties can jointly set monitoring priorities, strategies, and implementation plans to guide those who are responsible for monitoring, regulation, environmental protection and remediation.
4) Public reporting (annually) of monitoring results improve accountability.
5) Consideration of monitoring results can be undertaken and assessed against the ecosystem goals and management objectives.
6) Opportunities for cooperation and improved coordination in ecosystem monitoring can be investigated and pursued in the interests of maintaining sustainable ecosystems;

Other than recognizing that there exist several options for an administrative structure (e.g. committee, forum, council, etc.), we have not undertaken any review of the structural options for implementing IEM. Regardless of the chosen option, the intent remains the same, as do the benefits derived from members working together towards the common ecosystem goals and objectives.

Implementation of IEM should include communitiy participation. Communities in these basins have stressed that they want to be involved in environmental management and IEM presents two opportunities for such involvement. First, the IEM committee should include representatives from the community sector. Second, consideration should be given to incorporating volunteers within the notion of community-based monitoring.

Community-based monitoring is an increasingly popular method by which local groups can more actively participate in the monitoring and management of their local resources (O'Neill *et al.* 1992; Penrose and Call 1995). These programs allow local stakeholders to be involved in all aspects of the monitoring program from the setting of objectives, through field monitoring of the system and the interpretation of the collected data (Maas *et al.* 1991; Firehook and West 1995). In addition they allow the stakeholders to become more aware of, and involved in, local water quality issues, and can offer considerable financial savings to governments.

Box 11. Potential key duties of an IEM Committee.

- Maintain awareness (inventory) of basins' issues, monitoring and research
- Clarify for the public the roles and responsibilities of monitoring agencies, and other issues
- Review and evaluate the opportunities for improved consolidation, efficiency and effectiveness in the basins' monitoring and research
- Coordinate the development, adoption and implementation of a volunteer program, standardized protocols for design, collection, testing and data reporting, handling and storage, quality assurance, etc.
- Annually report to governments, public and stakeholders about basins' monitoring and research
- Review, assess and develop recommendations to provide guidance to monitoring and regulatory agencies concerning the consequences of monitoring findings
- Integrate science, public, governments' and other stakeholder points of view concerning priorities, findings, and actions required

A potential for initiating community-based monitoring in the northern river basins is in the area of assessing macroinvertebrate community structure. Local citizens groups throughout North America have begun to monitor their local water quality using invertebrate community structure (e.g. Fisheries and Oceans "Stream keepers Program" and the Tennessee Valley Authority's "River Pulse", and the Save Our Streams Program in the United States). These programs tend to focus on the monitoring of small streams and rely on a relatively large number of volunteers. In contrast, the northern river basins human populations tend to be small and widely dispersed and the logistical challenges of working in the mainstem of large northern rivers are considerable. However, it should be possible to modify existing programs to perform on these large systems and their tributaries, particularly on a local or regional scale. The opportunity to engage volunteers represents an important opportunity to monitor these systems in a more holistic fashion. In order to ensure quality control of sampling methods employed and the resulting data collected, an education and ongoing training program should be developed.

With the conclusion of the official mandate of NRBS, the time has arrived for initiating a formal IEM process and to wait, will almost certainly erode the apparent will of the parties to cooperate in IEM exercise. It is not our vision that this IEM Committee would have any authorities that extend beyond the functions shown in Box 11. Although the need is for broader consideration integrating full ecosystem monitoring, immediate priority should be placed on aquatic issues, especially as related to aquatic ecosystem health, water quality and effluents where benefits can be realized at little effort and cost. It is therefore proposed that implementation of the IEM strategy be undertaken with the first two years focussing almost exclusively on establishing ecosystem goals, management objectives and indicators, and getting the aquatic monitoring situation rectified.

3.2 Assessment

3.2.1 Cumulative Effects Assessment

A principal recommendation of the 1990 Alberta-Pacific Environmental Impact Assessment Hearings dealt with the importance of assessing cumulative environmental impacts. The ALPAC review Board concluded; " *Due to the critical nature of the river to downstream and other users, and the roles played by different jurisdictions in managing the Athabasca-Peace-Slave River system, the Review Board believes the scientific work [vis-a-vis cumulative effects] should be under the broad direction of a management team with representation from all major stakeholders.* " This recommendation formed the underlying basis for the formation of the multi-stakeholder NRBS Study Board and established the foundation for the assessment of cumulative environmental effects within the NRBS.

The 25 member Study Board formulated two questions that focused specifically on the assessment of cumulative environmental effects in the Athabasca-Peace-Slave river systems (Box 12). In doing so, the NRBS Study Board implicitly recognized that an "ecosystem-approach" was necessary to identify, understand and predict the combined effects of all multiple, anthropogenic stressors that affect the health of these northern

Box 12. NRBS Board questions concerned with cumulative effects assessment.

13a.
What predictive tools are required to determine the cumulative effects of man-made discharges on the water and aquatic environment?

13b.
What are the cumulative effects of man-made discharges on the water and aquatic environment?

rivers. In addition, through the formulation of questions 13a,b, the Board explicitly recognized major shortcomings associated with conventional environmental impact assessment (EIA) studies.

Conventional EIAs are conducted under relatively short time frames that are usually dictated by a project's life-cycle, although the primary emphasis is most often on the pre-startup and implementation phases of the proposed development. Moreover, the spatial boundaries of such EIAs are typically confined to local geographic scales that are defined by the type of project or the jurisdictional requirements for approval. Consequently, such limited temporal and spatial dimensions generally narrow the degree of a conventional EIA to: 1) consideration of only a single perturbation (e.g., the effect of a specific point-source effluent); 2) assessment of only simple cause-effect relationships, first-order impacts and immediate effects; 3) a focus only on specific environmental attributes (e.g., measure only the concentration of dioxins/furans or other related persistent organochlorine compounds discharged by the proposed pulp-mill); and, perform the assessment within an extremely narrow geographic context (e.g., the immediate vicinity of the proposed development) (Spaling and Smit 1993). Because of the limitations inherent in most traditional EIAs, they overlook environmental change and impacts involving multiple perturbations (both natural and anthropogenic), complex causation for observed ecological responses (e.g., additive and synergistic impacts), higher-order impacts and interacting processes, time-lags, and extended spatial boundaries (Beanlands and Duinker 1983; Bedford and Preston 1988; Clark 1986; Spaling and Smit 1993; Dixon and Montz 1995). The importance of assessing cumulative effects in the EIA process has been more recently reaffirmed in the Canadian Environmental Assessment Act (CEAA) (Bill C-13) (FEARO 1993) and in the revised Alberta Environmental Protection and Enhancement Act (AEPEA) (Alberta Environmental Protection 1993).

NRBS Cumulative Assessment Framework

As outlined above, there is a need to identify the combined effects of multiple and diverse stressors on the aquatic ecosystems. Within the biophysical region of these basins several classes of cumulative environmental impacts are likely occurring. Given the range of point- and non-point anthropogenic stressors influencing these ecosystems, there was an explicit recognition of the complex and dynamic nature of the pathways contributing to observed cumulative environmental change. Hence, the factoring of various levels of ecological complexity occurring within the northern river basins, the identification of appropriate indicators and endpoints to assess direct and cumulative effects, and designing the science program in the context of addressing the range of societal concerns and research priorities in the various parts of the basin (NRBS Other Uses Synthesis Report No. 7, Wrona *et al.* 1996) presented unique challenges within the NRBS.

Box 13. Common components of cumulative effects assessment frameworks (after Spaling & Smit 1993).

1. **Perturbations/Causality** - identifying naturally occurring events, or human-induced actions, over time and space which contribute to cumulative environmental change.
2. **Ecosystem Structure and Processes** - understanding how the receiving ecological, economic, and/or social systems are affected by the perturbations, and the temporal and spatial processes influencing ecosystem response or recovery.
3. **Predicting Effects** - predicting the change in an ecosystem's (or other level of ecological organization) structure and functioning over time and space.

Numerous conceptual frameworks and approaches have been proposed to assess cumulative environmental change (e.g., Cline *et al.* 1983; Horak *et al.* 1983; Beanlands 1986; Baskerville 1986; Peterson *et al.* 1987; Sonntag *et al.* 1987; Lane *et al.* 1988; Constant and Wiggins 1991; Cocklin *et al.* 1992a,b). Although each approach has unique characteristics, all share three common components concerned with; 1) the identification of the potential cause(s), 2) understanding how ecosystem structure and process(es) are influenced, and 3) developing the capability to predict future effects (Box 13). The design of the overall science program in the NRBS was framed to provide insights into each of these components of cumulative effects assessment.

Interpretation of Cumulative Effects

An assessment of cumulative environmental impacts occurring within the NRBS is provided by Wrona *et al.* (1996). This assessment builds on the framework proposed by CEARC and NRC (1986), which differentiates cumulative effects on the basis of specific temporal and spatial attributes. This framework, subsequently expanded by Sonntag *et al.* (1987) and CEARC (1988), identifies eight general classes of cumulative effects (Table 10).

Table 10. Classes of Potential Cumulative Impacts. (after CEARC 1988)

Type of Cumulative Impact	Characteristics	Example
1) Time Crowding	Frequent / repetitive environmental change exceeds the capacity for the system to assimilate or recover from that change	Forest harvesting rates exceed stock regeneration time
2) Space Crowding	Higher density of environmental change alters spatial pattern or processes	Habitat fragmentation, convergence and merging of multiple contaminant plumes
3) Synergism	Two or more environmental changes contribute to another environmental change	Various pesticides combine to produce a different toxic compound
4) Time lags	Delays observed between exposure to a stress or perturbation and the response	Long-term exposure necessary before observed effects manifested
5) Space lags	Environmental change appears at some distance from the source(s)	Long-range aerial transport of contaminants
6) Triggers / Thresholds	Critical levels reached that results in a disruption / change in system behaviour	Reduction of "keystone species" below critical threshold
7) Indirect / Higher Order	Environmental changes produced by a complex pathway	Construction of a reservoir affects mercury bioavailability and measured body burdens in biota
8) Nibbling or Patchiness	Effects are incremental or decremental forms that involve one of the above categories	Incremental effects of small-scale cut-blocks on regional habitat quantity / quality

While this framework mixes typological criteria (Cocklin *et al.* 1992a,b) it provides a useful classification of the types of cumulative effects that could manifest themselves within the context of these basins. Cumulative effects assessment within the NRBS occurred in light of the above framework although the NRBS viewed cumulative effects assessment primarily as a scientific information-gathering activity in the context of a research program that recognized multiple causation, complex inter-relationships and temporally and spatially variable effects (Box 14).

Box 14. Key features of the cumulative effects assessment approach implemented by the NRBS.

- Cumulative effects philosophy allowed for the identification of potential anthropogenic impacts/problems in the Basins area.
- Knowledge gaps and data deficiencies were identified.
- Critical linkages and societal priorities/concerns were identified.
- Reinforced the requirement to adopt an "ecosystem - approach" to future Basin research/monitoring programs.
- Process identified and tested new endpoints and biological/ecological indicators of cumulative effects.

An important factor complicating the assessment of cumulative effects within the northern river basins study is that environmental perturbations/impacts within these basins have not remained constant in time or space. For instance, since the initiation of the NRBS in 1991, several key changes occurred with respect to upgrades in process technology of three of four pulp-mills situated on the Athabasca River. Specifically, in 1993 the Weldwood Mill in Hinton changed its bleaching process from elemental chlorine to 100% chlorine dioxide substitution. The Alberta Newsprint mill at Whitecourt had a significant operational change in 1992 that also involved moving to 100% chlorine dioxide substitution. Finally, the Alberta-Pacific mill went into full production in 1993, thereby altering the total pulp-mill related loadings into the Athabasca River. Cumulatively, such changes are predicted to have a significant effect in reducing measured levels of dioxins/furans and other associated organochlorine contaminants in downstream components of the environment and in the food chain. Both the Science Advisory Committee and the Science Component groups recognized that in order to understand the potential cumulative impacts from such changes, it was necessary to develop a mechanistic understanding of how the physical, chemical, biological and ecological processes are related and interact in these large northern river systems. A more detailed analysis of cumulative anthropogenic effects in these basins is presented in (Wrona *et al.* 1996).

A final factor relating to cumulative effects assessment involves the communication of results to stakeholders and decision-makers. In turn, these groups will use the information to make more rationale decisions regarding the adequacy of existing environmental guidelines and regulations that are in place to protect and conserve the environment and to provide a scientific basis to assess how future developments would impact these ecosystems. In addition, feedback would be provided into the design of future monitoring/assessment programs taking into consideration stakeholder concerns and priorities. The NRBS Study Board will play an important role in this regard. Through its recommendations on Question 16, the Study Board will identify both the processes and jurisdictional mechanisms that could be used to assess these results in light of other economic and social considerations/objectives for these river basins.

3.2.2 Ecological Risk Assessment

Introduction

Closely related to issues of cumulative environmental effects is the area of ecological risk (the probability of an undesired event) assessment. Ecological risk assessment can be thought of as an estimate of the consequences of human activity on the ecology of an ecosystem but precise definitions of this process vary considerably (Cairns 1995).

Suter (1993b, pg. 499) defines ecological risk assessment as "the process of defining and quantifying risks to nonhuman biota and determining the acceptability of those risks." He further defines risk analysis as "determination of the probability and magnitude of adverse effects of environmental hazards (chemical, physical, or biological agents occurring in or mediated by the ambient environment) on nonhuman biota". Within this paradigm, stress is placed on obtaining an accurate and quantitative probability measure of an undesired event (risk) and to use that measure to compare and prioritize risks. In other words, the objective of this approach is to provide quantitative and predictive measures of ecological risk associated with anthropogenic activity. An example of such an approach within the Northern River Basins might be determining the probability that an increase in effluent discharge from a particular point source would result in an agreed upon undesirable event (e.g. the elimination of a particular fish species). It is also interesting to note that this definition specifically excludes risks to human health produced by anthropogenic activity and is thus distinguished from environmental risk assessment which considers risks to both human and nonhuman biota.

Suter (1993b) further distinguishes between projects or programs that attempt predict the impact of new or proposed developments (predictive ecological risk assessment) and those that seek to evaluate the historical and current impacts of past activities (retrospective ecological risk assessment). Retrospective ecological risk assessment has been of more direct concern to the NRBS (i.e., what have been the effects of development on the Northern River Basins) and will be discussed in more detail below.

In contrast to Suter's rather explicit definition other researchers have defined ecological risk assessment so broadly as to include all activities that evaluate the potential ecological consequences of proposed human activity or assess current ecological condition in systems impacted by such activity (US Environmental Protection Agency 1991; Cairns 1995). As discussed by Cairns (1995) the distinction between these two approaches rests primarily with the fact that the first approach is undertaken primarily by scientists seeking to quantify explicitly risk in order to provide information to the management and regulatory process whereas the second approach is a more broad-based activity engaged in by scientists, monitoring agencies and members of the general public and can involve less quantitative measures of risk. In both cases, the success of ecological risk assessment will be largely constrained by the quality and quantity of available information required to determine risk (Messer 1992; Suter 1993b).

Ecological Risk Assessment Within the NRBS

As discussed above, retrospective ecological risk assessment is of particular importance within the NRBS and is consistent with the studies objective of determining what the effects of anthropogenic activity within these basins has been. Figure 11 illustrates the process of retrospective ecological risk assessment as defined by Suter (1993b). Although the remainder of this section will follow Suter's model, other approaches to ecological risk assessment (e.g., US Environmental Protection Agency 1991; Lipton *et al* 1993; Solomon *et al.* 1993; UK Government/Industry Working Group 1995) all contain these same basic elements. The process of ecological risk assessment can be divided into four basic steps (Box 15).

The first step is one of hazard definition (Figure 11). This process involves an explicit elaboration of the reason(s) for, and goal(s) of, the ecological risk assessment. In the case of the NRBS this might be to assess the ecological effects of discharge from a particular source (industry or municipality) on the biological communities located downstream of that discharge. Note that the definition of motive is a critical step in that it determines the spatial area that must be assessed and helps to determine what types of measurement (i.e., ecological indicators) and assessment (desired state) endpoints will be included.

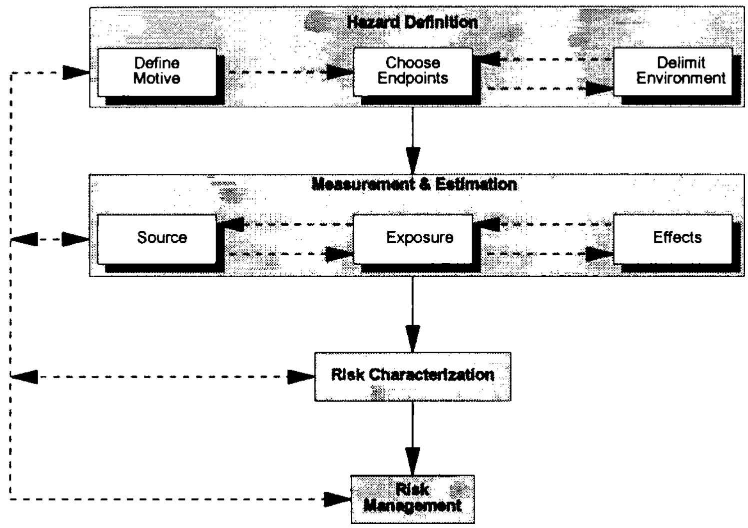

Figure 11. Ecological Risk Assessment.

Box 15. Major steps in retrospective ecological risk assessment.

1. Hazard Definition
2. Measurement and Estimation
3. Risk Characterization
4. Risk Management

Following hazard definition is a process by which the source or sources of impact are identified and are linked, through a knowledge of exposure, to specific ecological or biological effects. Continuing with the NRBS example, this process would involve quantifying the nature of the discharge being assessed, determining the fate and distribution of various components of that discharge within the ecosystem and finally developing an understanding of the consequences of that exposure to biological communities downstream.

Knowledge of exposure and effects (Measurement and Estimation) will in turn allow researchers to quantify the risk to the downstream biological communities presented by the discharge (Risk Characterization). Finally, knowledge of risk will be used in the development of specific management strategies (Risk Management). While the sequential steps involved in ecological risk assessment may be straightforward (Figure 11) the interactions among those steps are myriad and complex. Indeed, knowledge, or lack of knowledge, about any one aspect of the process can greatly constrain other aspects of the overall process. Perhaps of greatest importance are those activities that comprise the Measurement and Estimation component of ecological risk assessment. An adequate characterization of the source of impact, the distribution of that impact (exposure) and its ecological consequences (effects) is essential to selecting appropriate indicators and to measuring ecological risk itself. This ability to measure exposure and effects is further constrained by any gaps in knowledge relating to basic ecosystem structure and function.

Although the value of ecological risk assessments have become widely recognized there has been considerably less success implementing this approach particularly on the scale of the northern river basins. The reasons for this rest largely with an incomplete knowledge of basic ecology of these systems coupled with a lack of understanding as to how human activities impact on these systems. There have been studies that claim to perform ecological risk assessments but in many cases these studies actually only measure the certain aspects of exposure (e.g., sediment or water column toxicology) and test for some subset of potential effects (e.g., changes in benthic community structure). These studies may provide information as to the potential effects of anthropogenic activity but they do not measure risk itself and thus should not properly be termed ecological risk assessments.

Clearly the process of ecological risk assessment is a complicated and involved one and stands in marked contrast to the relatively short-term and narrowly focused EIAs that have been the historical practice. Within the NRBS, much of the research effort has focused on providing the information and background required to perform adequate ecological risk assessments. As will be discussed in subsequent sections the Synthesis and Modelling Component has developed a framework within which general ecosystem goals can be refined into the explicit motive statements required for risk assessment. This same component has also developed a protocol for the selection of specific indicators that would aid in the assessment of ecological risk. Many of the technical studies conducted within NRBS have sought to quantify the distribution and fate of anthropogenic inputs within these systems and to determine their ecological effects. Similarly, NRBS has employed mathematical models to characterize better both exposure and effect processes which in turn will allow for a more precise characterization of ecological risk.

In some cases within NRBS, sufficient information has been collected to allow for a general risk assessment to be performed (NRBS Nutrients Synthesis Report No. 4; NRBS Contaminant Synthesis Report No. 3) but there also remain significant gaps in understanding that will only be filled by additional research and ongoing monitoring data. As new information becomes available through these activities it will help to characterize better ecological risk and to focus future monitoring activities. Despite the logistical difficulties associated with proper ecological risk assessment this is clearly the process which best enables environmental management. It is also important to note that the information required to perform proper ecological risk assessment also contributes directly to our understanding of basic ecosystem structure and function as well as cumulative effects and will thus contribute directly to improved management decisions even in those cases in which estimations of ecological risk are incomplete.

The final step in the procedure outlined in Figure 11 is that of risk management. While science certainly plays a role in this step so do economics, sociology and the public in general. This is a consequence of the fact that risk management necessitates a process by which "acceptable risk" is defined and balanced against the benefits of anthropogenic activity (Cairns 1995; UK Government/Industry Working Group 1995). The Other Uses and Traditional Knowledge components of the NRBS have taken an important first step in attempting to identify the priorities and concerns of those people living within the Northern River Basins but the process by which those concerns are quantified and expressed in the same units as ecological risk has yet to be undertaken. Indeed, risk-benefit analyses of this type are still in the early development stages and while there exist several paradigms whose aim is the precise quantification of benefit this goal involves a process no less complicated than the quantification of ecological risk (UK Government/Industry Working Group 1995).

4.0 SUMMARY, PRINCIPLES AND RECOMMENDATIONS

Monitoring continues to provide society with one of the only effective means of observing and quantifying its interaction with the ecosystem and of providing the knowledge required for making informed decisions. In relatively undisturbed areas, monitoring and research can be used to help protect the ecosystem from the environmental impacts experienced elsewhere with industrial, agricultural and municipal development. On the other hand, in impacted ecosystems, monitoring can be used to guide society's progress toward some prescribed improved ecosystem state. No matter what, for a society to evolve without understanding the consequences of its actions to date, is to move forward without care and regard for the environment and the future generations that follow. More specifically, monitoring observations can provide society with information on the following:

- what effects developments are having on the environment
- how well do we satisfy are stated ecosystem goals and objectives
- where and what type of action must be taken to address past actions
- how the ecosystem is responding in terms of its health
- how effective our regulatory and voluntary controls are
- how often and well regulatory requirements are met
- if and when humans and the environment may be at risk (e.g. drinking water)
- if new resource management approaches and decisions are required
- where research and development is required
- if our predictive models are sound or need improvement

Uncertainty in our ability to predict the effects of land and water uses on the quality of ecosystems is perhaps the primary reason for ensuring that monitoring is an ongoing feature of integrated resource management strategies. There is a need for a "feed back loop" within management strategies that return the monitoring data and information to those who make decisions about licensing and to the peoples of the basins who ultimately are directly affected. As a society, we must accept that uncertainties are pervasive and the way we assess the impact of human activity will change as new science and/or technology arrives. The philosophy of 'adaptive management' requires that we obtain, on an ongoing basis, scientifically credible information that can be used to direct these adjustments towards minimizing (eliminating) the impacts of human activities.

4.1 Science Principals Related to Integrated Ecosystem Monitoring

In order to design and implement an effective Integrated Ecosystem Monitoring Program, several science-based principals that must be adhered to:

1. An ecosystem approach to integrated resources management must in based on sound scientific principles.
2. Integrated Ecosystem Monitoring (IEM) is an ongoing process requiring periodic scientific review, evaluation and adjustment, as required.

3. Quality assurance and quality control is an integral component of IEM design, implementation and evaluation.
4. Monitoring and assessment protocols must be standardized to ensure data quality and maximize opportunities for data integration.
5. IEM recognizes the critical ongoing role played by the public and stakeholders.
6. Communication of scientific findings to the public is necessary.
7. Monitoring activities must meet accepted scientific standards and the scrutiny of a peer scientific review process.
8. Traditional knowledge plays an important role in assessing the state of the ecosystem.

The above principals were used as a foundation to the development of the following recommendations:

4.2 Recommendations

Recommendation 1: We recommend a basins' Integrated Ecosystem Monitoring Committee (IEMC) be established to coordinate all ecosystem monitoring in the northern river basins.

Governments, industries, some municipalities and to a lesser extent other organizations conduct various types of monitoring. This committee should play a key role in overseeing all aspects of monitoring within these basins (e.g., scientific implementation and assessment of societal goals/objectives, evaluate protocols for design, data collection, analyses, quality assurance and data management).

Recommendation 2: We recommend that the IEMC adopt the ecosystem approach to environmental monitoring and the Integrated Ecosystem Monitoring framework described in this report.

This synthesis report has provided in some detail the basis for the design and implementation of a holistic and integrated ecosystem monitoring program and should be considered at the starting point for future monitoring in the basins.

Recommendation 3: We recommend a panel of scientific experts (including representatives of Traditional Knowledge) be established to advise the IEMC.

A scientifically rigorous IEM program requires expert advice on its design, implementation, data interpretation, and scientific recommendations. Similar to the Science Advisory Committee of the NRBS, this committee would serve as an independent and objective reviewer of the IEM program.

Recommendation 4: We recommend current and future monitoring activities within the basins be integrated following the framework developed in this report. Particular attention must be given to standardization of monitoring activities and the adoption of appropriate quality assurance \ quality control protocols.

There is a need to ensure that monitoring within the basins is coordinated and avoids duplication. Appropriate priority needs and scientifically acceptable protocols must be identified and applied across agencies. Quality assurance and quality control practices as well as procedural standardization must incorporated into all aspects of monitoring activities.

Recommendation 5: We recommend an IEM database for the basins be established and maintained.

A critical component to an effective integration of monitoring data is the existence of a standardized database that will allow for interpretation of monitoring information at a variety of scales (spatial and temporal). A process is required by which this database can monitored, updated and made publicly available.

Recommendation 6: We recommend a process be established whereby the integration of monitoring data collected in the basins be subject to scientific interpretation by an independent group.

The individual agencies contributing to the IEM database are responsible for the interpretation of their own monitoring data. However, there is also a need for interpretation of the integrated data. Such an interpretation should be scientifically-based and consider a broader range of issues that would any single monitoring agency. It is also necessary that the scientific validity of monitoring activity be assessed by independent experts.

Recommendation 7: We recommend that volunteer organizations and individuals be incorporated into the IEM implementation strategies.

Community involvement in the implementation of basin-wide monitoring provides a unique opportunity. The involvement of volunteers (including schools) in monitoring results in a more holistic consideration of ecosystem health. A major challenge will be to adapt community-based monitoring to the scale of the northern river basins. Paramount in any decision to introduce community-based participation in monitoring will be the development of appropriate manuals, other educational material and the adoption of an ongoing training plan.

Recommendation 8: We recommend that future management programs recognize that the aquatic ecosystem is directly related to the adjacent terrestrial ecosystem and that the evaluation of aquatic ecosystem health must include considerations of land use activities (forestry, agriculture, urban development, mining, etc.).

The Study Board deliberated at length about the inclusion of terrestrial components within the research program of the NRBS. Due to its restricted mandate and limited budget, NRBS was unable to incorporate such issues as forestry management and other land uses, climate change and biodiversity. The science components responsible for the design and implementation of the NRBS science program also recognized the need to focus primarily on the aquatic ecosystem, but expressed concerned over the limited research pertaining to terrestrial issues. Future IEM in these basins should extend beyond the mainstems of the major rivers and tributaries to consider importance of terrestrial activities and processes.

Recommendation 9: We recommend a process of public consultation be undertaken every 3-5 years to assess and re-evaluate societal priorities and to identify emerging issues.

As essential component of an effective IEM is the requirement to assess periodically and re-evaluate societal priorities, goals, and objectives for these basins and to incorporate this information in the refinement of monitoring activities. As discussed in this synthesis report, the identification of appropriate ecosystem indicators is dependent on the development of precise statements of ecosystem goals and objectives.

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Synthesis Report

The Northern River Basins Study was established to examine the relationship between industrial, municipal, agricultural and other development and the Peace, Athabasca and Slave river basins.

Over four and one half years, about 150 projects, or "mini studies" were contracted by the Study under eight component categories including contaminants, drinking water, nutrients, traditional knowledge, hydrology/hydraulics, synthesis and modelling, food chain and other river uses. The results of these projects, and other work and analyses conducted by the Study are provided in a series of synthesis reports.

This Synthesis Report documents the scientific findings and scientific recommendations of one of these component groups. This Synthesis Report is one of a series of documents which make up the Northern River Basins Study's final report. A separate document, the Final Report, provides further discussion on a number of scientific and river management issues, and outlines the Study Board's recommendations to the Ministers.

Project reports, synthesis reports, the Final Report and other NRBS documents are available to the public and to other interested parties.