A Discussion Paper on the Development of Ecosystem Maintenance Indicators for the Transboundary River Systems within the Mackenzie River Basin: Slave, Liard, and Peel Rivers

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Executive Summary

The Mackenzie River basin is the largest river system in Canada, with a total drainage area of approximately 1 766 000 km^2. This river basin comprises several large fluvial systems, including the Mackenzie, Slave, Liard, Peace, Athabasca, Arctic Red, and Peel rivers. Of these, the Mackenzie River is the longest, flowing some 1700 km from Great Slave Lake to the Beaufort Sea. In addition, this drainage basin includes Great Bear Lake, Great Slave Lake, and Lake Athabasca, as well as myriad smaller lakes, rivers, and streams. Its most distant water source is high in Alberta's Rocky Mountains, some 4200 km from the mouth of the Mackenzie River.

The size of the watershed and number of jurisdictions involved complicates the management of water resources in the Mackenzie River Basin. Authority for managing water resources in this watershed is vested in several First Nations, three provinces, two territories, and the federal government. The Mackenzie River Basin Committee has been established to facilitate cooperation among these jurisdictions, through the development of the Mackenzie River Basin Master Agreement and the related bilateral agreements.

All of the jurisdictions in the Mackenzie River Basin have agreed to adopt the ecosystem approach to guide water management decision-making in the watershed. Implementation of this approach, as it applies to water quantity management, necessitated the development of a framework in which to express the policies that have been established for managing the ecosystem. This framework consisted of broad management goals, more specific ecosystem objectives, ecosystem maintenance indicators, and ecosystem metrics.

The results of extensive public consultation were used to define ecosystem goals and objectives for the Slave, Liard, and Peel river basins. Maintenance of the integrity of these northern ecosystems was identified as the highest priority goal. However, the preservation of traditional culture and subsistence lifestyles, protection of drinking water supplies, maintenance of river navigability, and provision of economic development opportunities were also identified as important long-term goals.

The main focus of this study was to identify and evaluate candidate ***ecosystem maintenance indicators (EMIs)*** for the three major transboundary streams in the Mackenzie River Basin. In the context of this study, EMIs were defined as components of aquatic and riparian ecosystems which provide information on the health and vitality of the ecosystem as a whole. Importantly, candidate EMIs must provide information on the effects of alterations in the hydrological regime on the biological components of the ecosystem. For this reason, it was necessary to establish linkages between the candidate EMIs and the hydrological characteristics of these riverine systems.

A system for evaluating candidate EMIs was proposed to support the selection of a suite of indicators for each river basin. Using the two-tiered system, candidate EMIs are first evaluated to determine their biological and hydrological relevance. Candidate EMIs that pass this first screening step would be considered further. In the second tier of the evaluation, the relative applicability of each candidate EMI is assessed in terms of its utility for providing information for assessing the status and trends of the ecosystem, providing an early warning of changes in the structure or function of the ecosystem, and establishing linkages between ecosystem components. Limitations on the existing knowledge base restrict the evaluation of many candidate EMIs. However, it is anticipated that traditional environmental knowledge and local experience will provide additional information for identifying and evaluating candidate EMIs in the Mackenzie River Basin.

A preliminary evaluation of the candidate EMIs for the Slave, Liard, and Peel river basin was conducted to demonstrate the tiered system described above. The results of this assessment suggest that northern pike and muskrats would provide suitable EMIs for the Slave River Basin. In the Liard River Basin, the arctic cisco was identified as a suitable indicator species for evaluating ecosystem health and vitality. Arctic char was identified as a suitable EMI for the Peel River Basin. In addition to a suite of biological indicators, it is anticipated that several physical and/or chemical variables will be adopted as EMIs in the Mackenzie River Basin.

The establishment of EMIs represents one step towards the implementation of the ecosystem approach in the Mackenzie River Basin. In addition, ecosystem metrics must be identified, as well as the acceptable ranges or targets for these variables. For example, the population of young of the year northern pike in the Slave River Delta could be identified as a suitable ecosystem metric for the Slave River Basin. Once the EMIs and ecosystem metrics are incorporated into the various bilateral agreements under the Mackenzie River Basin Master Agreement, monitoring programs should be designed and implemented to evaluate the current status and trends of the EMIs. Such monitoring programs will also provide essential data for defining and refining the targets for the ecosystem metrics.

Effective implementation of the ecosystem approach will also require numerical water quantity objectives. These numerical objectives should define the hydrological conditions in the transboundary reaches of the Slave, Liard, and Peel rivers that would protect the health and vitality of these ecosystems. In turn, these water quantity objectives will provide each jurisdiction with a basis for making sound water management decisions (that is, decisions that will not adversely affect water uses in downstream jurisdictions). Several approaches to the development of these objectives were proposed in this document.

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Chapter 1

Introduction

1.0 Geographic Setting

The Mackenzie River basin is the largest river system in Canada, with a total drainage area of approximately 1 766 000 km^2. This river basin comprises several large fluvial systems, including the Mackenzie, Slave, Liard, Peace, Athabasca, Arctic Red, and Peel rivers. Of these, the Mackenzie River is the longest, flowing some 1700 km from Great Slave Lake to the Beaufort Sea. In addition, this drainage basin includes Great Bear Lake, Great Slave Lake, and Lake Athabasca, as well as myriad smaller lakes, rivers, and streams. Its most distant water source is high in Alberta's Rocky Mountains, some 4200 km from the mouth of the Mackenzie River (Figure 1).

The major physiographic regions contained within the Mackenzie River basin include the Canadian Shield, the Interior Plains, and the Western Cordillera. The Canadian Shield region is characterized by ice-deepened valleys, eroded ridges, and extensive deposits of glacial till and lacustrine clays (Prowse 1990). In contrast, the Western Cordillera region comprises mountains, plateaus, and plains, with rocks primarily of sedimentary origin. Between these two regions lie the Interior Lowlands, which is comprised of a series of plateaus ranging in height from 150 to 1200 m (Owen 1967). These areas are characterized by extensive bog and muskeg lowlands, and dominated by glacio-lacustrine silts and clays (Prowse 1990). These diverse physiographic features, along with its unique climate, give the watercourses within the Mackenzie River basin a complex array of hydrological regimes, ranging from arctic nival to muskeg (Church 1974).

1.1 Issues and Concerns in the Mackenzie River Basin

Implementation of effective water quantity management programs within the Mackenzie River basin is challenging for a number of reasons. First, the Mackenzie River and its tributaries drain areas within five provinces and territories, including British Columbia, Alberta, Saskatchewan, Yukon, and the Northwest Territories (NWT). Each of these jurisdictions have management goals (i.e., designated water uses) for the water resources that flow within its borders; however, these goals may differ between jurisdictions.

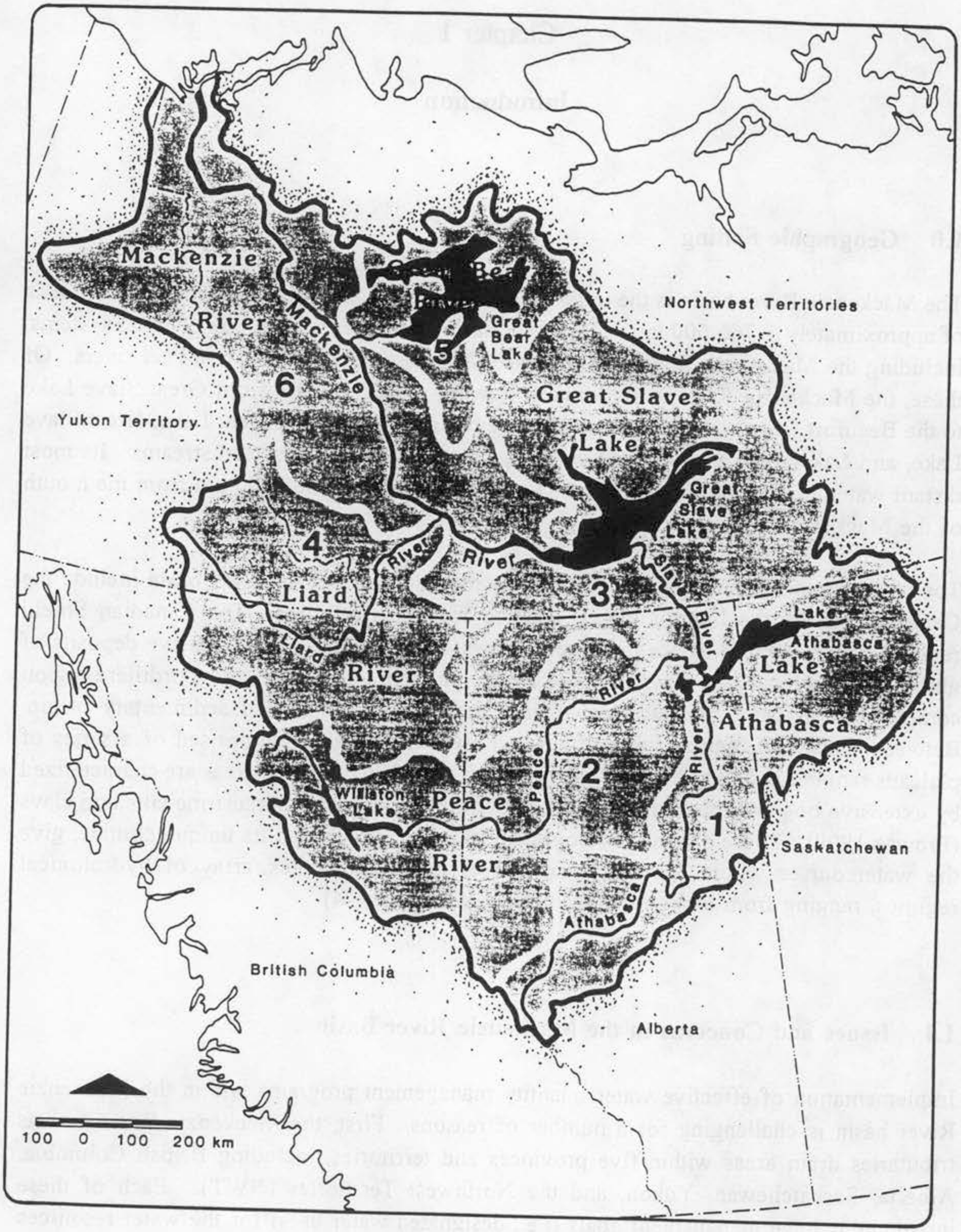


Figure 1. Mackenzie River Basin, showing the six designated subbasins.

Second, the diversity of natural resources that exist in the basin have the potential to support an array of economic development initiatives. Several types of natural resource developments have the potential to affect the hydrological regime of the river system. For example, major hydroelectric development projects have been proposed on the Slave, Liard, and Peace rivers, any one of which could have significant impacts on downstream water uses. In addition, a variety of water diversion schemes have been considered for the Mackenzie River basin, which could result in the transfer of a significant proportion of the flow into other drainages. Furthermore, there is a range of ongoing land use activities, such as forest management, mining, and urbanization, that could influence the hydrological characteristics of the Mackenzie River basin (Table 1).

Finally, the Mackenzie River basin encompasses a relatively large number of virtually pristine wilderness areas. As such areas are rapidly disappearing throughout the southern portion of the country, there will be increasing pressure to protect and conserve those which remain in the north. In addition, northern residents, including First Nations, have identified ecosystem protection as a priority water management goal for the transboundary streams in the Mackenzie River basin. Ecosystem protection is required to ensure that water resources continue to support the traditional lifestyles that are so important to northern residents.

The distinct approaches to water management that exist among the five jurisdictions in the Mackenzie River basin have the potential to create conflicts over the use of water resources. In particular, developmental activities in upstream jurisdictions have the potential to compromise high priority water uses in downstream areas. For this reason, the Mackenzie River Basin Committee has been actively negotiating a Master agreement to coordinate the management of water resources within the drainage. While many of the concerns identified will be addressed in this agreement, traditional approaches to water management do not provide an adequate basis for ensuring that both upstream and downstream interests (with respect to streamflow) are adequately addressed. Hence, additional management tools are needed to support resource use planning activities.

1.2 Purpose of the Study

The Mackenzie River Basin Committee has adopted the ecosystem approach to water management. As extensive public consultation has indicated broad support for more holistic management of aquatic resources, all of the parties involved have indicated their commitment to the maintenance of the ecological integrity of the aquatic and riparian ecosystems. The Master Mackenzie River Basin Agreement currently contains seven bilateral agreements between neighbouring jurisdictions to address specific water

Table 1. Hydrological characteristics of the Slave, Liard, and Peel rivers.

Basin	Length (km)	Drainage Area (sq. km)	Discharge (in cubic metres per second)				
			Mean Annual	Summer Monthly Mean	Winter Monthly Mean	Maximum Daily	Minimum Daily
Slave River (at Ft. Fitzgerald)	415	380,000	3520	5050	1920	11,200	530
Liard River (at Mouth)	1100	277,000	2580	4610	518	-	260
Peel River (at Ft. McPherson)	440	109,500	700	1300	94	-	-
Mackenzie River (at Arctic Red River)	1650	363,000	9630	15300	3110	-	2230

Data from Mackenzie River Basin Committee (1981) and Wedel (1993).

management issues. Each of these bilateral agreements includes a series of schedules that list the transboundary streams considered and define the ecosystem objectives for those waters. These ecosystem objectives are further defined in terms of ecological indicators, water quality objectives, and water quantity objectives.

Currently, the water quantity objectives are defined using narrative statements which specify that, 'there will be no significant change in the flow regime that could affect the aquatic system.' However, as yet, the term 'significant effect' has not been operationally defined. Therefore, the narrative statement that is now in use provides little explicit guidance on the management of the hydrological regime in transboundary rivers. For this reason, there is a need to determine which biological components of the aquatic system could be affected by hydrological alterations and to clearly define the relevant metrics, such as population size and harvest rate, that pertain to each of these species.

The goal of this study is to develop and evaluate a procedure for assessing ecosystem maintenance in the transboundary streams of the Mackenzie River basin. Specifically, the goal is to identify key aquatic and terrestrial species in the Slave, Liard, and Peel river systems that could be affected by anthropogenically-induced alterations in the hydrological regime of these watercourses. In addition, it is necessary to evaluate each of these candidate ecosystem maintenance indicators (EMIs) in order to identify the ones that would be most appropriate for assessing the status and trends of the ecosystem, providing an early warning of changes in the structure or function of the ecosystem, and establishing linkages between ecosystem components. Traditional environmental knowledge and public consultation will provide essential information for identifying and evaluating candidate EMIs in the Mackenzie River Basin.

1.3 Study Approach

In this study, EMIs are defined as components of aquatic and riparian ecosystems which provide information on the health and vitality of the ecosystem as a whole. The identification and evaluation of candidate EMIs for the three largest transboundary streams within the Mackenzie River basin was conducted in several steps, including:

- (i) development of a framework for implementing the ecosystem approach;
- (ii) identification of management goals and ecosystem objectives;
- (iii) establishment of selection criteria for EMIs;
- (iv) review of linkages between the hydrological and biological characteristics of the ecosystem;

(iii) identification of candidate EMIs;
(iv) preliminary evaluation of the candidate EMIs; and,
(v) preparation of a discussion paper to support a multistakeholder workshop.

The first step in the EMI identification and evaluation process was to establish a framework for implementing the ecosystem approach in the Mackenzie River Basin. To this end, the approaches and procedures that have been used in other jurisdictions and other applications were reviewed. A description of the ecosystem approach is presented in Chapter 2. General descriptions of riverine and riparian ecosystems are presented in Chapter 3. The framework that was selected is presented in Chapter 4.

Next, management goals and ecosystem objectives for the Mackenzie River basin were identified. To this end, the reports and discussion papers that have been prepared to support transboundary negotiations were reviewed. The water management information relevant to the Slave, Liard, and Peel rivers was then assembled and translated into broad management goals and ecosystem objectives. It should be noted that these goals and objectives integrate the input from an extensive public consultation process. Hence, they are likely to reflect the aspirations of First Nations and other northern residents (see Chapter 4).

Selection criteria were subsequently established to provide a consistent basis for evaluating the applicability of candidate EMIs. Additional bibliographic database searches were conducted to identify the approaches that have been used to select ecosystem indicators for specific applications. Information on approaches that had not been published were sought by contacting experts in this field directly. Information on each of the approaches was reviewed and the salient elements of each procedure were incorporated into the selection criteria for identifying EMIs for the Slave, Liard, and Peel rivers. The section criteria that were established in this investigation are presented in Chapter 5.

Development of effective EMIs for this application depends on the establishment of linkages between river hydrology and the biological components of aquatic and riparian ecosystems. As such, a preliminary review of the literature was conducted to determine the potential effects of hydrological alterations on the biological resources in the Mackenzie River Basin. The various linkages that were identified are presented in Chapter 6.

The next step in this process was to identify candidate ecosystem maintenance indicators for the three transboundary river systems under consideration. Accordingly, bibliographic database searches were conducted to obtain information on the biological characteristics of the Slave, Liard, and Peel river ecosystems. The results of these searches were reviewed and relevant citations were retrieved, catalogued, and incorporated into a project database to facilitate their subsequent recovery and use. In addition, researchers and managers working within the basin were contacted to acquire information that was not available in the primary literature. Each of the aquatic or terrestrial organisms that was known to occur in one or more of the river systems was identified as a candidate EMI.

The penultimate step in the process was to conduct a preliminary evaluation of the candidate EMIs. This evaluation consisted of applying the selection criteria that were established previously to each of the candidate EMIs. This resulted in the establishment of an initial, prioritized set of indicators for each river system (see Chapters 7, 8, and 9).

Finally, a discussion paper was prepared to support a multistakeholder workshop on the development of ecosystem maintenance indicators for the transboundary streams in the Mackenzie River basin. This discussion paper was designed to provide potential participants with sufficient information to contribute effectively during the course of the workshop. For this reason, background information on the existing and proposed developmental activities within the basin and on the ecosystem approach to resource management were presented, along with the more specific information that pertained to the identification and evaluation of candidate EMIs. Hence, workshop participants could accept the recommendations in the discussion paper or develop alternate procedures for establishing EMIs for the Slave, Liard, and Peel rivers.

Chapter 2

Toward an Ecosystem Approach to Environmental Management

2.0 Introduction

Since the industrial revolution, anthropogenic activities have resulted in widespread and severe environmental degradation. While local impacts were commonly evident in the vicinity of human settlements, increasing evidence indicates that large scale industrial developments are responsible for effects that are significant on regional and, even, global scales (Rapport 1990). These challenges to the integrity of aquatic, riparian, and terrestrial ecosystems have lead to the development of a series of strategies or approaches to environmental management, that were primarily designed to ensure that the human uses of these systems were conserved and protected. However, the discovery of toxic and persistent chemicals, such as mirex, toxaphene, and DDT, in human food webs in the Great Lakes region in the 1970's indicated that traditional management approaches did not adequately address the complex interactions that occur in the environment. In addition, the concept of sustainability was notably absent from these earlier management approaches. Together, these discoveries suggested that conventional approaches did not provide an adequate basis for protecting human health or the environment.

2.1 Emergence of the Ecosystem Approach

The ecosystem approach to planning, research and management is the most recent phase in an historical succession of environmental management approaches. Previously, humans had been considered to be separate from the environment in which they lived. This *egocentric approach* viewed the external environment only in terms of human uses. However, recent monitoring data indicate that human activities can have significant and far-reaching impacts on the environment and on the humans who reside in these systems. Therefore, there was a need for a more holistic approach to environmental management, in which humans were considered as integral components of the ecosystem. The ecosystem approach provides this progressive perspective by integrating the egocentric view that characterized earlier management approaches, with an *ecocentric view* that considers the broader implications of human activities.

Implementation of the ecosystem approach necessitates the development of an integrated set of policies and managerial practices that relate people to ecosystems of which they are a part instead of to the external resources or environments with which they interact (Vallentyne and Beeton 1988). The essence of the ecosystem approach is that it relates *wholes* at different levels of integration (i.e., humans and the ecosystems containing humans) rather than the interdependent parts of those systems (i.e., humans and their environment; Christie *et al.* 1986). The identifying characteristics of the ecosystem approach include: a synthesis of integrated knowledge on the ecosystem; a holistic perspective of interrelating systems at different levels of integration; and, actions that are ecological, anticipatory, and ethical (Christie *et al.* 1986; Vallentyne and Hamilton 1987).

The primary distinction between the environmental and ecosystem approaches is whether the system under consideration is external to (in the environmental approach) or contains (in the ecosystem approach) the population under study (Vallentyne and Beeton 1988). The conventional concept of the environment is like that of *house* - external and detached; in contrast, ecosystem implies *home* - something that we feel part of and see ourselves in, even when we're not there (Christie *et al.* 1986). The change from the environmental approach to the ecosystem approach necessitates a change in the view of the environment from a political or people-oriented context to an ecosystem-oriented context (Vallentyne and Beeton 1988). This expanded view then shapes the planning, research, and management decisions that are made within and pertaining to the ecosystem.

2.2 Benefits of the Ecosystem Approach

The ecosystem approach is superior to the approaches to environmental management that have been used previously for a number of reasons. First, the ecosystem approach provides a basis for the long-term protection of natural resources, including threatened and endangered species. In the past, management decisions were typically made with a short-term vision (i.e., within a single political mandate). In contrast, the ecosystem approach necessitates a long-term view of the ecosystem which necessarily considers the welfare of its biotic components. Hence, management decisions are more likely to be based on the sustainability of natural resources and the protection of weak populations.

Second, the ecosystem approach provides an effective framework for evaluating the real costs and benefits of developmental proposals. Previously, decisions regarding the development of industrial and municipal projects were heavily weighted toward financial benefits and job creation. Neither the long-term impacts of these projects nor the sustainability of the resources upon which they depended were fully considered. In contrast, implementation of the ecosystem approach demands that the long-term effects of developmental activities be incorporated into the assessment process. Therefore, management decisions are less likely to be taken based solely on political considerations, such as job creation.

The ecosystem approach also enhances the multiple use of natural resources. In the past, governments have allocated vast quantities of natural resources to single industrial users. For example, the Aluminum Company of Canada (Alcan) has been allocated 88% of the original streamflows of the Nechako River to power its aluminum smelter in Kitimat, B.C. Completion of this water diversion project will significantly diminish the production of resident fish species and severely reduce anadromous fish stocks (Slaney *et al.* 1983). In addition, little water will be available for irrigation or dilution of municipal wastewater discharges. Implementation of the ecosystem approach in this watershed would ensure that all of the stakeholders would have an opportunity to establish the management goals for the ecosystem and that governments would not make political decisions that benefit a single user group, at the expense of other beneficial uses of water resources.

Environmental research and monitoring activities are an essential element of any management program. The ecosystem approach provides a basis for focusing these activities by establishing very clear management goals for the ecosystem. Therefore, research and monitoring activities are driven by the needs of the program, rather than by the interests of individual scientists or by political expediency.

One of the most important benefits of the ecosystem approach is that it directly involves the public in decision-making processes. Specifically, this approach provides a forum for public input at a non-technical level (i.e., during the establishment of management goals and ecosystem objectives), which is both effective and non-threatening. The detailed technical issues are then left to the managers of these ecosystems (i.e., First Nations and various levels of government). And, the framework for implementing the approach (see Chapter 4) assures that these managers are accountable for the decisions that they make.

Traditionally, environmental impact assessments have not consistently provided reliable information for evaluating the effects of anthropogenic developments on the ecosystem. In the ecosystem approach, however, the functional relationships between human activities, changes to the physical and chemical environment, and alterations in the biological components of the ecosystem are established before making important management decisions. Therefore, subsequent monitoring activities can focus on the ecosystem components that are most likely to be affected.

The ecosystem approach also facilitates the restoration of damaged and degraded natural resources. By explicitly identifying the long-term impacts of degraded ecosystems, this approach more clearly delineates the benefits of restoration and remedial measures.

Therefore, limited resources can be focused on restoration projects that are likely to yield the greatest benefits to the ecosystem as a whole.

2.3 Implementation of the Ecosystem Approach

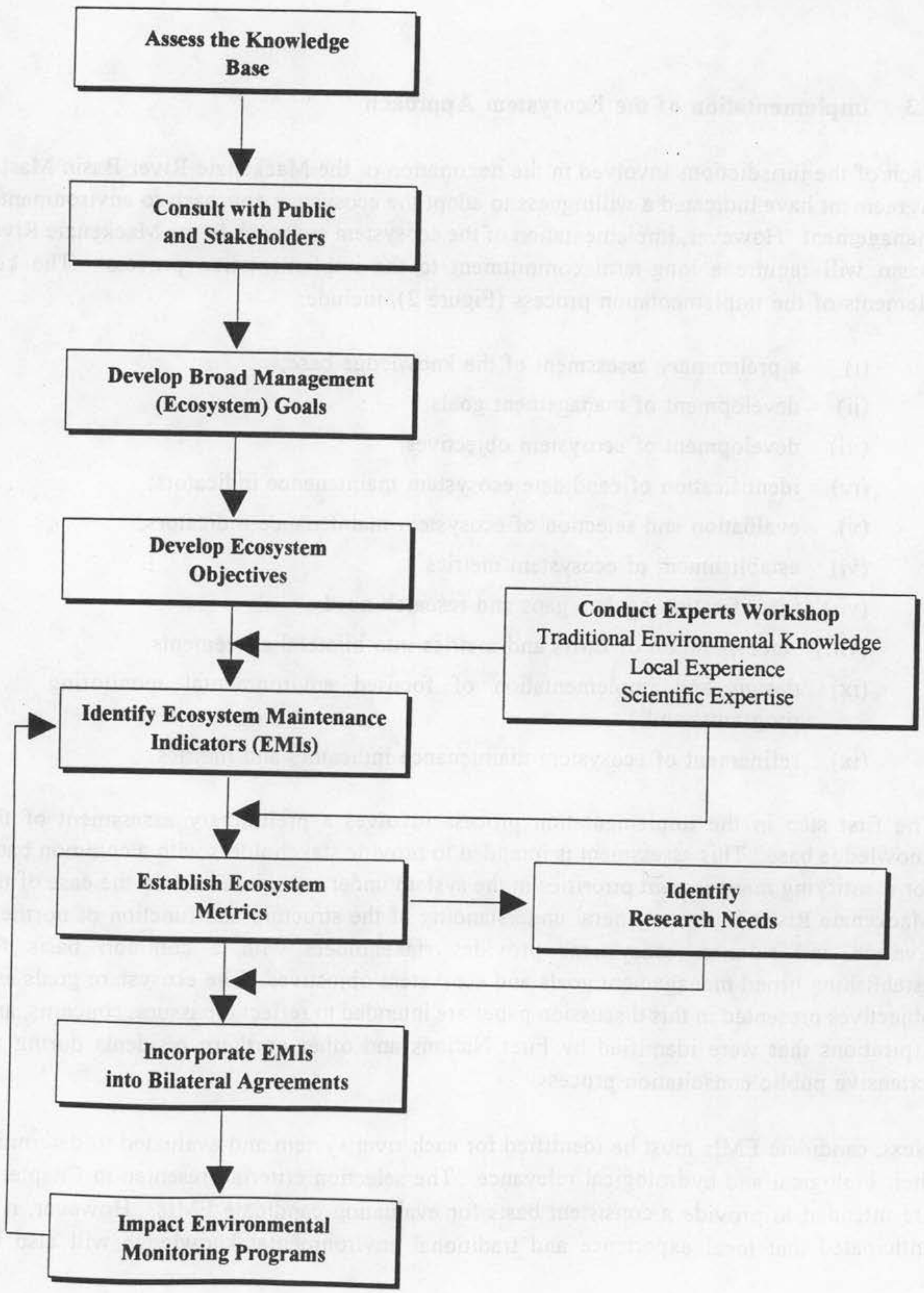
Each of the jurisdictions involved in the negotiation of the Mackenzie River Basin Master Agreement have indicated a willingness to adopt the ecosystem approach to environmental management. However, implementation of the ecosystem approach in the Mackenzie River Basin will require a long-term commitment to the implementation process. The key elements of the implementation process (Figure 2), include:

- (i) a preliminary assessment of the knowledge base;
- (ii) development of management goals;
- (iii) development of ecosystem objectives;
- (iv) identification of candidate ecosystem maintenance indicators;
- (v) evaluation and selection of ecosystem maintenance indicators;
- (vi) establishment of ecosystem metrics;
- (vii) identification of data gaps and research needs;
- (viii) incorporation of EMIs and metrics into bilateral agreements;
- (ix) design and implementation of focused environmental monitoring programs; and,
- (ix) refinement of ecosystem maintenance indicators and metrics.

The first step in the implementation process involves a preliminary assessment of the knowledge base. This assessment is intended to provide stakeholders with a common basis for identifying management priorities in the system under consideration. In the case of the Mackenzie River Basin, a general understanding of the structure and function of northern riverine and riparian ecosystems provides stakeholders with a common basis for establishing broad management goals and ecosystem objectives. The ecosystem goals and objectives presented in this discussion paper are intended to reflect the issues, concerns, and aspirations that were identified by First Nations and other northern residents during an extensive public consultation process.

Next, candidate EMIs must be identified for each river system and evaluated to determine their biological and hydrological relevance. The selection criteria presented in Chapter 5 are intended to provide a consistent basis for evaluating candidate EMIs. However, it is anticipated that local experience and traditional environmental knowledge will also be

Figure 2. An overview of the implementation process for the ecosystem approach.



required to establish a suite of EMIs that adequately reflects the goals and objectives that have been established for the Slave, Liard, and Peel rivers. This type of input may be obtained in public meetings, expert workshops, or directly from local residents.

Ecosystem metrics are also required to support the implementation of the ecosystem approach. These metrics identify quantifiable attributes of the EMIs and define acceptable ranges or targets for these variables. For example, if muskrat was identified as an EMI for the Slave River Basin, then the population of muskrats in the Slave River Delta might be established as an ecosystem metric. If all of the measured attributes or metrics fall within acceptable ranges, then the ecosystem as a whole would be considered to be healthy and vital. The information collected during this process will also provide a basis for identifying data gaps and research needs to support implementation of the ecosystem approach.

A key element of the implementation process will involve incorporation of the management goals, ecosystem objectives, EMIs, and ecosystem metrics into the various bilateral agreements that comprise the Mackenzie River Basin Master Agreement. In addition, focused environmental monitoring programs must be developed to evaluate the status of the species that are selected as EMIs. The results of these monitoring programs will provide a scientific basis for further evaluating the EMIs, refining the ecosystem metrics, and determining if the goals and objectives for these river systems have been achieved.

Chapter 3

The Ecosystem as a Resource

3.0 Introduction

The earth can be conceptually divided into a number of functional units which are tied together by the structure and function of their component parts. These units, termed ecosystems, are comprised of both the living and the non-living components of the environment. Ecosystems may be defined on numerous scales, ranging from a small pond to a continent and, ultimately, to the entire globe.

Irrespective of size, the common thread that runs through all ecosystems is the interdependence of the living (biotic) and nonliving (abiotic) elements of the system and the existence of some definable boundaries. The non-living elements of the ecosystem include all of the physical (e.g., temperature, discharge, etc.) and chemical (e.g., organic and inorganic substances) factors that define the basic conditions of the ecosystem. The living elements of the ecosystem consist of a diversity of organisms that either derive energy directly from the sun (or, in some cases, from chemical constituents; autotrophs) or from biological sources (heterotrophs). The interactions that are established between each of the elements define the structure and function of the ecosystem as a whole.

3.1 Riverine Ecosystems

Rivers, from an energetic standpoint, are open ecosystems. That is, some portion (frequently a substantial portion) of the biological energy flow is based on organic matter that is imported from adjacent terrestrial (i.e., riparian) or upstream (i.e., lake) ecosystems (Odum 1975; Vannote *et al.* 1980). As such, riverine ecosystems are naturally adapted to process a variety of organic substances which may be contributed from outside sources (Minshall 1978). This characteristic (and their unidirectional flow pattern) has made rivers a prime target for disposal of anthropogenic wastes.

In southern regions, gradient and streamflow are probably the two most important physical factors that contribute to the morphology of riverine ecosystems. High gradients and streamflows are characteristic of eroding basins and, as such, the streambed is generally firm. Lower gradients and streamflows create conditions which favour the deposition of suspended materials and, therefore, streambeds in these areas tend to be composed of soft sediments. The nature of the streambed is a dominant factor in determining the structure of the benthic community and, thereby, the structure of the communities that are dependent on benthic production in riverine systems. For example, soft sediments are frequently dominated by burrowing organisms (like oligochaetes and lamprey ammocoetes), while hard sediments provide habitat for a diversity of plants and animals that live on or under rocks (such as periphyton and the larvae of many insects).

In northern regions, river ice may be one of the most important physical factors affecting river morphology and hydrology. Once ice cover becomes established, its most obvious effect is on water levels, with decreased flow in downstream areas and higher levels in upstream areas (Prowse and Gridley 1993). The formation of anchor ice alters the nature of streambed substrates and likely reduces biological activity in these areas (Prowse and Gridely 1993). However, ice scour can significantly influence streambed substrate and streambank characteristics during break-up and may represent the most severe type of physical disturbance in some northern rivers (Beltaos *et al.* 1993). In addition, ice-jam flooding plays an essential role in the maintenance of northern river deltas (Prowse and Gridley 1993).

3.2 Riparian Ecosystem

Riparian ecosystems are complex assemblages of organisms and their environment existing adjacent to and nearby flowing water. The riparian zone may be functionally defined as the zone of direct interaction between the terrestrial and aquatic environments. While riparian ecosystems may be defined on the basis of vegetation, hydrology, soils, and/or topography, such definitions serve more to confuse than to clarify the classification of these areas. For this reason, it is generally more helpful to define riparian zones in terms of their function than by their structure (Oliver and Hinckley 1987).

Although riparian zones differ widely in terms of their characteristics, they all share common functional traits that relate to the aquatic ecosystem. Specifically, riparian vegetation outside the river channel provides shade (which controls temperature and primary productivity), a source of plant detritus, and a source of terrestrial insects for the stream system (Culp and Davies 1985). In addition, riparian vegetation provides a source of large organic debris for the stream channel, which influences the routing of water and sediment, shapes habitat features, and provides a substrate for biological activity. On streambanks, the roots of trees and other plants increase bank stability and provide cover for aquatic organisms (Bilby and Bisson 1987). Furthermore, the plants on the floodplain tend to retard the movement of water, sediment, and floating organic debris during flood flows, which in turn reduces erosion and promotes sedimentation (Oliver and Hinckley 1987). This latter function is important for the maintenance and growth of deltas at the mouths of large rivers. Riparian areas also provide essential habitats for a diverse array of avian and mammalian species, particularly those that are dependent on aquatic or wetland resources.

Chapter 4

A Framework for Implementing the Ecosystem Approach in the Mackenzie River Basin

4.0 Introduction

In Canada, water managers are faced with the complex and difficult task of integrating the needs of diverse water users into comprehensive basin management policies. Historically, water quantity management in Canada has focused primarily on satisfying human needs for stable water supplies, flood protection, and electricity. While these uses of water resources produce important benefits, they may also result in serious conflicts between upstream and downstream jurisdictions. In some regions, apportionment agreements have been established (e.g., by the Prairie Provinces Water Board) to facilitate equitable sharing of water resources and, thereby, reducing conflicts (Lewis 1986). However, this traditional management approach generally does not consider the potential effects of alteration in stream hydrology on biological resources or their uses. As ecosystem protection has been identified as a high priority management goal, the ecosystem approach has been adopted to guide water management decisions in the Mackenzie River basin.

Implementation of the ecosystem approach on a site-specific basis requires a framework in which to express the environmental management policies that have been established for the ecosystem. In general, this framework is comprised of three functional elements. The first element is a statement of broad management goals for the ecosystem. These goals must reflect the importance of the ecosystem to local area residents and other Canadians. The second element of the framework is a set of objectives for the various components of the ecosystem which clarify the scope and intent of the ecosystem goals. The final elements of the framework are a set of ecosystem maintenance indicators and ecosystem metrics, which provide an effective means of measuring the level of attainment of each of the ecosystem goals and objectives. This framework is described in more detail in the following sections.

4.1 Development of Ecosystem Goals for the Slave, Liard, and Peel Rivers

Ecosystem goals are broad narrative statements that define the management goals that have been established for a specific ecosystem. Definition of management goals for the aquatic ecosystem is a fundamental step towards the development of defensible ecosystem maintenance indicators. Definition of these ecosystem goals requires input from a number of sources to ensure that societal values are adequately represented. Open consultation with the public should be considered a primary source of information for defining these goals. Government agencies, non-government agencies, and other stakeholders may also be consulted during this phase of the process. Specifically, information on the existing and potential uses of the aquatic resources within the basin and on concerns regarding resource developments (e.g., water diversions, hydroelectric projects, etc.) which could affect these uses should be solicited.

Recently, the federal and territorial governments have collaborated with northern residents to identify the interests and needs of the Northwest Territories in transboundary negotiations in the Mackenzie River Basin (Grey et al. 1990). During these consultations, four major areas of concern were identified with respect to aquatic resource management within the basin. These concerns were focused on northern ecosystem maintenance (including traditional lifestyles, wildlife and habitat, tourism and aesthetics, and fisheries resources), community drinking water supplies, navigation, and future economic development opportunities (related to both renewable and non-renewable resources). Likewise, the interests and needs of Yukon with respect to aquatic resources have been identified by Mactavish (1991). The four major areas of concern identified in Yukon included ecosystem productivity, traditional culture, cooperative hydroelectric development, and natural resource development. The ecosystem goals that are recommended for the Slave, Liard, and Peel river basins reflect these concerns to ensure that societal values are adequately addressed in resource management decision-making. Using the available information, a total of five broadly-based ecosystem goals are recommended:

(i) maintain the integrity of northern ecosystems (the term 'ecosystem integrity' is defined as the physical, chemical, hydrological, and biological conditions necessary to maintain a healthy and diverse aquatic ecosystem);
(ii) preserve traditional culture and subsistence lifestyles;
(iii) protect drinking water supplies;
(iv) maintain the navigability of northern rivers; and,
(v) provide economic development opportunities that are consistent with the principles of responsible stewardship.

Of the ecosystem goals listed above, maintenance of northern ecosystem integrity was identified as the most important long-term goal. While this document does not explicitly address navigation and potable water supplies, these water uses must be addressed in the Mackenzie River Basin Master Agreement and in the various bilateral agreements that are under development. Therefore, these water uses have also been considered in the following section on the development of ecosystem objectives for the Mackenzie River Basin.

4.2 Development of Ecosystem Objectives for the Slave, Liard, and Peel Rivers

The ecosystem goals identified previously are too general to support development and implementation of meaningful planning, research, and management initiatives. To be useful, these ecosystem goals must be further clarified and refined to establish ***ecosystem objectives*** that are linked more closely with ecosystem science (Harris *et al.* 1987). In turn, ecosystem objectives support the identification of ecosystem maintenance indicators, which provide important information for evaluating the health and integrity of the ecosystem, as a whole.

The ecosystem objectives for the transboundary reaches of the Slave, Liard, and Peel river basins were established using the interests and need papers developed by Yukon (Mactavish 1991) and the Northwest Territories (Grey *et al.* 1990; Letourneau *et al.* 1988). Hence, the following objectives incorporate the results of extensive public consultation. Nonetheless, further consultation may identify the need for refinements or alterations. In each case, the underlying rationale for the ecosystem objective has also been presented.

1a. *The aquatic, wetland, and riparian habitats within the Slave, Liard, and Peel river basins should be of sufficient quality and quantity to support communities of wildlife species that are healthy, diverse, reproducing, and self-sustaining, including those species which are hunted for food and trapped for subsistence use and income.*

> **Rationale:** Wildlife that feed on fish and other aquatic organisms are important components of the Slave, Liard, and Peel river ecosystems. They include birds, mammals, amphibians, and reptiles, and they occupy many ecological niches. Some are permanent residents of the ecosystem, while others are seasonal residents or migratory species.
>
> Many of the delta areas within the Mackenzie River basin have been identified as important rearing areas for wildlife species. In 1983, for example, over 90% of the muskrat lodges observed in the Slave River basin were located in the delta (EMA 1984b). However, delta areas are dependent on regular flooding to replenish nutrients for the growth of both terrestrial and aquatic plant species. In turn, these plants provide food and habitat for resident and transient wildlife species. Disruption of this cycle, through changes in the hydrologic regime and especially

reductions in spring flood levels, has the potential to severely affect sensitive wildlife species.

Every wildlife species is dependent on the maintenance of suitable environmental conditions, often with a narrow range of tolerance. Many mammalian and avian wildlife species are dependent on aquatic organisms as sources of food for themselves and for their young. In addition, the aquatic environment satisfies other requirements of these wildlife species. Changes in the quality and/or quantity of aquatic resources produced in the basin could result in adverse effects on susceptible wildlife species. These effects could, in turn, compromise the ability of aboriginal peoples to engage in subsistence lifestyles or result in the loss of country foods or income for trappers who are reliant on these species.

It should be noted that large portions of the Peel River basin is covered under the Gwich'in Comprehensive Land Claim Agreement and the Nacho Nyak Dun Final Agreement. Wildlife harvesting and management have been identified as key elements of both of these agreements (INAC 1992).

1b. *The aquatic, wetland, and riparian habitats within the Slave, Liard, and Peel river basins should be of sufficient quality and quantity to support communities of* ***aquatic organisms*** *that are healthy, diverse, reproducing, and self-sustaining, including those species which are utilized in the subsistence, domestic, sport, and commercial fisheries.*

Rationale: The Slave, Liard, and Peel rivers currently produce a wide range of fish species which contribute to the subsistence, domestic, sport, and commercial fisheries. Subsistence fishing is carried out by aboriginal peoples as an integral part of their traditional lifestyle. The rights of aboriginal peoples to fish for food, social, and ceremonial purposes have been confirmed by the Supreme Court of Canada (R. v. Sparrow); therefore, it is essential to assure continued access to fisheries resources. Domestic fishing is an important source of country foods for other northern residents. Sport fishing is a growth industry in Canada and represents an important source of revenue for many residents in the north. The commercial fishery in Great Slave Lake is well established and contributes more than 90% of the annual commercial harvest in the NWT. Disruption of any of these activities could have serious economic, social, and/or cultural consequences.

1c. *The aquatic, wetland, and riparian habitats within the Slave, Liard, and Peel river basins should be of sufficient quality and quantity to support **expanding recreational and aesthetic uses**.*

Rationale: Environmental aesthetics are more important in the north than in other areas of Canada because the 'pristine wilderness' is a major attraction for tourists to these areas. However, this tourism potential is not only based on the measured quality of aquatic resources, but also on the perception of an unspoiled wilderness. Major growth is occurring in activities associated with the wilderness experience, including sport fishing, hunting, nature excursions, and historical site visitations. Loss of the wilderness experience due to real or perceived impacts from resource developments may significantly limit future tourism and economic growth in the north.

2. *The aquatic, wetland, and riparian resources within the Slave, Liard, and Peel river basins should be of sufficient quality and quantity to support the **traditional cultures and subsistence lifestyles** of the aboriginal peoples who reside in these areas.*

Rationale: Living off the land is an integral component of the culture of the aboriginal people who live within the Mackenzie River basin. Recent court decisions and land claim settlements have recognized the rights of aboriginal peoples to engage in traditional lifestyles. However, maintenance of opportunities to pursue this traditional way of life depends directly on protection of the productivity of aquatic and riparian ecosystems, the potability of water sources, and the edibility of the fish and wildlife harvested from these areas. In addition, sites of cultural, spiritual, and archaeological value that may be affected by development activities must be protected.

3. *The aquatic resources of the Slave, Liard, and Peel rivers should be of sufficient quality and quantity to provide **potable water supplies** to the communities that currently utilize these resources.*

Rationale: The Slave River, Hay River, Great Slave Lake, Mackenzie River, and several other water bodies provide potable water for more than 16,000 residents in 12 communities in the NWT. In addition, communities within British Columbia and Yukon also utilize these water resources. Alteration of the hydrological characteristics of these water bodies could result in major direct costs to relocate community water supply intakes. Similarly, changes in the quality of these sources could require direct expenditures to upgrade water treatment systems, since existing water withdrawals require little treatment (Grey *et al.* 1990).

4. *The hydrological regime of the Slave, Liard, and Peel rivers should be such that the current **navigability** of these systems, and that of the Mackenzie River, is maintained.*

   Rationale: The Mackenzie River is the major navigable river system in the NWT. Communities all along its length are supplied with basic goods through an extensive commercial summer barging program. Future hydrocarbon-based development in the Mackenzie Delta/Beaufort Sea area could increase barge traffic by up to 300%. However, the rapids and shoals that occur at various locations on the river can seriously limit navigation even under natural conditions. Reduction in flows during the late summer could drop water levels below the minimum required for maximum barge loads at these locations (Letourneau *et al.* 1988) or could impede the movement of other vessels (e.g., freighter canoes, etc.). Therefore, summer streamflows must be maintained at or above current levels to assure the navigability of the Mackenzie River.

   The watercourses within the Mackenzie River Basin also provide important transportation routes during the winter. After freeze-up, northern residents frequently travel along these systems by dogsled or snowmobile. Alterations in stream hydrology that alter the timing of freeze-up, the stability of river ice, or the timing of break-up could disrupt the navigability of these systems. Therefore, winter flows should be maintained at current levels within the Mackenzie River basin.

5. *Human activities and decisions regarding the management of natural resources within the Slave, Liard, and Peel river basins should embrace **environmental ethics** and should demonstrate a commitment to **responsible stewardship**.*

   Rationale: Both NWT and Yukon are dependant on, and committed to, the development of natural resources to support their long-term economic, social, and cultural objectives. However, the litany of environmental problems (and their associated social and economic costs) that have become evident in recent years indicate that many economic development projects are not as benign or cost-effective as purported by

> developers and politicians. The sensitivity and importance of aquatic and riparian resources in the Slave, Liard, and Peel river basins necessitate that we accept responsibility for maintaining the existing structure of these ecosystems, preserving biological diversity in the north, and following the principles of sustainable use of resources. Responsible stewardship includes aggressive conservation education, advocating and supporting environmentally-sound behaviour in individuals, communities, corporations, and governments, and implementing scientifically-based programs for the management of aquatic and riparian resources.

4.3 An Approach to the Development of Ecosystem Maintenance Indicators

The ecosystem objectives that have been proposed are narrative statements that reflect and focus the ecosystem goals for the Slave, Liard, and Peel river basins. These ecosystem objectives pertain to each of the transboundary river systems under consideration in this document. However, it is not possible to measure attainment of these objectives directly. For this reason, implementation of these ecosystem objectives necessitates the development of physical, chemical, and biological indicators which will provide more direct measurements of the most important attributes of the ecosystem.

The term '**indicator**' is used in a variety of environmental applications and is, generally, defined as a feature of the environment which provides managerially and scientifically useful information on the quality of the ecosystem as a whole. If measurements of these attributes fall within acceptable bounds (targets), it is assumed that the ecosystem as a whole is being protected. In the north, ecosystem maintenance has been identified as an environmental management priority because northern residents are dependent on aquatic and riparian resources. For this reason, specific indicators, termed '**ecosystem maintenance indicators (EMIs)**,' will be identified in this study to support the establishment of transboundary agreements on the Slave, Liard, and Peel rivers. In this study, EMIs are defined as components of aquatic and riparian ecosystems which provide information on the health and vitality of the ecosystem as a whole (i.e, indicator species).

The choice of EMIs is of paramount importance if the biological integrity and the human uses of the ecosystem are to be adequately addressed and protected. For this reason, a procedure for evaluating candidate EMIs for the transboundary rivers within the Mackenzie River Basin has been developed and is described in Chapter 5. Evaluation of candidate ecosystem maintenance indicators is dependent, in part, on the availability of information that links changes in the biological elements of the ecosystem to alterations in the hydrological regime. As such, a brief summary of the available data on the biological effects of hydrological alterations has been compiled and is presented in Chapter 6. This information may be used in the evaluations of the candidate EMIs that have been identified for the Slave, Liard, and Peel river basins, as discussed in Chapters 7, 8, and 9, respectively.

Ecosystem metrics are also required to define acceptable ranges (or targets) for various attributes of the EMIs. These metrics provide a means of focusing environmental monitoring programs and determining if the ecosystem goals and objectives have been achieved. In the future, it will be necessary to establish metrics (and acceptable ranges) for the suite of EMIs that are ultimately selected for the Slave, Liard, and Peel river basins. However, that step is beyond the scope of the current study.

Chapter 5

Development of Selection Criteria for Identifying Ecosystem Maintenance Indicators

5.0 Introduction

River and stream corridors provide a variety of valuable natural resources, including aquatic habitat for fish and other organisms and riparian habitat for terrestrial wildlife. In addition to supporting rich and diverse biological communities, these unique ecosystems are central elements of the traditional lifestyles that are practised by northern residents. In many areas, however, expanding populations and the need for economic growth have increased pressures for altering natural flow patterns to enhance hydroelectric power production and other anthropogenic developments (Brown *et al.* 1992). In the north, as in other areas, these alterations in the hydrological regime have the potential to significantly affect both aquatic and riparian ecosystems. Ecosystem maintenance indicators will provide an efficient and cost-effective basis for averting adverse effects on water uses in the Slave, Liard, and Peel river basins.

There are a wide range of indicators that could be used to evaluate the health and vitality of northern riverine ecosystems relative to changes in the hydrological regime. In the past, physical indicators such as maximum and minimum discharge have been used to provide a means of identifying gross changes in the hydrological regime. In turn, this type of information has been used to assess the impacts of such changes on downstream water uses, such as irrigation or domestic water supplies. Similarly, chemical indicators (such as total suspended sediment and/or nutrient concentrations) have been used to assess the nature and extent of modifications in the abiotic components of the ecosystem that are related to changes in hydrological regime. Subsequent comparison of monitoring data to established water quality guidelines (e.g., Canadian Water Quality Guidelines; CCREM 1987) allowed water managers to determine the degree to which downstream water uses were affected by hydrological changes.

More recently, significant effort has also been directed at the development of biological indicators of ecosystem integrity or biocriteria, (as they are commonly referred to in the United States). These biological indicators may apply to one or more levels of organization and encompass a large number of metrics ranging from biochemical variables to community parameters. Ideally, environmental monitoring activities would include each of the physical, chemical, and biological variables that could, potentially, be affected by alterations in the hydrological regime of these northern rivers. However, limitations on human and financial resources preclude this possibility. For this reason, it is necessary to develop selection criteria to support the identification of the most appropriate EMIs for the Mackenzie River Basin.

5.1 Approaches to the Development of Criteria for Ecosystem Indicator Selection

Detailed data on every ecosystem component that has significant biological, social, and/or economic relevance would provide comprehensive information for assessing ecosystem integrity and supporting environmental management decisions. However, it is virtually impossible to measure everything in the environment. Therefore, it is necessary to select a suite of indicators that will meet the specific needs for timely and cost-effective environmental information.

A number of approaches have been used to establish criteria for selecting ecosystem indicators in various jurisdictions. For example, the International Joint Commission (IJC) recently proposed a framework for developing biological indicators of ecosystem health (IJC 1991). This document provides detailed guidance on the development of ecosystem management goals, the establishment of monitoring programs to assess attainment of these goals, and the identification of physicochemical, biological, and sociological indicators of ecosystem health. Likewise, Environment Canada has proposed a national framework for developing biological indicators for evaluating and reporting ecosystem health (DOE 1993) and specific guidance on their application (DOE 1991). The common elements of each of these approaches are the need to identify the purpose of the resultant monitoring data and the desirable characteristics of the final ecosystem indicators.

Identification of the purpose of the monitoring data is a central consideration in the selection of ecosystem maintenance indicators. The IJC (1991) recognized five distinct purposes for which environmental data are collected, including:

- **Assessment** - assessing the current status of the environment in order to determine its adequacy for supporting specific uses (i.e., fish and aquatic life). That is, monitoring the attainment of the ecosystem objectives;

- **Trends** - documenting trends in environmental conditions over time. That is, monitoring the degradation, maintenance, or rehabilitation of the ecosystem under consideration;

- **Early Warning** - providing an early warning that hazardous conditions exist before they result in significant impacts on sensitive and/or important components of the ecosystem;

- **Diagnostic** - identifying the nature of any hazardous conditions that may exist (i.e., the specific causes of ecosystem degradation) in order to develop and implement appropriate management actions to mitigate against adverse impacts; and,

- **Linkages** - demonstrating the linkages between indicators to improve the effectiveness and efficiency of monitoring programs and to reinforce the political will to make environmentally sound management decisions.

It is important to identify the ultimate purpose of the monitoring data because no single indicator will be universally applicable in every application. For example, because of their relative tolerance of environmental stressors (that is, it is unlikely that they would be eliminated by even large changes in environmental conditions), midge larvae (Chironomidae) may represent suitable indicators for assessing long-term trends in ecosystem integrity. However, this same trait would also make them quite inappropriate for use as early warning indicators. By clearly stating the anticipated uses of the monitoring data, it is possible to evaluate candidate indicators in the context of their applicability to the specific monitoring program under development.

The characteristics of individual ecosystem indicators have also been used as a basis in their selection for specific management applications. The desirable characteristics of indicators of ecosystem integrity have been listed by various researchers (e.g., Ryder and Edwards 1985; IJC 1991) and summarized by Environment Canada (Table 2; DOE 1993). In addition, the IJC (1991) has developed a system for evaluating individual indicators that is based on the purpose of the indicators and their characteristics (Table 3). This system was developed primarily to address environmental quality issues in the Great Lakes Basin. In contrast the EMIs for the Mackenzie River Basin are intended to support assessments of the biological effects associated with alterations in hydrological regimes. While the selection of indicators in the Great Lakes was supported by an extensive scientific information base, northern rivers have not been characterized as rigorously. Nonetheless, the IJC (1991) system provides a valuable model for establishing appropriate criteria for selecting EMIs for the Slave, Liard, and Peel river systems.

Table 2. Desirable characteristics of ecosystem indicators.

Characteristic of Indicator	Definition / Rationale
Hydrologically relevant	Known to be sensitive to changes in the hydrological regime.
Biologically relevant	Important in maintaining a natural community and indicative of other components of the ecosystem.
Socially relevant	Of obvious value to, and observable by, shareholders or predictive of a measure that is.
Sensitive	Responsive to stressors without an all-or-none response or extreme natural variability.
Broadly applicable	Responsive to many stressors and appropriate for many sites.
Diagnostic	Of the particular stressor causing the problem.
Measurable	Capable of being operationally defined and measured, using a standard procedure.
Interpretive	Capable of distinguishing acceptable from unacceptable conditions.
Cost-effective	Inexpensive to measure, providing maximum information per unit effort.
Integrative	Capable of summarizing information from many unmeasured indicators.
Historic data available	Possible to define natural variability, trends, and acceptable conditions using scientific data and/or traditional environmental knowledge.
Anticipatory	Capable of identifying degradation before serious harm has occurred.
Nondestructive	Of the ecosystem (that is, the process of measuring the indicator should not harm the ecosystem).
Continuity	Capable of supporting long-term monitoring activities.
Appropriate scale	Applicable to the whole area under consideration.
Lack of redundance	Capable of providing unique information from that provided by other indicators.
Timely	Capable of providing information before unacceptable damage has occurred.

From IJC (1991), with slight modification.

Table 3. The importance of each characteristic of candidate ecosystem indicators relative to the anticipated uses of the resultant environmental monitoring data.

Characteristic of Indicator	Purpose of Monitoring Program				
	Assessment	Trends	Early Warning	Diagnostic	Linkages
Hydrologically relevant	3	3	3	2	3
Biologically relevant	3	3	2	2	2
Socially relevant	3	3	2	2	2
Sensitive	*	*	*	*	*
Broadly applicable	2	2	2	1	1
Diagnostic	1	1	1	3	1
Measurable	*	*	*	*	*
Interpretive	3	3	2	1	1
Cost-effective	*	*	*	*	*
Integrative	2	2	1	1	2
Historic data available	*	*	*	*	*
Anticipatory	1	1	3	1	2
Nondestructive	*	*	*	*	*
Continuity	2	3	1	1	1
Appropriate scale	*	*	*	*	*
Lack of redundance	*	*	*	*	*
Timeliness	2	2	3	3	2

Table entries are on a scale of importance from one to three., where one indicates lower importance and three indicates an essential attribute.
Characteristics that are universally desirable and do not differ between purposes are marked with an asterisk.
From IJC (1991), with slight modification.

5.2 Selection Criteria for Ecosystem Maintenance Indicators for Stream Systems in the Mackenzie River Basin

Ecosystem maintenance indicators for the Slave, Peel, and Liard rivers will be selected, primarily, to provide timely information on the integrity of these ecosystems relative to changes in the hydrological regime. In this application, it is essential that the suite of indicators selected facilitate identification of adverse environmental conditions ***before*** significant impacts occur on the structure or function of the ecosystem. Monitoring data collected in these three river systems will be used to assess trends in environmental quality and compliance with transboundary water quantity objectives that will be established under the various bilateral agreements that form part of the Mackenzie River Basin Master Agreement. Northern riverine ecosystems are not as well understood as systems in more temperate regions; hence, future monitoring should provide information on ecosystem structure and function. Therefore, effective EMIs should provide an early warning of impending environmental degradation, support the assessment of the status and trends in environmental quality conditions, and improve our understanding of the linkages between indicators.

There are a wide variety of ecosystem maintenance indicators that could be selected and integrated into long-term monitoring programs in the Mackenzie River Basin. As it is not possible to monitor each of the potentially important aspects of the ecosystem, it is necessary to select a limited suite of indicators that will provide useful information for assessing the status of the ecosystem overall. The development and use of selection criteria provide a consistent and defensible means of identifying the ecosystem maintenance indicators that are most appropriate for their designated purposes.

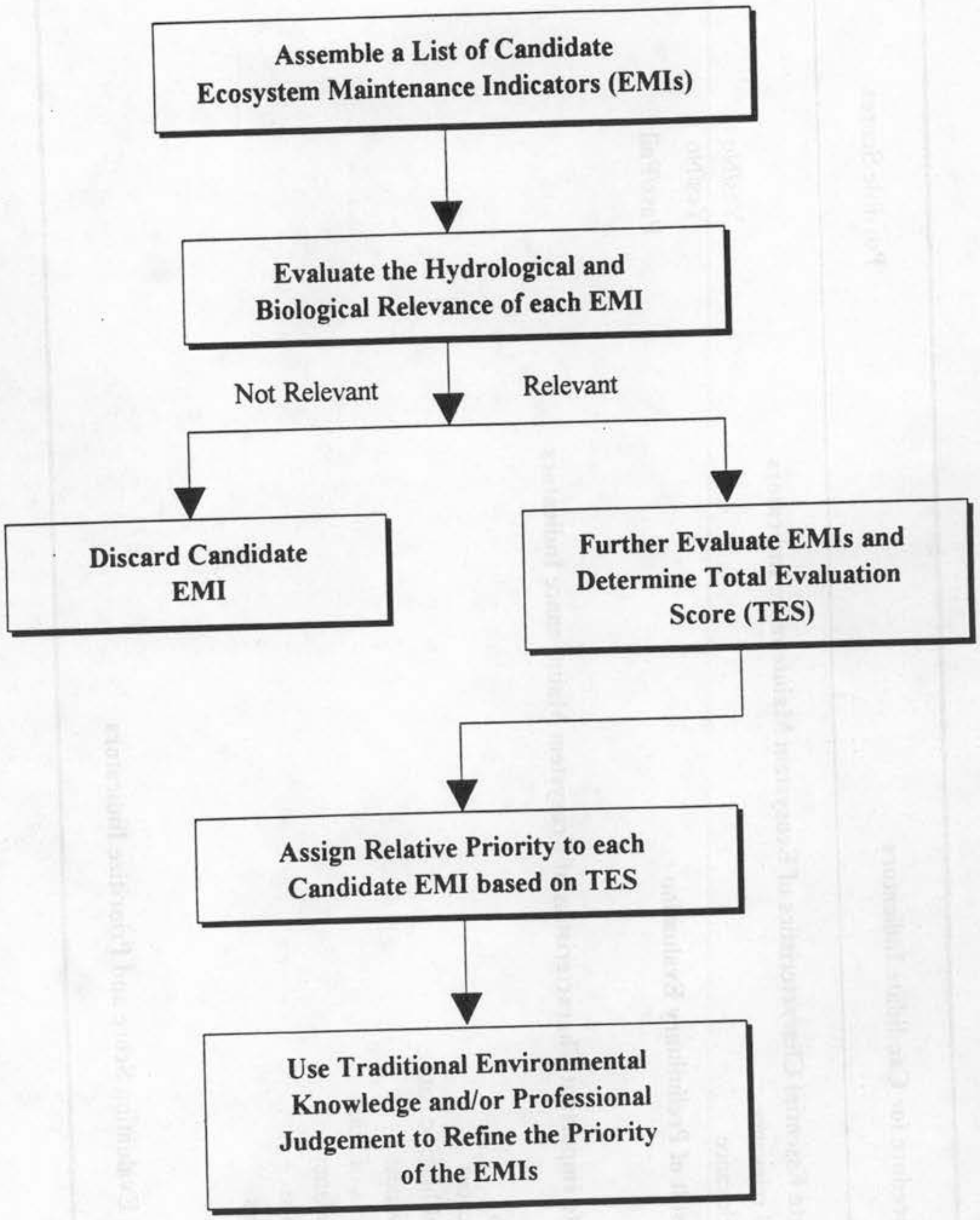
A two-stepped selection process is recommended for identifying ecosystem maintenance indicators for the transboundary rivers within the Mackenzie River Basin (Figure 3); Table 4). The first step in this process is to identify the most important characteristics of the indicators relative to the anticipated uses of the resultant monitoring data. To address the intended uses of the resultant environmental monitoring data, EMIs must be:

- **Hydrologically Relevant** - that is, candidate EMIs must be known to be sensitive to changes in the hydrological regime; and,

- **Biologically Relevant** - that is, candidate EMIs must be important for maintaining a balanced community and indicative of many other, unmeasured biological indicators.

Therefore, candidate ecosystem maintenance indicators should initially be evaluated in terms of their hydrological and biological relevance. Information which may be useful for

Figure 3. An overview of the proposed procedure for evaluating candidate ecosystem maintenance indicators (EMIs).



Note: See text for explanation of how the TES is calculated.

Table 4. A recommended procedure for evaluating candidate ecosystem maintenance indicators for the Slave, Liard and Peel river basins.

Evaluation Procedure for Candidate Indicators	Possible Scores	Possible Scores
Step 1 - Evaluate Essential Characteristics of Ecosystem Maintenance Indicators		
- Hydrological relevance	Yes/No	
- Biological relevance	Yes/No	
Determine Result of Preliminary Evaluation	**Pass/Fail**	
Step 2 - Evaluate Important Characteristics of Ecosystem Maintenance Indicators		
- Sensitivity		0, 1, 2
- Measurability		0, 1, 2
- Cost-effectiveness		0, 1, 2
- Availability of historic data		0, 1, 2
- Nondestructiveness		0, 1, 2
- Appropriateness of scale		0, 1, 2
- Lack of redundancy		0, 1, 2
- Social relevance		0, 1, 2
- Interpretiveness		0, 1, 2
- Anticipatory		0, 1, 2
- Timeliness		0, 1, 2
Calculate Total Evaluation Score and Prioritize Indicators		**0 to 22**

assessing the biological and hydrological relevance of candidate indicators is presented in Chapter 6. Candidate indicators that meet both of these criteria should be further evaluated to determine their relative applicability for evaluating the biological effects of alterations in the hydrological regime of the stream systems under consideration. Candidate EMIs that do not meet these criteria need not be considered further.

The second step in the selection process is to consistently apply a set of selection criteria to the remaining candidate EMIs. The IJC (1991) has identified seven characteristics of indicators of ecosystem health that are universally desirable, regardless of the intended use of the indicators. Four more characteristics have been identified based on their importance to the intended uses of the EMIs in the Mackenzie River Basin. Therefore, candidate indicators should fulfil each of the following criteria:

- **Sensitive** - that is, candidate EMIs should exhibit graded responses to environmental stresses, should not be tolerant of environmental changes, and should not exhibit extreme natural variability;

- **Measurable** - that is, candidate EMIs should have operational definitions and determination of their status should be supported by procedures for which it is possible to document the accuracy and precision of the measurements (easy to measure);

- **Cost-effective** - that is, candidate EMIs should be relatively inexpensive to measure and provide the maximum amount of information per unit effort;

- **Supported by historical data** - that is, sufficient scientific or traditional information should be available to support the determination of natural variability, trends, and targets for the ecosystem metrics;

- **Non-destructive** - that is, collection of the required data on the candidate EMIs should not result in changes in the structure and/or function of the ecosystem, or on the status of individual species;

- **Of the appropriate scale** - that is, candidate EMIs should be applicable for determining the status to the ecosystem as a whole, not only to limited geographic areas within the ecosystem; and,

- **Non-redundant** - that is, candidate EMIs should provide unique information on the status of the ecosystem.

- **Socially relevant** - that is, candidate EMIs should be of obvious value to, and observable by, stakeholders or be predictive of an indicator that has these attributes;

- **Interpretable** - that is, candidate EMIs should provide information which supports evaluations of the status of the ecosystem and compliance with the terms of transboundary agreements on water resources (acceptable ranges or targets should be definable);

- **Anticipatory** - that is, candidate EMIs should be capable of providing an indication that environmental degradation is occurring before serious harm has occurred; and,

- **Timely** - that is, candidate EMIs should provide information quickly enough to support the initiation of effective management actions before significant and lasting effects on the ecosystem have occurred.

Evaluation of candidate EMIs using the above criteria provides a means of prioritizing or ranking indicators in terms of their broad applicability and scientific-defensibility. For each of the characteristics identified, it is proposed that a score of 0 be assigned if an indicator does not have the desired characteristic. If it is unknown if the indicator has the desired characteristic, a score of 1 should be assigned. A score of 2 should be allocated if the indicator has the desired characteristic. A total evaluation score should then be calculated as the sum of the scores assigned for each characteristic. For example, candidate EMIs that have all of the desired characteristics would be assigned the maximum total evaluation score (TES) of 22.

The ES should be used to determine the relative priority of each of the candidate EMIs on the list that was previously developed. High scores indicate that the candidate indicator is highly applicable for the anticipated uses of the resultant monitoring data. Lower scores indicate that the candidate indicator is generally applicable for evaluating the status of the ecosystem, but would not provide information that is directly relevant for assessing environmental impacts and trends, for providing an early warning of impending damage to the ecosystem, and for establishing linkages. This system is designed to provide a consistent basis for evaluating and prioritizing candidate EMIs. However, is not intended to preclude the use of traditional environmental knowledge and/or professional judgement in the EMI selection process.

Ideally, adequate information would be available to support a comprehensive evaluation of each of the candidate EMIs that are identified. In reality, however, insufficient data may be available to fully evaluate many of the candidate EMIs that are identified in this document. For this reason, it will be difficult to develop a prioritized list of EMIs using the scoring system alone. It is anticipated that both traditional environmental knowledge and professional judgement will also be required to complete the EMI evaluation process. A workshop involving regional experts and scientists would provide an efficient means of obtaining the additional information needed to finalize a suite of EMIs for the Mackenzie River Basin.

Chapter 6

Linkages Between River Hydrology and the Biological Components of Aquatic and Riparian Ecosystems

6.0 Introduction

Development of meaningful ecosystem maintenance indicators for evaluating the ecological significance of changes in the hydrological regime of the transboundary rivers in the Mackenzie River Basin requires the establishment of linkages between developmental activities, changes in the physical and chemical environment, and effects on the biological components of the ecosystem. Establishment of these linkages provides a scientific basis for identifying sensitive indicators that will provide tools for detecting changes in the ecosystem before serious damage has occurred and for assessing the impacts of these alterations. In addition, data from carefully designed monitoring programs will support the assessment of trends in environmental quality and the further understanding of the linkages between the hydrological and biological characteristics of the ecosystem.

The available information on the environmental impacts associated with the construction and operation of the WAC Bennett Dam on the Peace River provides valuable insight for identifying the effects of changes in the hydrological regime within the Mackenzie River basin. However, these data are by no means comprehensive. For this reason, information on other river systems that have been affected by certain development activities (such as dam construction, water diversion, and logging) was assembled and reviewed to supplement the site-specific data on the Peace River. It should be noted that a great deal of information exists on this topic and that the following discussion is not intended to provide an exhaustive review of the literature. Instead, relevant examples are presented to provide an overview of the functional linkages that exist in riverine ecosystems.

6.1 Potential Influences on the Hydrological Regime of the Mackenzie River Basin

There are a wide range of anthropogenic developments that could, potentially, influence the hydrological regime of the transboundary streams within the Mackenzie River basin. These include hydroelectric power projects, water diversions, land use patterns, and several consumptive water uses. Global climate change also has the potential to result in significant alterations in the hydrological characteristics of northern rivers. However, this issue is beyond the scope of the Mackenzie River Basin Master Agreement and, hence, is not considered in this discussion paper. Nevertheless, resource managers must be cognisant of the potential effects of climate change on stream hydrology and design effective monitoring programs to dissociate these effects from those resulting directly from activities in upstream areas.

Hydroelectric power developments probably have the potential to cause the most severe and long-lasting effects on stream hydrology in the study area. To date, three dams have been constructed in the Mackenzie River Basin, including the WAC Bennett and Peace Canyon dams on the Peace River in British Columbia and the Tazin Lake dam on the Charlot River in Saskatchewan. In addition, hydroelectric power developments have been considered at 12 sites in the Peace River drainage, two sites in the Athabasca River drainage, and at one site on the Slave River mainstem (MacDonald 1989). While various development proposals have been considered in the Yukon portion of the Liard River basin, potential developments in B.C. have received the most attention in recent years. Specifically, B.C. Power and Hydro Authority has now selected a project design that involves the construction of two dams on the Liard River upstream of the B.C.-NWT border (MESL 1992). In the Peel River basin, at least five sites that have significant hydroelectric power development potential have been identified, one on the Snake River, two on the Bonnett Plume River, and two on the Rat River (Simpson 1988). However, it is not clear if feasibility studies have been completed on any of these sites.

Major river diversions, either out of the Mackenzie River basin or between sub-basins, have the potential to significantly alter the existing hydrological regimes of the Slave, Liard, and/or Peel river systems. However, the Mackenzie River Basin Committee has adopted the prohibition of major river diversions in or out of the basin as a management principle. While large, international water transfers have been considered in the past, the technical, economic, and political difficulties associated with these projects have, thus far, prevented their implementation. Nonetheless, increasing demands on water resources in California and other dry states will continue to catalyze the proposition of outrageous transboundary water diversion projects, that could include drainages within the Mackenzie River basin. Of more imminent concern, perhaps, are the plethora of headwater diversion projects that have been proposed to supply water to the drier areas of southern Alberta (Grey *et al.* 1990). Sub-basin water transfers have already occurred in Saskatchewan, where the waters of the Tazin River have been diverted from the Great Slave Lake sub-basin to the Lake Athabasca sub-basin to augment hydroelectric power generation at the Tazin Lake site (Grey *et al.* 1990).

Of the existing land uses in the Mackenzie River basin, forest management activities probably have the greatest potential to influence stream hydrology. In the Slave River basin, there are at least 10 operating pulp mills which, collectively, produce nearly 6000 metric tonnes of pulp per day (MacDonald 1989). Assuming that each of these mills operates for about 300 days per year, at least 1.8 million m^3 of timber would be required annually to support these operations (MacDonald 1989). In addition, several large scale expansions and new pulp mills have been proposed within this area, which could utilize a further 2.8 million m^3 of timber annually. It is difficult to estimate how much timber is processed at the myriad saw mills that operate within this drainage basin. While there are no pulp and paper operations in the Liard River basin, approximately 0.98 and 0.20 million m^3 of timber (3600 ha) are harvested annually in British Columbia and Yukon, respectively, most of which is used to produce lumber and plywood. However, some of this timber is still exported as raw logs (MESL 1992). No information was located on logging activities in the Peel River basin. Large scale timber harvest activities, along with accidental fires and prescribed burns (for wildlife management or other purposes), have the potential to cause transient alterations in the drainage patterns in affected watercourses and the streamflow conditions at transboundary sites. Subsequent conversion of forested lands to agricultural lands could result in longer lasting hydrological impacts.

Other land use activities also have the potential to affect stream hydrology. For example, certain flood control projects, such as dyking, are likely to have only limited and local effects on stream flow characteristics; however, impoundment construction or ice dam demolition activities could have more far-reaching impacts. In general, the hydrological effects of mining activities and urbanization would be localized, although there is potential for significant water transfers and diversions. Likewise, the consumptive uses associated with municipal developments, local agriculture, and industrial activities are likely to be minor compared to the other anthropogenic activities discussed previously. However, when large land areas are affected by consumptive uses, then significant impacts on water resources may be predicted. A summary of the potential effects of land and water use activities on stream hydrology is presented in Table 5. Workshop participants are encouraged to identify the relationships between development activities and hydrological/habitat variables.

6.2 Potential Effects of Anthropogenic Developments on the Existing Hydrological Regimes of the Slave, Liard, and Peel Rivers

Of the existing and proposed activities in the Mackenzie River basin, hydroelectric power developments probably have the highest probability of affecting hydrological regimes. The effects of hydroelectric developments on downstream water quantity can occur both during the construction and operational stages of development. During construction, suspended sediment transport may be increased due to the extensive use of fill materials in the building of earthen dams or diversion channels. Subsequent deposition in low velocity stream reaches can be expected, with associated impacts on substrate quality (Hirst 1991).

Table 5. Potential effects of anthropogenic developments on stream hydrology and habitat.

Land/Water Use Activity	Flow-related Factors									Ice-related Factors							Water Quality-related Factors						
	Peak Flow - Magnitude	Peak Flow - Duration	Probability of Flooding	Low Flow - Magnitude	Low Flow - Duration	Mean Monthly Flow	Water Velocity	Water Level	Water Storage	Timing of Ice Formation	Location of Ice	Quantity of Ice	Stability of Ice	Duration of Ice Cover	Timing of Ice Break-up	Probability of Ice Jamming	TSS Concentrations/Loadings	Nutrient Concentrations	Trace Metal Concentrations	Organics Concentrations	Water Temperature	Dissolved Oxygen Levels	Organic Carbon Loadings
Impoundment (Hydro)																							
- Construction																							
- Operation																							
Water Diversion																							
- Large-scale																							
- Small-scale																							
Forest Management																							
- Clear-cutting																							
- Selective harvest																							
- Prescribed burns																							
Consumptive Uses																							
- Municipal																							
- Agriculture																							
Land Uses																							
- Urbanization																							
- Agriculture																							
- Mining																							
- Flood control																							
- Wildlife management																							
Climate Change																							
Other Activities																							
-																							
-																							

Table 5. Potential effects of anthropogenic developments on stream hydrology and habitat (continued).

Land/Water Use Activity	Instream Geomorphic Factors										Riparian Zone Factors												
	Stream Width	Stream Depth	Stream Gradient	Pool/Riffle Ratios	Substrate Composition	Substrate Stability	Quantity of LOD	Quantity of Instream Cover	Channel Morphology		Quality of Shoreline Habitat	Extent of Flooding	Duration of Flooding	Timing of Flooding	Frequency of Flooding	Degree of Ice Scour	Rate of Sedimentation						
Impoundment (Hydro)																							
- Construction																							
- Operation																							
Water Diversion																							
- Large-scale																							
- Small-scale																							
Forest Management																							
- Clear-cutting																							
- Selective harvest																							
- Prescribed burns																							
Consumptive Uses																							
- Municipal																							
- Agriculture																							
Land Uses																							
- Urbanization																							
- Agriculture																							
- Mining																							
- Flood control																							
- Wildlife management																							
Climate Change																							
Other Activities																							
-																							
-																							

After the completion of construction activities, the reservoir filling period is typically characterized by severe flow depletions in downstream areas and major attenuation of natural sediment transport regimes (Baxter 1977; GNWT undated).

During the operation phase of the project, high flows tend to be reduced, while low flows tend to be increased (Berkes 1989; Troelstrup and Hergenrader 1990; Wedel 1993). While overall variability in streamflow tends to decease, short-term variability in streamflows may increase substantially, with flow variations typical of seasonal changes occurring on weekly or even daily bases (Bain *et al.* 1988; Weisberg and Burton 1993). These large variations in streamflow result in changes in the water levels, depth, wetted width, velocity, and flooding in downstream areas (Morgan *et al.* 1991). Similarly, changes in the discharge patterns may result in decreased water temperatures in the summer and increased water temperature in the winter (Penczak *et al.* 1984). Changes in the water temperature and flow regimes can also have serious impacts on a number of ice-related variables (such as timing of ice formation, ice thickness and stability, and timing of break-up; Kellerhals and Gill 1973). Changes in suspended sediment concentrations and loadings, turbidity, total organic carbon concentrations, and nutrient concentrations have also been observed downstream of large impoundments (Baxter 1977; Nelson *et al.* 1987).

Large scale water diversions have the potential to seriously impact the hydrological regimes of transboundary river systems. Unlike hydroelectric power developments, which tend to alter the timing of stream discharge, water diversions actually affect the total discharge of affected watercourses. As such, streamflows may be reduced or increased during both open water and ice cover periods. For example, the Kemano Completion Project on the Nechako River (B.C.) is expected to result in an 84% decrease in the total annual discharge of this system (Mundie and Bell-Irving 1986). Such reductions in streamflow will, undoubtedly, result in reductions in the available spawning and rearing habitat (Slaney *et al.* 1983). The frequency and severity of flooding events, which are essential for maintaining wetland habitats, will also be reduced. Reductions in suspended sediment loadings will also be associated with reduced streamflows, which could affect the stability of river delta areas.

Large scale water diversions will also influence water temperatures in affected rivers, resulting in increased temperatures during in the summer and decreased temperatures in the winter (Mundie and Bell-Irving 1986). Changes in water temperature will also cause alterations in the timing, duration, and severity of ice cover conditions. In turn, these alterations could affect the morphology of riverine habitats.

Clearcut logging activities can cause marked changes in the hydrological regimes of watercourses located nearby the area of disturbance and those located downstream. The direction and degree of change in water yield after timber harvest are a function of: the area cut as a percent of the given watershed; the species of tree harvested; the density of the stand harvested; and the local topography of the area affected (Verry 1986). Of these, the percentage of the watershed cut and the local topography are probably the most important.

Investigations into the effects of clearcutting hardwood forests suggest that streamflows are likely to increase during the period of harvest and for up to 3 years thereafter (Hornbeck *et al.* 1986). Annual increases in water yield of up to 114% over background were recorded in Hubbard Brook, New Hampshire after strip and clearcutting activities were initiated. Large increases in streamflow were also reported after clearcutting aspen forests in Minnesota (Verry 1972). These data suggest that measurable and significant increases in streamflow are likely to be observed in stream reaches located near harvesting operations. While changes in the hydrological regime of the Slave, Liard, and Peel rivers as a result of widespread timber harvest are possible, these alterations are likely to be masked by large streamflows and the effects of hydroelectric developments.

6.3 Potential Effects of Changes in the Hydrological Regime on the Aquatic and Riparian Ecosystems of the Mackenzie River Basin

Changes in the hydrological regime of large rivers can have significant and lasting impacts on the organisms that reside in the basin. These impacts are not confined to stream habitats, but extend to the biota of the deltas and the adjacent riparian areas (Fraser 1972). The nature, extent, and severity of these biological impacts are likely to be dependent on the types of hydrological changes that occur, as well as their duration and magnitude. The following discussion is not intended to provide a comprehensive review of the literature on the biological effects of developmental activities that influence stream hydrology. Instead, it is designed to illustrate the functional linkages between the biotic and abiotic environment, as they relate to hydrological variables.

6.3.1 Alterations in Stream Discharge

Changes in the magnitude and duration of streamflow events are likely to be associated with a range of effects on the organisms that utilize stream and riparian habitats, including aquatic plants, benthic macroinvertebrates, fish, birds, and mammals. However, the nature and severity of these effects vary between species and between taxonomic groups, primarily because each organism has unique habitat requirements.

The relationships between discharge and the status of benthic macroinvertebrate communities are complex and difficult to quantify. Nonetheless, information from a number of studies indicate that the structure of benthic invertebrate communities is significantly affected by high flow conditions (Fisher 1982; Sousa 1985; Resh *et al.* 1988). For example, storm-related flooding was associated with large reductions in the abundance of caddisfly larvae (late instar) in a California stream over a period of four years (Feminella and Resh 1990). The densities of late instar caddisfly larvae were not affected by moderate peak streamflow events; however, smaller adults with lower fecundities were produced under these conditions. In contrast, the densities of middle instars appeared to be independent of the magnitude of peak discharge. These data indicate that even different life stages of the same species can respond very differently to flow alterations. Hence, it is dangerous to make generalizations based on limited data.

Allen (1959) reported that high flows affected insect densities differently depending on the stability of the substrate. The most dramatic effects were observed in areas with unstable substrates, while less severe effects occurred in areas that were dominated by large diameter bed materials. In addition to the composition of bed materials, substrate stability is also dependent on the average gradient and depth of the river (Cobb *et al.* 1992).

Alterations in stream discharge have been associated with both positive and negative effects on freshwater fish. For example, increased feeding and growth rates were observed in white perch, yellow perch, and channel catfish downstream of the Conowinga Dam (Maryland) when minimum flows were maintained throughout the summer low flow period (Weisberg and Burton 1993). Likewise, increases in the number and total biomass of brown trout have been observed in the North Esk-St. Patricks River (Tasmania) when mean annual streamflow was increased by a factor of three (Davies *et al.* 1988). These investigators concluded that increased flow in the shallow headwater streams, particularly during low flow periods, resulted in increased survival of juvenile trout and improved reproductive success.

Negative effects on riverine fish communities have also been reported when natural stream discharges have been altered. While abundance of fish in reservoir tailwaters tends to be higher than it is in unregulated systems, these populations also tend to be less stable. For example, Jacobs and Swink (1983) reported that fish populations, particularly cyprinids (minnows) and catastomids (suckers), in the tailwater of the Barren River Lake Reservoir in south central Kentucky were less stable than those in an unregulated stream. These investigators concluded that altered flow, low summer water temperatures, and poor summer water quality were probably responsible for the unstable fish populations in the tailwater. Similarly, the growth of rainbow trout juveniles was compromised when discharge was reduced by 32% and 60% in experimental stream channels, presumably due to reduced habitat area and, hence, increased competition for the available food resources (Rimmer 1985).

Large-scale reductions in fish spawning habitat have also been observed in association with decreased streamflows downstream of major impoundments. In the Trinity River, California, spawning habitat was reduced by 44% in downstream areas following the construction of the Lewiston Dam, with as much as 80 - 90% of the habitat eliminated in certain stream reaches (Nelson *et al.* 1987). Accordingly, the population of fall-run chinook salmon decreased from approximately 71,000 to about 11,250 fish. The main cause of the habitat reduction was the loss of flushing flows associated with natural flood events and high sediment production from extensive land use disturbances.

6.3.2 Short-Term Variability in Stream Discharge

Short-term variability in stream discharge is frequently associated with the operation of hydroelectric power generating facilities. Such short-term fluctuations in stream discharge may result in significant impacts on benthic invertebrate communities, due to increased bed and bank instability, dewatering of marginal habitats, higher invertebrate drift rates, and changes in food availability (Armitage 1984; Cushman 1985). For example, Troelstrup and Hergenrader (1990) reported invertebrate communities on artificial substrates that were subjected to daily fluctuations in flow averaged 3 taxa per sample (91 organisms/m^3), whereas an average of 12 taxa per sample (743 organisms/m^3) were observed on the substrates that were not subjected to daily fluctuations in discharge. Similarly, the total density of invertebrates, the abundance of individual taxa, and the quality of the invertebrate community all increased downstream of an impoundment when the operating regime was modified to eliminate rapid changes in streamflow (Morgan *et al.* 1991).

6.3.3 Water Velocity

Large short-term variations in velocity and depth can have a variety of direct effects on instream water uses. For example, Perry and Perry (1986) investigated the effects of flow regulation on stream invertebrates in the Flathead and Kootenai Rivers in Montana, and concluded that invertebrate drift was highly correlated with water velocity. Increased invertebrate drift rates were observed at high water velocities during both the ascending and descending limbs of the hydrograph. Therefore, changes in stream hydrology that result in increased water velocities could cause significant reductions in benthic invertebrate populations.

Alterations in the water velocity of river systems can also affect fish communities. For example, Bain *et al.* (1998) examined the effects of water velocity on the shallow and slow water fishes in the Connecticut River system. This group of fish, which included a total of 13 centrarchid, catostomid, and cyprinid species, was affected by artificially high variability in flow. Significantly, this fish guild was absent in river habitats with a mean current velocity of 21.5 cm/sec and present in river habitats with a mean current velocity of 8.1 cm/sec. These data emphasize the potential effects of alterations in the velocity of river systems.

6.3.4 Water Level and Depth

Variations in water level, and hence stream depth, can be associated with a range of adverse effects on the organisms that utilize aquatic and riparian habitats. Short-term variations in water level tends to cause dewatering of shallow shoreline areas and stranding of macroinvertebrates and fish utilizing these areas (Corrarino and Brusren 1983). In large systems, these nearshore areas tend to be the most productive, so repeated dewatering of these areas could cause severe effects on aquatic biota (Bain *et al.* 1988).

Variations in water level can also modify waterfowl habitat. Currently, migratory ducks and geese in the Slave River concentrate their nesting activities on low alluvial islands that are protected from terrestrial predators. Lowering of water levels during the spring and early summer could enlarge and coalesce some of these islands such that waterfowl no longer find them attractive for nesting (Kellerhals and Gill 1973). However, the results of a five-year study in Montana indicate that Canada goose productivity (i.e., hatching success) in the Thompson Falls reservoir (which was formed upstream of a run-of-the-river dam on the Clark Fork River) was not affected when water levels were altered by as much a 4 m during the nesting season (O'Neil 1988).

6.3.5 Flooding and Ice Scour

Flooding and ice scour are important hydrological processes which combine to shape aquatic and riparian habitats in northern river systems. In fact, annual northern river ice break-up is the environmental set point for the year (Milburn and Prowse 1993). Changes in the hydrological regime that result in reductions in the frequency, areal extent, or severity of flooding and ice scour events could have significant effects on the biological components of the ecosystem. For example, elimination of flooding can immediately alter the quality of floodplain and deltaic spawning habitats. Fish species, such as northern pike, spawn during high flows in delta and floodplain lakes that are not accessible during low flow conditions. Elimination of this spawning habitat as a result of low streamflows would adversely affect this species (Kellerhals and Gill 1973). Likewise, Bidgood (1971) demonstrated that low water levels in the Peace-Athabasca Delta between 1968 and 1971 were detrimental to walleye, due both to trapping of walleye fry in shallow lakes and to fungal infection in post-spawn adults.

Reduced flooding and ice scour could enhance succession of rapidly growing willows on alluvial islands, which could make them unsuitable for nesting by migratory ducks and geese. Invasion of woody vegetation into riparian areas and alluvial islands could also decrease the abundance of grasses and sedges. As these plants tend to be important food sources for migrating and nesting waterfowl, reductions in their abundance could affect the survival or reproduction of these species.

Aquatic mammals are dependent on the effects of flooding and ice scouring to maintain the natural productivity of northern floodplains. For example, muskrats tend to utilize shallow water systems as breeding and rearing habitats because they provide an abundance of food and cover. In the Peace-Athabasca Delta, reductions in the frequency and magnitude of flooding (due to regulation at the WAC Bennett Dam) has resulted in significant losses of muskrat habitat due to the drying of small lakes and the shrinkage of larger lakes (Dirschl 1971). Moreover, the decrease in the depth of these waterbodies can result in freezing to the bottom, which effectively eliminates muskrat populations (Kellerhals and Gill 1973). Artificial delay of ice breakup can also affect muskrat populations by eliminating the possibility of multiple litters in a single year by older females (Stevens 1955).

6.3.6 Water Temperature

Water temperature is one of the most basic and important variables in the environment. Water temperature influences the rate of every biological process that occurs in aquatic ecosystems. The direct effects of unfavourable temperature regimes on aquatic organisms include acute toxicity (by exceeding the thermal tolerance limits, TTL, of one of the life stages of a sensitive species), disruption of metabolic processes, and alteration of developmental processes (Alabaster and Lloyd 1980). The biological significance of temperature changes depends on the magnitude of the modification and the organism's capability to adapt to that change.

In large northern rivers, water temperatures are unlikely to approach or exceed the TTLs of resident species. However, alterations in water temperature could result in significant biological effects that have the potential to disrupt the integrity of the aquatic ecosystem. For example, decreased water temperature during the summer period could decrease the growth and productivity of many aquatic organisms (Beschta *et al.* 1987). This is important in northern ecosystems because growth rates are typically lower than they are in more temperate climates, and further reductions could result in delayed maturity, smaller size at a given age, and lower fecundity.

The development of the embryos of fall-spawning fish species could be affected by alterations in the winter temperature regime. For example, Alderdice and Velsen (1978) reported that salmonid egg and alevin development is closely related to water temperatures. Increased water temperatures during the winter would accelerate development and result in premature emergence from the gravel substrate. The survival of salmonid fry could be lower if the necessary food sources are not available or if other habitat variables are unfavourable at the time of emergence.

Alteration of river water temperatures can also have significant effects on fish communities. For example, Penczak *et al.* (1984) studied the effects of impoundment on fish taxocenes (communities) in the Speed River (Ontario). The results of these investigations indicated that the fish taxocene was altered after the construction of a dam on the river. Three new fish species appeared and four fish species were eliminated in downstream reaches following dam construction. These researchers attributed the changes in the fish community to changes in water temperature associated with the release of cold water from the hypolimnion during the summer.

6.3.7 Sediment Transport

The biological effects of fine inorganic sediment have been studied extensively over the past 50 years (see Cordone and Kelly 1961; Langer 1980; Newcombe and MacDonald 1991 for reviews). While the majority of this research has focused on the assessment of the direct toxicity of suspended sediments (TSS) to aquatic biota, alteration of sediment transport regimes may also result in habitat degradation. Depending on the species considered and the areas affected, habitat degradation may result in serious impacts on aquatic and riparian ecosystems.

The impacts of elevated levels of suspended sediments occur at three levels, including lethal effects (direct acute or chronic toxicity), sublethal effects (decreased growth or reproduction, increased metabolic rate, etc.), and behavioural effects (avoidance responses, changes in migration patterns, etc.; Alabaster and Lloyd 1980). Newcombe and MacDonald (1991) developed a model for assessing the impacts of suspended sediments in aquatic organisms. This model demonstrated that the severity of effects was dependent on both the concentration of suspended sediments and the duration of exposure. Subsequently, MacDonald and Newcombe (1994) developed a framework for identifying the types of effects that would be associated with pollution episodes of various intensities (where intensity = concentration of TSS x duration of exposure). This framework indicates that reductions in the intensity of suspended sediment episodes, which are likely to be associated with certain changes in the hydrological regime, would have a beneficial effect on aquatic organisms.

The transport and deposition of fine inorganic sediment in stream systems are natural processes, which are dependent on a number of site-specific factors. Certain land use activities, such as logging and road building, tend to accelerate sediment production. However, other activities, such as dam construction, tend to reduce sediment transport in downstream areas (Reid and Dunne 1984). In general, the deposition of fine sediment in stream ecosystems is detrimental to aquatic organisms, causing reductions in streambed substrate permeability (McNeil and Ahnell 1964; Koski 1972) and stability (Cobb *et al.* 1992). In turn, these alterations in the physical environment can decrease egg-to-fry survival rates in fish (Valiela *et al.* 1987), reduce benthic macroinvertebrate production (Tebo 1955; Gammon 1970; Slaney *et al.* 1977), and smother periphyton communities (Langer 1980). Together, these data suggest that reductions in sediment transport would, generally, be beneficial to aquatic biota. However, habitat degradation can still occur under reduced sediment transport regimes if flushing flows are decreased or eliminated (Burt and Mundie 1986; Nelson *et al.* 1987).

While decreased sediment transport may be beneficial in many situations, it may be harmful in others. For example, river deltas are formed as a result of the deposition of fine sediments in areas with low water velocities (such as lake or ocean environments). Typically, the maintenance and expansion of these areas are dependant on a continuing supply of suspended sediments from upstream areas. Reductions in the quantity of materials that are transported by a river could result in a decrease in the area of the delta by disturbing the equilibrium between erosion by the lake (or ocean) and deposition of sediment by the river (Baxter 1977). An important consideration is that a decrease in sediment transport is likely to reduce the transport of nutrients to delta areas, which would influence its productivity. Some or all of the organisms that utilize aquatic and riparian habitats within the river delta could be adversely affected by alterations in the size, stability, or productivity of the delta habitats.

6.3.8 Channel Morphology

The term channel morphology relates primarily to the shape of the stream channel. In temperate climates, stream channel morphology is influenced by factors such as the quantity and size of sediment, duration and magnitude of peak flows, slope and width of the valley bottom, steepness of the side slopes, and local geology (MacDonald *et al.* 1991). Some of these factors are constant for the system under consideration, while others may change as a result of land use activities. In northern rivers, however, river ice significantly influences the morphology of stream channels, with ice scouring and ice-jam flooding playing important roles. Stream channel characteristics are useful to monitor, because their temporal variability is relatively low in many areas (excluding river deltas) and changes in these variables can be linked directly to effects on fisheries resources (MacDonald *et al.*

1991). Some of the variables which are considered most frequently include pool to riffle ratios, channel cross-sectional topography, channel width to depth ratios, wetted width, pool depth, residual pool depth, and pool area.

Information on the channel morphology can provide important insights into channel stability, bank stability, and the relative balance between sediment transport and discharge (Beschta and Platts 1986). Changes in hydrological variables, such as peak flow, ice jamming, and sediment transport, can result in alterations in stream width, channel cross-sectional area, bed elevation, and bank slope and stability (MacDonald *et al.* 1991). In turn, these alterations could affect stream temperature, the quality and quantity of spawning and rearing habitat, the habitat available for algae and benthic invertebrates, and the likelihood of flooding. Hence, channel morphology is an important variable that can significantly affect biological productivity in stream systems.

6.3.9 Migration Barriers

One of the most obvious effects of hydroelectric power developments and certain flood control activities is the creation of partial or complete barriers to fish passage. As many species of freshwater and anadromous fish undertake sizeable migrations from rearing areas to spawning areas, barriers that limit fish passage can have devastating effects on affected species. For example, construction of a dam at the outlet of Elsie Lake (British Columbia) prevented young adult lamprey (*Lampetra tridentata*) from going to sea and adult lamprey from spawning above the dam (Beamish and Northcote 1989). After a period of seven years, neither scarred fish nor lamprey ammocoetes were found in the lake, indicating that the population has been extirpated. Similarly, numerous salmon and steelhead stocks in the Columbia River system have been reduced or eliminated due to dam construction, even though fishways have been constructed to facilitate passage around these structures (Mundie 1991; WDF *et al.* 1993). Barriers to fish passage would be particularly damaging to certain salmonine fishes in the Liard and Peel rivers, which utilize spawning habitats located upstream of proposed dam sites.

6.4 Physical and Chemical Indicators of Ecosystem Integrity

As indicated in Chapter 4, effective implementation of the ecosystem approach necessitates the identification of ecosystem goals and objectives to focus research, management, and planning initiatives in the Mackenzie River basin. In addition, ecosystem maintenance indicators are required to provide a basis for directly measuring the degree to which those

goals and objectives are attained. While the balance of this discussion paper will focus on biological indicators of ecosystem integrity, it is important to remember that physical and chemical indicators are also required. Workshop participants will need to determine the biological relevance of these physical and chemical variables (that is, the degree to which these candidate EMIs affected stream biota). In addition, workshop participants will need to evaluate the relative applicability (i.e., prioritize) of each of these candidate EMIs.

Chapter 7

Development of Ecosystem Maintenance Indicators for the Slave River Basin

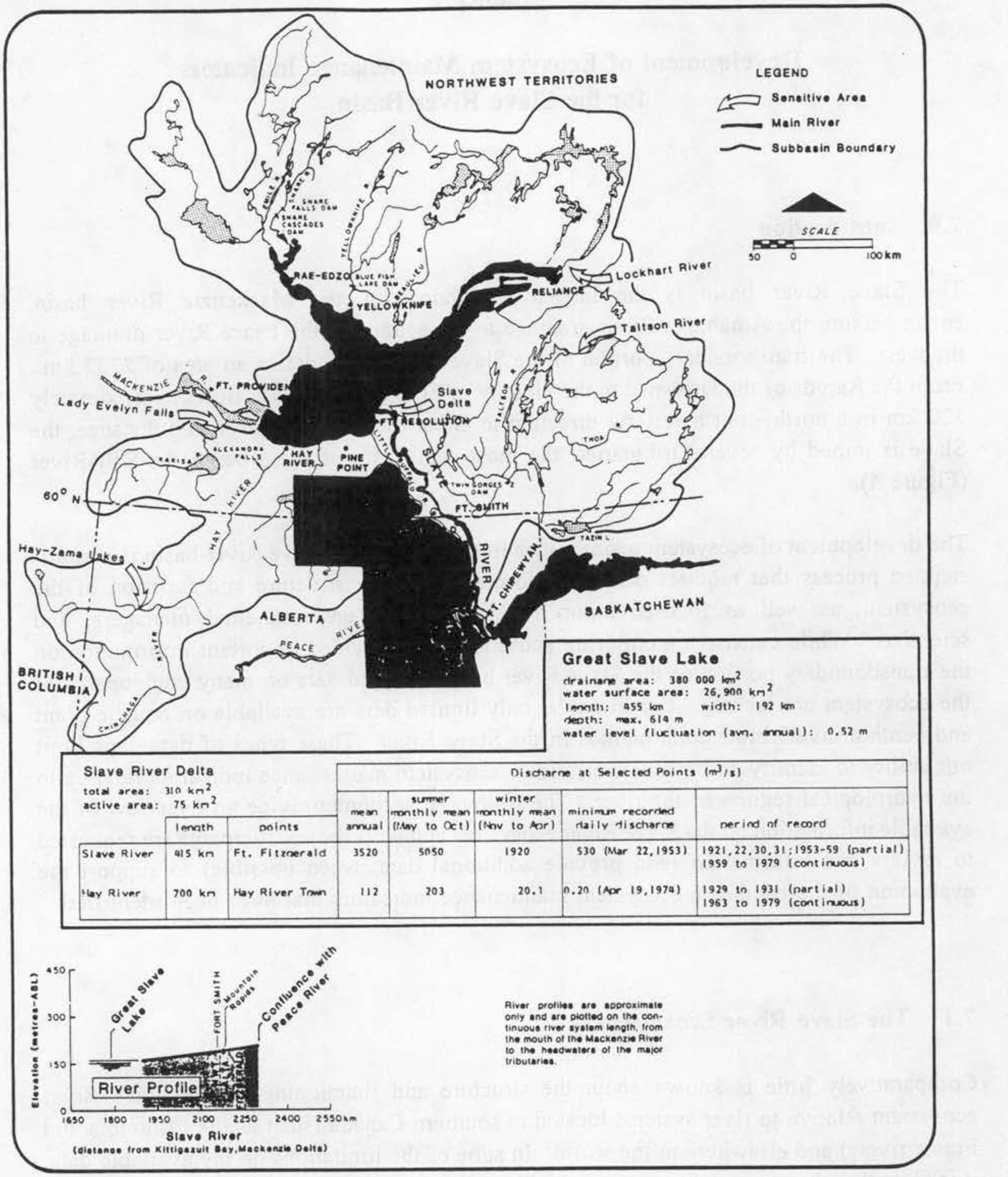
7.0 Introduction

The Slave River basin is the largest component of the Mackenzie River basin, encompassing the Athabasca River drainage to the south and the Peace River drainage to the west. The transboundary portion of the Slave River basin drains an area of 2252 km^2. From the Rapids of the Drowned in the vicinity of Ft. Smith, the river flows approximately 320 km in a north - northwesterly direction to Great Slave Lake. Over that distance, the Slave is joined by several tributaries, the most significant of these being the Salt River (Figure 4).

The development of ecosystem maintenance indicators for the Slave River basin is a multi-stepped process that requires detailed information on the structure and function of the ecosystem, as well as focused input from the public, environmental managers, and scientists. While extensive monitoring activities have provided important information on the transboundary portion of the Slave River basin, detailed data on many components of the ecosystem are lacking. For example, only limited data are available on aquatic plant and benthic invertebrate communities in the Slave River. These types of data gaps limit our ability to identify and evaluate candidate ecosystem maintenance indicators relative to the hydrological regime of the river. The following sections provide an overview of the available information on the Slave River ecosystem and workshop participants are requested to review this information (and provide additional data, when possible) to support the evaluation of the candidate ecosystem maintenance indicators that have been identified.

7.1 The Slave River Ecosystem

Comparatively little is known about the structure and functioning of the Slave River ecosystem relative to river systems located in southern Canada (such as the Columbia and Fraser rivers) and elsewhere in the world. In spite of the limitations on the available data, it is clear that the territorial portion of the Slave River is a very complex system, which is greatly influenced by the Peace River and Lake Athabasca to the south and Great Slave Lake to the north.



	length	points	Discharge at Selected Points (m^3/s) mean annual	summer monthly mean (May to Oct)	winter monthly mean (Nov to Apr)	minimum recorded daily discharge	period of record
Slave River	415 km	Ft. Fitzgerald	3520	5050	1920	530 (Mar 22, 1953)	1921, 22, 30, 31; 1953-59 (partial) 1959 to 1979 (continuous)
Hay River	700 km	Hay River Town	112	203	20.1	0.20 (Apr 19, 1974)	1929 to 1931 (partial) 1963 to 1979 (continuous)

Figure 4. Slave River Basin.

From a human perspective, the central component of the Slave River ecosystem is its fish and wildlife resources. Large populations of resident and migratory fish species utilize the Slave River for spawning and/or rearing activities. Many of the fish species produced in the Slave River may also be targets of the sport and commercial fisheries that operate in Great Slave Lake and, to a lesser extent, in the Slave River. In addition, beaver and muskrat are trapped throughout the river basin. These activities are important sources of revenue within the basin, and contribute significantly to the economy of the NWT. However, the economic importance of fish and wildlife produced by the Slave River may be eclipsed by their social and cultural importance to aboriginal people and other residents of the area. In addition to representing major sources of food for many residents in the vicinity of the Slave River, the domestic fishery is also an integral component of the traditional lifestyle that is practised in the region. In this area, both the act of fishing and the fish caught in the domestic fishery are important aspects of native culture. Impairment of these fisheries resources could have serious and far-reaching impacts on aboriginal communities throughout the basin. Likewise, alterations in the abundance of wildlife (including waterfowl, muskrat and beaver) would have significant effects on many of the residents of this area.

In spite of their importance, the fish and wildlife resources of the Slave River can not be considered in isolation. Fish and wildlife are linked to the rest of the ecosystem by a complex set of interactions with the physical, chemical, and biological (including human) components of the system. Therefore, changes in characteristics of one or more elements of the system have the potential to affect other components of the system, and, in so doing, affect the overall stability of the ecosystem. As such, there is a need to establish the functional linkages between stream hydrology and biological integrity in this river system.

Conceptual modelling of the Slave River ecosystem is impaired by the dearth of information on key elements of the ecosystem. To date, monitoring activities have focused primarily on water quality, water quantity, and fisheries resources. Comparatively less effort has been expended to examine the other components of the system. However, recent surveys conducted on the Slave River in the vicinity of Ft. Smith provided some information on the characteristics of benthic habitats and on associated invertebrate communities (North-South Consultants Ltd. 1991). These investigations may also provide some insights into the relative importance of benthic production in the Slave River compared to inputs from upstream areas.

Evaluation of the available information suggests that the Slave River is a complex open ecosystem that is reliant on inputs from outside sources to maintain the diversity and abundance of its biological community. Many of the fish species that spawn in the Slave River are migratory. This suggests that rearing habitat may be a limiting factor on fisheries production. This premise is, at least partially, supported by the results of a recent study that indicated that benthic productivity may be limited in the reach between the Rapids of the Drowned and the Salt River (North-South Consultants Ltd. 1991). If this is the case, then resident fish species must be highly dependent on the limited food resources that are produced in the immediate vicinity of rearing sites and on food organisms that originate in upstream areas. Changes in the quality and/or quantity of these food organisms could, therefore, have dramatic effects on resident fish and, possibly, on the stability of the ecosystem as a whole. It is important to note, however, that the timing of the sampling (October), and the extreme hydrological conditions experienced in 1990, limit the utility of these data in terms of understanding the dynamics of the system.

While limited invertebrate production has been highlighted here as a potential factor in limiting ecosystem stability, there are a number of attributes which make northern rivers vulnerable to anthropogenic challenges. These include simplicity of food chains, wide oscillations in populations, and slow growth rates. This vulnerability means that northern ecosystems have a lower tolerance for stresses that may occur as a result of developmental activities. The challenge, then, is to identify sensitive and socially-relevant biological indicators, which can be used to assess the overall integrity of the Slave River ecosystem.

7.2 Candidate Ecosystem Maintenance Indicators in the Slave River Basin

Candidate biological indicators of ecosystem maintenance in the transboundary reach of the Slave River basin (Rapids of the Drowned to Great Slave Lake) include aquatic plants, a variety of benthic macroinvertebrate taxa and community metrics, 37 resident and migratory fish species, 58 avian species, and four mammalian species. The information that was located on each of these groups of organisms is discussed in the following sections.

7.2.1 Aquatic and Riparian Plants

Aquatic macrophytes provide spawning and rearing habitats for a number of fish species in the Slave River basin. In the delta region, several aquatic macrophytes are found in the shallow protected areas along the river channels and outer delta, including sago weed (*Potomogeton pectinatus*), pickerel weed (*Potomogeton richardsoni*), and pond weed (*Potomogeton gramineus;* Tripp *et al.* 1981). River horsetail (*Equisetum fluviatale*) is the most common emergent aquatic macrophyte in the Slave River delta, and is, therefore, more likely to provide cover for small fish than any other plant species (Tripp *et al.* 1981). Sedges (*Carex sp.*), cattails (*Typha sp.*), rushes (*Scirpus sp.*), and bur-weed (*Sparganium sp.*) are also present in various locations throughout the delta. Willow (*Salix sp.*) are the most common plant species that occurs beyond the ice scour zone, with alder (*Alnus sp.*), poplar (*Populus sp.*), and spruce (*Picea sp.*) more prevalent in the drier habitats. A list of aquatic and riparian plant species that could, potentially, be used as EMIs is presented in Table 6.

Of the aquatic and riparian plant species that occur in the Slave River delta area, sedges and willow may be the most appropriate ecosystem maintenance indicators because their abundance is affected by ice scour (and flooding) and is linked to the production of socially important species. For example, waterfowl could be affected by a reduction in the availability of food (grasses and sedges) and a loss of nesting habitat due to proliferation of willows and other woody plant species that could occur if ice regime or annual spring floods are altered. Similarly, the conversion of wetland areas to forest (due to reduced flooding) could severely reduce muskrat habitat (Dirschl 1971).

7.2.2 Aquatic Invertebrates

In general, rich and diverse communities of benthic macroinvertebrate communities have been reported in the Slave River delta (Tripp *et al.* 1981). In this area, the standing crops of benthic macroinvertebrates were observed in the fall (September 12 - November 7, 1978), with spring (May 9 - June 30, 1980) macroinvertebrate densities being about 25% of those measured in the fall. Overall, the community was somewhat more diverse in the spring (50 species in < 1 m water depth) compared to the fall (28 species). The importance of shallow water habitats in terms of benthic invertebrate production is emphasized by the high densities recorded in waters with a depth of less than one metre (mean = 3,120 organisms/m^2). By comparison, invertebrate densities were, on average, 573, 377, 133 organisms/m^2 in waters with depths of 1.0 - 2.9 m, 3.0 - 4.9 m, and > 5.0 m, respectively (Tripp *et al.* 1981).

Tolerant invertebrate species, such as oligochaetes (aquatic worms) and chironomids (midges), were by far the most common group of aquatic invertebrates collected between 1978 and 1980, accounting for 93% and 66% of all invertebrates collected during the fall and spring, respectively (Tripp *et al.* 1981). At all water depths, chironomids were the dominant group of invertebrates during the spring, while oligochaetes dominated in the fall (particularly in shallow waters; < 3.0 m). Ostracods and nematodes comprised a significant portion of the benthic community during the spring at virtually all water depths; however, these groups of organisms were present only at low levels in the fall. The EPT taxa (Ephemeroptera, Plecoptera, and Trichoptera), which are important fish food species, were generally present at relatively low densities; however, these groups were important in the fall in deeper waters (3.0 - > 5.0 m; Tripp *et al.* 1981).

Table 6. List of candidate ecosystem maintenance indicators (EMIs) for the Slave River basin: Aquatic plants, microbiota and invertebrates.

Candidate EMI	Essential Characteristics		Important Characteristics of EMIs for Their Intended Uses											
	Hydrological Relevance	Result of Preliminary Evaluation	Sensitivity	Measurability	Cost-Effectiveness	Availability of Historic Data	Nondestructiveness	Appropriateness of Scale	Lack of Redundancy	Social Relevance	Interpretiveness	Anticipatory	Timeliness	Total Evaluation Score
Aquatic plants														
- Sago weed *(Potomogeton pectinatus)*														
- Pickerel weed *(Potomogeton richardsoni)*														
- Horsetail *(Equisetum fluviatale)*														
- Sedges *(Carex sp.)*														
- Cattails *(Typha sp.)*														
- Rushes *(Scirpus sp.)*														
- Bur-weed *(Sparganium sp.)*														
- Willows *(Salix sp.)*														
Algae and Microbiota														
- Periphyton														
- Fungi														
- Bacteria														
Aquatic Invertebrates														
- Coleoptera (beetles)														
- Diptera (flies)														
- Chironomidae (midges)														
- Ephemeroptera (mayflies)														
- Plecoptera (stoneflies)														
- Trichoptera (caddisflies)														
- Hemiptera (true bugs)														
- Oligochaeta (worms)														
- Pelecypoda (bivalve molluscs)														
- Gastropoda (univalve molluscs)														
- Crustacea														

Table 6. List of candidate ecosystem maintenance indicators (EMIs) for the Slave River basin: Aquatic plants, microbiota and invertebrates (continued).

Candidate EMI	Essential Characteristics		Important Characteristics of EMIs for their Intended Uses												
	Hydrological Relevance	Result of Preliminary Evaluation	Sensitivity	Measurability	Cost-Effectiveness	Availability of Historic Data	Nondestructiveness	Appropriateness of Scale	Lack of Redundancy	Social Relevance	Interpretiveness	Anticipatory	Timeliness	Total Evaluation Score
Invertebrate Community Metrics														
- Species richness														
- Species diversity														
- Abundance of key taxa														
- Total abundance														
- Abundance of EPT taxa														
- Community similarity index														
- Invertebrate community index														

A list of candidate aquatic invertebrates and community metrics that could, potentially, be used as ecosystem maintenance indicators is presented in Table 6.

7.2.3 Fish

A wide variety of fish species are known to inhabit the Slave River mainstem and delta throughout a portion or all of their life cycles. At least three anadromous fish species utilize spawning habitats within the Slave River basin. In addition, a number of resident or migratory species are also utilized in the domestic fishery on the Slave River. Furthermore, the Slave River supports a relatively diverse assemblage of forage fish, including cyprinids, cottids, gasterostids, and percopsids. Arctic lampreys, which may be anadromous or migratory within freshwater systems, also utilize habitats in the Slave River for spawning and rearing activities. A list of the fish species that utilize the Slave River mainstem and Slave River delta is presented in Table 7.

A variety of anadromous and freshwater fish species utilize habitats in the Slave River mainstem during some portion of their life history. For example, lake whitefish, inconnu, and chum salmon migrate upstream as far as the Rapids of the Drowned to conduct spawning activities each autumn. Likewise, spring spawning species, such as goldeye and walleye, utilize spawning habitats in the upper portions of the Slave River; however, goldeye also overwinter in these areas. All of these species are caught in the domestic fishery, with lake whitefish being the most abundant species. Inconnu, goldeye, walleye, northern pike, longnose suckers, and white suckers are also caught in this fishery (RL & L/EMA Slave River Joint Venture 1985).

The Slave River delta is also utilized extensively by a variety of fish species. In addition to the species identified in the upper portions of the river, the delta is also utilized by rainbow trout, lake char, arctic grayling, round whitefish, lake cisco, arctic cisco, least cisco, burbot, and yellow perch. Based on the results of a fisheries inventory program conducted between 1978 and 1980 (Tripp *et al.* 1981), the greatest densities of fish occurred in the lower Slave River and Resdelta Channel. Within these areas, northern pike, goldeye, burbot, walleye, and longnose suckers were the most abundant species. Goldeye was the dominant species in all other areas of the delta, including East Channel, Middle Channel, Steamboat Channel, and Nagel Channel. While site-specific data are generally not available to assess the hydrological requirements of fish species in the Slave River basin, some general information is available on their habitat requirements (Table 8).

Table 7. List of candidate ecosystem maintenance indicators (EMIs) for the Slave River basin: Fish.

Candidate EMI	Essential Characteristics		Important Characteristics of EMIs for Their Intended Uses											
	Hydrological Relevance	Result of Preliminary Evaluation	Sensitivity	Measurability	Cost-Effectiveness	Availability of Historic Data	Nondestructiveness	Appropriateness of Scale	Lack of Redundancy	Social Relevance	Interpretiveness	Anticipatory	Timeliness	Total Evaluation Score
Anadromous Fish														
- Arctic cisco														
- Least cisco														
- Chum salmon														
Migratory/Resident Fish														
- Rainbow trout														
- Lake char														
- Arctic grayling														
- Lake whitefish														
- Round whitefish														
- Lake cisco														
- Inconnu														
- Goldeye														
- Burbot														
- Northern pike														
- Walleye														
- Longnose sucker														
- White sucker														
- Yellow perch														
Forage Fish/Other Species														
- Lake chub														
- Flathead chub														
- Northern pearl dace														
- Pearl dace														
- Slimy sculpin														
- Spoonhead sculpin														
- Spottail shiner														

Table 7. List of candidate ecosystem maintenance indicators (EMIs) for the Slave River basin: Fish (continued).

	Essential Characteristics		Important Characteristics of EMIs for their Intended Uses											
Candidate EMI	Hydrological Relevance	**Result of Preliminary Evaluation**	Sensitivity	Measurability	Cost-Effectiveness	Availability of Historic Data	Nondestructiveness	Appropriateness of Scale	Lack of Redundancy	Social Relevance	Interpretiveness	Anticipatory	Timeliness	**Total Evaluation Score**
Forage Fish/Other Species (cont.)														
- Emerald shiner														
- Trout-perch														
- Ninespine stickleback														
- Arctic lamprey														
Fish Community Metrics														
- Species diversity														
- Species richness														
- Equitability														
- Trophic composition														
- Abundance and condition														
- Index of biotic integrity														

Table 8. A summary of the habitat requirements of fish in the Slave River basin.

Habitat Variable	Lake whitefish	Round whitefish	Lake cisco	Arctic cisco	Least cisco	Inconnu	Arctic grayling	Lake char	Rainbow trout	Chum salmon	Goldeye	Burbot	Northern pike	Walleye	Yellow perch	Longnose sucker	White sucker
Social Significance																	
- Slave R. Mainstem	H	L	L	L	L	H	L	L	L	L	H	H	H	H	L	L	L
- Slave R. Delta	H	L	L	L	L	H	L	L	L	L	H	H	H	H	L	H	L
Spawning Habitat																	
- Timing	F	F	F	F	F	F	S	F	S	F	S	W	S	S	S	S	S
- Location	USR	SRD	SRD	SRD	SRD	USR	?	GSL	?	USR	USR	SR/SRD	SRD	USR	?	SR/SRD	SR/SRD
- Spawning Behaviour	BRD	BRD	BRD	BRD	BRD	BRD	BRD	NST	NST	NST	BRD	BRD	BRD	BRD	MASS	BRD	BRD
- Spawning Substrate	C	C	C	C	C	F - C	C	C	C	C		F	VEG	C	VEG	C	C
- Spawning Temp. (C)	< 7.8	4.5	3.3-5	2.2-7.2		< 8.3	7-10	8.9-13.9	10-15.5		5-14	0.5-1.7	4.4-11	5.6-11.1	8.9-12.2	9-15	> 10
- Incubation Temp. (C)	0.5-6.1		0.5-5.6				7-11									> 10	> 10
- Lethal Temp. (C)	10																
- Water Velocity (m/sec)	0.7-0.8					0.3-0.75								F		0.3-0.45	
- Water Depth (m)	4.2-4.8	< 7	< 3			1.3-6.9		< 12				< 3.0				< 1	
Rearing Habitat																	
- Location	GSL	GSL	GSL	GSL	GSL	GSL	GSL	GSL	?		SR/SRD	GSL	SR/SRD	SRD/GSL	GSL	SRD/GSL	SRD/GSL
- Water Velocity (m/sec)																	
- Water Depth (m)		< 45	< 50														
- Principle Food	B.INV	B.INV	PLK	B.INV		F	B.INV	INV/F	INV/F		INV	F	F	F	B.INV	B.INV	B.INV

Social Significance: H = high; L = low.
Timing: S = spring; F = fall; W = winter
Location: USR = upper Slave River; LSR = lower Slave River; SR = Slave River; SRD = Slave River delta; GSL = Great Slave Lake.
Spawning Behaviour: BRD = broadcast spawner; NST = redd builder; MASS = egg masses deposited on vegetation or other substrate.
Spawning Substrate: C = gravel and rocks; F = sand and silt; VEG = vegetation.
Water Velocity: F = fast.
Food: INV = invertebrates; B.INV = benthic invertebrates; PLK = plankton; F = fish.

7.2.4 Waterfowl and Shorebirds

Myriad waterfowl and shorebirds utilize habitats within the Slave River basin (Fort Smith to Great Slave Lake) on a seasonal basis. While the Slave River Delta is an essential staging area for many bird species during the spring and fall, it also provides important nesting and rearing habitats. For example, the results of a survey conducted in the summer of 1978 indicated that the breeding population of ducks in the delta consisted of approximately 5,218 pairs; however, only 47 successful broods (201 ducklings) were located in this study (Thompson 1979). Geese did not breed on the delta in that year; nonetheless, 790 Canada and white-fronted geese were observed during the spring survey. The peak number of waterfowl on the delta in the fall of 1978 was 7,600, with another 3,000 shorebirds recorded (Thompson 1979).

During the fall of 1983, a total of 14,783 waterfowl and 315 shorebirds were enumerated during aerial and ground surveys, respectively (EMA 1984a). Mallard ducks were the most common species encountered during this study, accounting for between 32.7 and 38.1 of the total number of waterfowl. Lesser scaups (6.4 - 13.3%), Canada geese (9.8 - 16%), and tundra swans (10.2 - 11.6%) were abundant during this survey. Of the shorebirds, the greater and lesser yellowlegs, spotted sandpiper, Baird's sandpiper, and pectoral sandpiper were the most plentiful species. A list of bird species that have been observed within the Slave River basin is presented in Table 9.

7.2.5 Mammals

While a wide variety of mammals are present within the Slave River basin, muskrat, beaver, river otters, and mink are probably linked most directly to the aquatic environment. In the fall of 1983, a total of 583 muskrat lodges were located between Fort Smith and Great Slave Lake (EMA 1984b), 90.1% of which were located in the Slave River delta. Muskrats were found only in areas where emergent and submergent vegetation were abundant as a food source and for lodge construction (EMA 1984b). The preferred habitat for this species was sedge-bordered wetlands with horsetail. As such, muskrats are likely to be extremely sensitive to changes in the hydrological regime that would affect the distribution and abundance of aquatic macrophytes.

Beavers are distributed throughout the transboundary reach of the Slave River, with a total of 161 active beaver lodges located in 1984 (EMA 1984b). Only 17 beaver lodges were located in the Slave River delta during this survey. Most of the lodges were located on tributaries to the Slave River, generally on islands or shorelines sheltered from current or wave action (EMA 1984b). Areas with abundant supplies of aspen, balsam poplar, and alder represented the preferred habitats for beavers. Twenty-two lodges were found further

Table 9. List of candidate ecosystem maintenance indicators (EMIs) for the Slave River basin: Birds and mammals.

Candidate EMI	Essential Characteristics		Important Characteristics of EMIs for Their Intended Uses											
	Hydrological Relevance	**Result of Preliminary Evaluation**	Sensitivity	Measurability	Cost-Effectiveness	Availability of Historic Data	Nondestructiveness	Appropriateness of Scale	Lack of Redundancy	Social Relevance	Interpretiveness	Anticipatory	Timeliness	**Total Evaluation Score**
Birds														
- American widgeon														
- Common goldeye														
- Barrow's goldeye														
- Blue-winged teal														
- Green-winged teal														
- Mallard duck														
- Ruddy duck														
- Northern shoveller														
- Ring-necked duck														
- Pintail duck														
- Redhead duck														
- Canvasback														
- Bufflehead														
- Gadwall														
- Oldsquaw duck														
- Coot														
- Lesser scaup														
- Greater scaup														
- White-winged scoter														
- Surf scoter														
- Canada goose														
- White-fronted goose														
- Snow goose														
- Common merganser														
- Red-breasted merganser														
- Least sandpiper														
- Pectoral sandpiper														
- Solitary sandpiper														

Table 9. List of candidate ecosystem maintenance indicators (EMIs) for the Slave River basin: Birds and mammals (continued).

Candidate EMI	Essential Characteristics		Important Characteristics of EMIs for Their Intended Uses											
	Hydrological Relevance	**Result of Preliminary Evaluation**	Sensitivity	Measurability	Cost-Effectiveness	Availability of Historic Data	Nondestructiveness	Appropriateness of Scale	Lack of Redundancy	Social Relevance	Interpretiveness	Anticipatory	Timeliness	**Total Evaluation Score**
Birds (cont.)														
- Spotted sandpiper														
- Semipalmated sandpiper														
- Baird's sandpiper														
- Sanderling														
- Greater yellowlegs														
- Lesser yellowlegs														
- Sora														
- Yellow rail														
- Semi-palmated plover														
- Black-bellied plover														
- Lesser golden plover														
- Common snipe														
- Red-winged blackbird														
- Rusty blackbird														
- Ring-billed gull														
- Bonaparte's gull														
- Sandhill crane														
- Whooping crane														
- Pacific loon														
- Common loon														
- Red-throated loon														
- Pied-billed grebe														
- Red-necked grebe														
- Horned grebe														
- Whistling swan														
- Tundra swan														

Table 9. List of candidate ecosystem maintenance indicators (EMIs) for the Slave River basin: Birds and mammals (continued).

Candidate EMI	Essential Characteristics: Hydrological Relevance	Essential Characteristics: Result of Preliminary Evaluation	Important Characteristics of EMIs for Their Intended Uses: Sensitivity	Measurability	Cost-Effectiveness	Availability of Historic Data	Nondestructiveness	Appropriateness of Scale	Lack of Redundancy	Social Relevance	Interpretiveness	Anticipatory	Timeliness	Total Evaluation Score
Birds (cont.)														
- Black tern														
- American bittern														
- White pelican														
Mammals														
- Beaver														
- Muskrat														
- Mink														
- River otter														

upstream on the Slave River mainstem, mainly in locations with moderately steep (slumping) banks (EMA 1984b). A list of mammalian species that could be used as ecosystem maintenance indicators is presented in Table 9.

7.3 Candidate Physical and Chemical Ecosystem Maintenance Indicators

In addition to the biological EMIs discussed previously, a number of physical and chemical variables could also be utilized to evaluate the health and vitality of the aquatic ecosystem. A list of physical and chemical variables that could be used as EMIs is presented in Table 10. One of the main advantages of these candidate EMIs is that they are typically easier to measure than biological variables. Workshop participants are encouraged to evaluate each of the candidate EMIs presented and identify additional EMIs for the Slave River Basin.

7.4 Potential Ecosystem Maintenance Indicators

Two indicators species, including the northern pike and the muskrat, hold significant potential for evaluating ecosystem integrity in the Slave River basin. Northern pike are recommended because changes in stream hydrology that affect the quality or quantity of spawning habitats (i.e., sloughs, side channels, and back channels with abundant aquatic macrophytes) will, likely, adversely affect this species. In particular, decreases in the magnitude of peak flows or low flows, changes in ice scour or sediment transport, and alterations in water velocity or depth could reduce the spawning success and/or growth of this species. The northern pike is a suitable indicator species because, as a top predator, it integrates changes in the ecosystem that occur at lower trophic levels. The abundance of young of the year northern pike in the Slave River delta, which could be assessed by sampling key rearing habitats, would provide a suitable metric for evaluating reproductive success. Data on the average size at age, from fish sampled in the domestic fishery or a directed fisheries investigations, could be used to evaluate growth.

The muskrat may also be useful for assessing ecosystem integrity in the Slave River basin because it is dependent on the wetland habitats that currently exist in the Slave River delta. Alterations in the hydrological regime that influence the quality or quantity of these rearing habitats (that is, by reducing the total wetland areas or the abundance of aquatic macrophytes) would adversely affect this species. In addition, alteration in the timing of break-up could affect this species by reducing the incidence of multiple litters in a single year, which is now common in older muskrat females. Furthermore, this species integrates

Table 10. List of candidate ecosystem maintenance indicators (EMIs) for the Slave River basin: Physical variables.

Candidate EMI	Essential Characteristics		Important Characteristics of EMIs for Their Intended Uses											
	Biological Relevance	Result of Preliminary Evaluation	Sensitivity	Measurability	Cost-Effectiveness	Availability of Historic Data	Nondestructiveness	Appropriateness of Scale	Lack of Redundancy	Social Relevance	Interpretiveness	Anticipatory	Timeliness	Total Evaluation Score
Flow-related Variables														
- Magnitude of peak discharge														
- Duration of peak discharge														
- Magnitude of low flow														
- Duration of low flow														
- Mean monthly discharge														
- Mean annual discharge														
- Water level														
- Variability in water level														
Ice-related Variables														
- Timing of ice formation														
- Location of river ice														
- Quantity of river ice														
- Stability of river ice														
- Duration of ice cover														
- Timing of river ice break-up														
- Frequency of ice jamming														
- Severity of ice jamming														
- Duration of ice jamming														
Water Quality-related Variables														
- Suspended sediment concentration														
- Suspended sediment loading														
- Nutrient concentrations														
- Nutrient loadings														
- Organic carbon concentrations														
- Organic carbon loadings														
- Trace metal concentrations														

Table 10. List of candidate ecosystem maintenance indicators (EMIs) for the Slave River basin: Physical variables (continued).

Candidate EMI	Essential Characteristics		Important Characteristics of EMIs for their Intended Uses											
	Biological Relevance	Result of Preliminary Evaluation	Sensitivity	Measurability	Cost-Effectiveness	Availability of Historic Data	Nondestructiveness	Appropriateness of Scale	Lack of Redundancy	Social Relevance	Interpretiveness	Anticipatory	Timeliness	Total Evaluation Score
Water Quality-related Variables (cont.)														
- Trace metal loadings														
- Organic contaminant concentrations														
- Water temperature														
- Dissolved oxygen levels														
Instream Geomorphic Variables														
- Wetted width														
- Stream depth														
- Stream gradient														
- Pool to riffle ratios														
- Wetted area in side channels														
- Depth in side channels														
- Substrate composition														
- Substrate stability														
- Quantity of large organic debris														
- Quantity of instream cover														
- Channel morphology														
Riparian Zone Variables														
- Quality of shoreline habitat														
- Size of delta areas														
- Sedimentation rates in delta areas														
- Quantity of wetlands														
- Extent of flooding														
- Duration of flooding														
- Timing of flooding														
- Frequency of flooding														
- Extent of ice scour														

the effects of hydrological changes on aquatic plants and, hence, provides a good indicator of ecosystem integrity. Individual metrics that could be used to assess the status of Slave River delta muskrat populations include the annual harvest, harvest per unit effort, the ratio of young-of-the-year to adult muskrat in the harvest, and the number of lodges in key habitats.

7.5 Research Needs

The preliminary evaluation of the candidate EMIs conducted in this study emphasizes the limitation on the existing knowledge base. Future research should be directed at filling these data gaps and developing a more comprehensive knowledge of the structure and function of the ecosystem. It is anticipated that workshop participants will identify research needs during the EMI evaluation process. Traditional environmental knowledge and local experience may provide much of the information needed to fill these data gaps.

Chapter 8

Development of Ecosystem Maintenance Indicators for the Liard River Basin

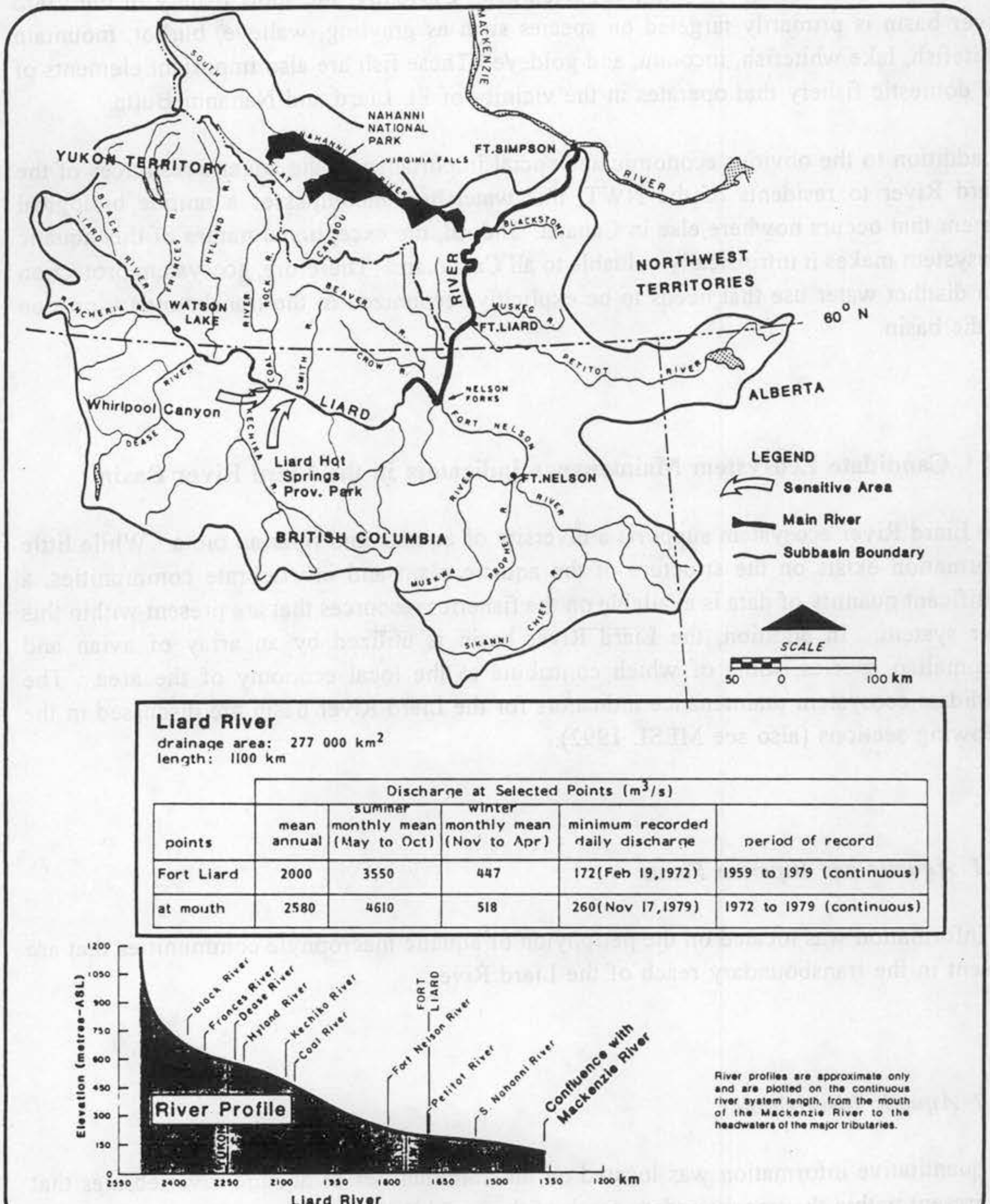
8.0 Introduction

The Liard River basin is one of the largest tributaries to the Mackenzie River, with a total drainage area of 277 000 km^2. From its headwaters in southcentral Yukon, the Liard River flows approximately 980 km to its confluence with the Mackenzie River at Fort Simpson. The Liard River basin represents a unique challenge for environmental managers because of its abundance of relatively undeveloped natural resources, its diverse assemblages of aquatic and terrestrial communities, and because it drains areas within two provinces and two territories. Effective management of these resources is especially important because the Liard River basin is one of the few relatively pristine watersheds left in Canada today (Figure 5). .

The Liard River and its numerous tributaries support a diversity of water uses, including those associated with domestic water supplies, recreation and aesthetics, fish and aquatic life, agriculture, and industrial process water. Of these, instream water uses (such as fish and aquatic life) are at the forefront of management policy in the transboundary portion of the basin (Letourneau *et al.* 1988). Protection of fish and aquatic life, and their uses, is essential in NWT because these resources are utilized extensively by aboriginal peoples and other area residents. In addition, other designated water uses, such as recreation and aesthetics, are directly dependent on the health and vitality of the aquatic ecosystem. Further, many residents obtain raw water supplies directly from surface waters in the basin. Because of their importance to the people who reside in the basin, maintenance and enhancement of the existing high quality aquatic resources have been identified as high priority, long-term environmental management goals.

8.1 An Overview of the Liard River Basin

Comparatively little is known about the structure and function of the Liard River ecosystem. Nonetheless, it is clear that the Liard River ecosystem supports a diversity of aquatic biota of economic, sociological, and biological importance. Tourism is one of the most important industries in the NWT. However, unlike many other tourist destinations



	Discharge at Selected Points (m^3/s)				
points	mean annual	summer monthly mean (May to Oct)	winter monthly mean (Nov to Apr)	minimum recorded daily discharge	period of record
Fort Liard	2000	3550	447	172(Feb 19,1972)	1959 to 1979 (continuous)
at mouth	2580	4610	518	260(Nov 17,1979)	1972 to 1979 (continuous)

Figure 5. Liard River Basin.

in Canada, the success of this industry is dependent, at least in part, on providing visitors to the region with unique angling opportunities. Currently, the sport fishery in the Liard River basin is primarily targeted on species such as grayling, walleye, burbot, mountain whitefish, lake whitefish, inconnu, and goldeye. These fish are also important elements of the domestic fishery that operates in the vicinity of Ft. Liard and Nahanni Butte.

In addition to the obvious economic and social importance of the aquatic resources of the Liard River to residents of the NWT, this watershed encompasses a unique biological system that occurs nowhere else in Canada. Indeed, the exceptional nature of this aquatic ecosystem makes it intrinsically valuable to all Canadians. Therefore, ecosystem protection is a distinct water use that needs to be explicitly recognized in the transboundary portion of the basin.

8.2 Candidate Ecosystem Maintenance Indicators in the Liard River Basin

The Liard River ecosystem supports a diversity of aquatic and riparian biota. While little information exists on the structure of the aquatic plant and invertebrate communities, a significant quantity of data is available on the fisheries resources that are present within this river system. In addition, the Liard River basin is utilized by an array of avian and mammalian species, some of which contribute to the local economy of the area. The candidate ecosystem maintenance indicators for the Liard River basin are discussed in the following sections (also see MESL 1992).

8.2.1 Aquatic and Riparian Plants

No information was located on the periphyton or aquatic macrophyte communities that are present in the transboundary reach of the Liard River.

8.2.2 Aquatic Invertebrates

No quantitative information was located on the communities of aquatic invertebrates that are present within the transboundary reach of the Liard River. However, the results of two studies conducted in the early 1980's to assess the potential impacts on aquatic biota downstream of the proposed Liard River hydroelectric development provide some information for identifying candidate ecosystem maintenance indicators (McLeod *et al.*

1983; O'Neil *et al.* 1982). All of the aquatic invertebrates recorded in these studies belonged to the class Insecta, with the true flies (Diptera) present in the greatest diversity. A total of six families of flies were observed in the Liard River, including chironomids (non-biting midges), ceratogonids (biting midges), empidids (dance flies), simulids (black flies), and two other families. Other insect groups represented in this reach of the river included Ephemeroptera (mayflies; 3 families), Plecoptera (stoneflies; 4 families), Tricoptera (caddisflies; 1 family), Lepidoptera (butterflies and moths; 1 family) and Nematocera (craneflies; 1 family). While other classes and subclasses of invertebrates were found elsewhere in the river basin (including Apterygota - wingless insects, Oligochaeta - worms, Pelecypoda - mollusks, Gastropoda - snails, and Tubelifera - tubificid worms), they have not been recorded in the transboundary reach. A list of the aquatic invertebrates and community metrics that could be used as ecosystem maintenance indicators is presented in Table 11.

8.2.3 Fish

Significant populations of resident and migratory fish species utilize the Liard River and tributaries for spawning and/or rearing activities. A total of 33 fish species have been recorded in the Liard River basin, with many of them inhabiting the transboundary portion of the mainstem for at least a portion of their life history. However, spawning and rearing habitats in the tributaries are particularly important in this system due to the limitations associated with the habitats in the Liard River mainstem. To date, at least four anadromous fish species, 12 resident and migratory species that are utilized in the domestic fishery, and 6 forage fish species have been observed in the transboundary reach of this river system.

The anadromous fish that utilize spawning and rearing habitats within the Liard River basin include chum salmon, chinook salmon, arctic cisco and least cisco. While returns of adult chum and chinook salmon to the Liard River tend to be limited, these stocks are important because they represent the southernmost extension of these species' ranges in the Mackenzie River system. In addition, the salmon stocks that migrate beyond the Liard Grand Canyon would be severely affected by the proposed hydroelectric development on this system. Arctic cisco, which also migrates past the Beavercrow site on the Liard, would be similarly affected by dam construction and operation.

Several species of fish are caught in the domestic fisheries which operate within the territorial portion of the Liard River basin. These include arctic grayling, mountain whitefish, lake whitefish, round whitefish, inconnu, bull trout, goldeye, northern pike, walleye, burbot, longnose sucker, and white sucker. Of these, arctic grayling, mountain whitefish, lake whitefish, and longnose suckers are probably the most abundant, as they

Table 11. List of candidate ecosystem maintenance indicators (EMIs) for the Liard River basin: Aquatic plants and invertebrates.

	Essential Characteristics		Important Characteristics of EMIs for Their Intended Uses											
Candidate EMI	Hydrological Relevance	**Result of Preliminary Evaluation**	Sensitivity	Measurability	Cost-Effectiveness	Availability of Historic Data	Nondestructiveness	Appropriateness of Scale	Lack of Redundancy	Social Relevance	Interpretiveness	Anticipatory	Timeliness	**Total Evaluation Score**
Aquatic Plants, Algae and Microbiota														
- Macrophytes														
- Periphyton														
- Fungi														
- Bacteria														
Aquatic Invertebrates														
- Coleoptera (beetles)														
- Diptera (flies)														
- Chironomidae (midges)														
- Ephemeroptera (mayflies)														
- Plecoptera (stoneflies)														
- Trichoptera (caddisflies)														
- Hemiptera (true bugs)														
- Oligochaeta (worms)														
- Pelecypoda (bivalve molluscs)														
- Gatropoda (univalve molluscs)														
- Crustacea														
Invertebrate Community Metrics														
- Species richness														
- Species diversity														
- Abundance of key taxa														
- Total abundance														
- Abundance of EPT taxa														
- Community similarity index														
- Invertebrate community index														

represent significant proportions of the total catch in several fisheries investigations (Butcher 1981; O'Neil *et al.* 1982).

The forage fish that are known to occur in the Liard River basin include flathead chub, lake chub, spottail shiner, emerald shiner, troutperch, ninespine stickleback, slimy sculpin, and spoonhead sculpin (O'Neil *et al.* 1982; McLeod *et al.* 1983). Arctic lamprey are also known to utilize habitats within the transboundary portion of the Liard River basin. A list of the fish species that occur in the Liard River basin is presented in Table 12.

A number of studies have been conducted to obtain information on the distribution and abundance of important fish species, primarily to assess the impacts associated with the proposed Liard River hydro project (BCHPA 1979; Butcher 1981; O'Neil *et al.* 1982; McLeod *et al.* 1983). Together, the results of these investigations emphasize the sensitivity of the fish communities to changes in the hydrological regime associated with dam construction. In particular, the fish species that utilize spawning habitats upstream of the proposed dam sites (Sites A and E; such as lake whitefish and inconnu) will likely be prevented from successfully reproducing. Likewise, dewatering of important spawning habitats during reservoir filling will adversely affect those species that spawn in the Liard River mainstem downstream of Site E (such as arctic grayling, mountain whitefish, and goldeye). In addition, species that utilize side channels for rearing (such as arctic grayling, mountain whitefish, northern pike, walleye, and longnose sucker) will be adversely affected by reductions in streamflow (GNWT undated).

8.2.4 Waterfowl and Shorebirds

No information was located on the distribution and abundance of waterfowl and shorebirds in the transboundary portion of the Liard River basin. Nonetheless, a list of bird species that have been observed in the British Columbia portion of the basin (more specifically, in the vicinity of Liard Hot Springs) has been compiled (Table 13). This information indicates that an extremely diverse avian community exists in this area (St. Pierre 1980) and, potentially, in the NWT, as well. However, it is unlikely that the Liard River basin provides a large quantity of waterfowl nesting habitat, as it does not have a well defined delta area or many other suitable areas.

8.2.5 Mammals

Little information was located on the species of mammals that utilize aquatic and riparian habitats in the transboundary portion of the Liard River basin. However, furbearer harvest

Table 12. List of candidate ecosystem maintenance indicators (EMIs) for the Liard River basin: Fish.

Candidate EMI	Essential Characteristics		Important Characteristics of EMIs for Their Intended Uses											
	Hydrological Relevance	Result of Preliminary Evaluation	Sensitivity	Measurability	Cost-Effectiveness	Availability of Historic Data	Nondestructiveness	Appropriateness of Scale	Lack of Redundancy	Social Relevance	Interpretiveness	Anticipatory	Timeliness	Total Evaluation Score
Anadromous Fish														
- Arctic cisco														
- Least cisco														
- Chinook salmon														
- Chum salmon														
Migratory/Resident Fish														
- Dolly Varden char														
- Arctic grayling														
- Lake whitefish														
- Mountain whitefish														
- Lake cisco														
- Inconnu														
- Goldeye														
- Burbot														
- Northern pike														
- Walleye														
- Longnose sucker														
- White sucker														
Forage Fish/Other Species														
- Flathead chub														
- Slimy sculpin														
- Spottail shiner														
- Emerald shiner														
- Trout-perch														
- Ninespine stickleback														
- Arctic lamprey														

Table 12. List of candidate ecosystem maintenance indicators (EMIs) for the Liard River basin: Fish (continued).

Candidate EMI	Essential Characteristics		Important Characteristics of EMIs for Their Intended Uses											
	Hydrological Relevance	Result of Preliminary Evaluation	Sensitivity	Measurability	Cost-Effectiveness	Availability of Historic Data	Nondestructiveness	Appropriateness of Scale	Lack of Redundancy	Social Relevance	Interpretiveness	Anticipatory	Timeliness	Total Evaluation Score
Fish Community Metrics														
- Species diversity														
- Species richness														
- Equitability														
- Trophic composition														
- Abundance and condition														
- Index of biotic integrity														

Table 13. List of candidate ecosystem maintenance indicators (EMIs) for the Liard River basin: Birds and mammals.

Candidate EMI	Essential Characteristics		Important Characteristics of EMIs for Their Intended Uses											
	Hydrological Relevance	Result of Preliminary Evaluation	Sensitivity	Measurability	Cost-Effectiveness	Availability of Historic Data	Nondestructiveness	Appropriateness of Scale	Lack of Redundancy	Social Relevance	Interpretiveness	Anticipatory	Timeliness	Total Evaluation Score
Birds														
- American widgeon														
- Common goldeye														
- Barrow's goldeye														
- Blue-winged teal														
- Green-winged teal														
- Mallard duck														
- Ruddy duck														
- Northern shoveller														
- Ring-necked duck														
- Pintail duck														
- Redhead duck														
- Canvasback														
- Bufflehead														
- Gadwall														
- Oldsquaw duck														
- Coot														
- Lesser scaup														
- Greater scaup														
- White-winged scoter														
- Surf scoter														
- Canada goose														
- White-fronted goose														
- Snow goose														
- Common merganser														
- Red-breasted merganser														
- Belted kingfisher														
- Least sandpiper														

Table 13. List of candidate ecosystem maintenance indicators (EMIs) for the Liard River basin: Birds and mammals (continued).

	Essential Characteristics		Important Characteristics of EMIs for Their Intended Uses											
Candidate EMI	**Hydrological Relevance**	**Result of Preliminary Evaluation**	**Sensitivity**	**Measurability**	**Cost-Effectiveness**	**Availability of Historic Data**	**Nondestructiveness**	**Appropriateness of Scale**	**Lack of Redundancy**	**Social Relevance**	**Interpretiveness**	**Anticipatory**	**Timeliness**	**Total Evaluation Score**
Birds (cont.)														
- Solitary sandpiper														
- Spotted sandpiper														
- Western sandpiper														
- Semipalmated sandpiper														
- Baird's sandpiper														
- Sanderling														
- Greater yellowlegs														
- Lesser yellowlegs														
- Sora														
- Semi-palmated plover														
- Black-bellied plover														
- Lesser golden plover														
- Killdeer														
- Common snipe														
- Red-winged blackbird														
- Rusty blackbird														
- Dipper														
- Long-billed dowitcher														
- Herring gull														
- Mew gull														
- Ring-billed gull														
- Bonaparte's gull														
- Sandhill crane														
- Whooping crane														
- Pacific loon														
- Common loon														

Table 13. List of candidate ecosystem maintenance indicators (EMIs) for the Liard River basin: Birds and mammals (continued).

Candidate EMI	Essential Characteristics		Important Characteristics of EMIs for Their Intended Uses											
	Hydrological Relevance	Result of Preliminary Evaluation	Sensitivity	Measurability	Cost-Effectiveness	Availability of Historic Data	Nondestructiveness	Appropriateness of Scale	Lack of Redundancy	Social Relevance	Interpretiveness	Anticipatory	Timeliness	Total Evaluation Score
Birds (cont.)														
- Red-throated loon														
- Red-necked grebe														
- Horned grebe														
- Whistling swan														
- Tundra swan														
- American bittern														
- White pelican														
Mammals														
- Beaver														
- Ermine fisher														
- Marten														
- Mink														
- Muskrat														
- River otter														

data from British Columbia (Penner 1979) may provide some insight into the relative abundance of the species that are thought to occur in this area. It should be noted that the harvest of furbearers depends not only on the abundance of individual species, but also their value to the trapper. Hence, trappers are likely to target their effort only on those species that will provide a good return on their investment of time and resources.

Penner (1979) compiled the available data on the harvest of furbearers in the B.C. portion of the river basin for five seasons between 1973 and 1978. The results of this study indicated that a total of 1,444 marten, 223 beavers, and 103 ermine were harvested during this period. Only 41 mink, 37 river otters, 22 muskrats, and 3 fishers were harvested over the same period, suggesting that the populations of these species are limited in the Liard River basin. This supposition is partially confirmed by the results of track counts, which indicated high densities of marten, but much lower densities of mink, fishers, and river otters (Penner 1979). A list of mammalian species that have been observed in the Liard River basin is reported in Table 13.

8.3 Candidate Physical and Chemical Ecosystem Maintenance Indicators

In addition to the biological EMIs discussed previously, a number of physical and chemical variables could also be utilized to evaluate the health and vitality of the aquatic ecosystem. A list of physical and chemical variables that could be used as EMIs is presented in Table 14. One of the main advantages of these candidate EMIs is that they are typically easier to measure than biological variables. Workshop participants are encouraged to evaluate each of the candidate EMIs presented and identify additional EMIs for the Slave River Basin.

8.4 Potential Ecosystem Maintenance Indicators

The arctic cisco may be a suitable indicator species for evaluating the health and vitality of the Liard River basin. Like several other species (such as inconnu, chum salmon and chinook salmon), Liard River arctic cisco utilize spawning habitats at the southernmost limit of their range in the Mackenzie River system. Changes to the hydrological regime that may have an impact upon arctic cisco would most certainly affect a variety of fish species that migrate through the transboundary portion of the Liard River. This species would be severely affected by the construction of a structure that blocks or impedes upstream migration in this system. In addition, arctic cisco could be adversely affected by

Table 14. List of candidate ecosystem maintenance indicators (EMIs) for the Liard River basin: Physical variables.

	Essential Characteristics		Important Characteristics of EMIs for Their Intended Uses											
Candidate EMI	Biological Relevance	Result of Preliminary Evaluation	Sensitivity	Measurability	Cost-Effectiveness	Availability of Historic Data	Nondestructiveness	Appropriateness of Scale	Lack of Redundancy	Social Relevance	Interpretiveness	Anticipatory	Timeliness	Total Evaluation Score
Flow-related Variables														
- Magnitude of peak discharge														
- Duration of peak discharge														
- Magnitude of low flow														
- Duration of low flow														
- Mean monthly discharge														
- Mean annual discharge														
- Water level														
- Variability in water level														
Ice-related Variables														
- Timing of ice formation														
- Location of river ice														
- Quantity of river ice														
- Stability of river ice														
- Duration of ice cover														
- Timing of river ice break-up														
- Frequency of ice jamming														
- Severity of ice jamming														
- Duration of ice jamming														
Water Quality-related Variables														
- Suspended sediment concentration														
- Suspended sediment loading														
- Nutrient concentrations														
- Nutrient loadings														

Table 14. List of candidate ecosystem maintenance indicators (EMIs) for the Liard River basin: Physical variables (continued).

	Essential Characteristics		Important Characteristics of EMIs for their Intended Uses											
Candidate EMI	Biological Relevance	Result of Preliminary Evaluation	Sensitivity	Measurability	Cost-Effectiveness	Availability of Historic Data	Nondestructiveness	Appropriateness of Scale	Lack of Redundancy	Social Relevance	Interpretiveness	Anticipatory	Timeliness	Total Evaluation Score
Water Quality-related Variables (cont.)														
- Organic carbon concentrations														
- Organic carbon loadings														
- Trace metal concentrations														
- Trace metal loadings														
- Organic contaminant concentrations														
- Water temperature														
- Dissolved oxygen levels														
Instream Geomorphic Variables														
- Wetted width														
- Stream depth														
- Stream gradient														
- Pool to riffle ratios														
- Wetted area in side channels														
- Depth in side channels														
- Substrate composition														
- Substrate stability														
- Quantity of large organic debris														
- Quantity of instream cover														
- Channel morphology														
Riparian Zone Variables														
- Quality of shoreline habitat														
- Size of delta areas														
- Sedimentation rates in delta areas														

Table 14. List of candidate ecosystem maintenance indicators (EMIs) for the Liard River basin: Physical variables (continued).

Candidate EMI	Essential Characteristics		Important Characteristics of EMIs for their Intended Uses											
	Biological Relevance	Result of Preliminary Evaluation	Sensitivity	Measurability	Cost-Effectiveness	Availability of Historic Data	Nondestructiveness	Appropriateness of Scale	Lack of Redundancy	Social Relevance	Interpretiveness	Anticipatory	Timeliness	Total Evaluation Score
Riparian Zone Variables (cont.)														
- Quantity of wetlands														
- Extent of flooding														
- Duration of flooding														
- Timing of flooding														
- Frequency of flooding														
- Extent of ice scour														

changes in the timing or magnitude of low flows (i.e., redd dewatering), the magnitude of high (or flushing flows), or water temperature.

The abundance of adult arctic cisco in the major spawning areas would provide a relevant ecosystem maintenance indicator for the Liard River basin. Alternately, the abundance of downstream emigrants could be utilized as an EMI for this system. The major advantage of the latter metric is that it would integrate the effects of alterations on the hydrological regime during incubation, as well as indicating upstream migration success.

8.5 Research Needs

The preliminary evaluation of the candidate EMIs conducted in this study emphasizes the limitation on the existing knowledge base. Future research should be directed at filling these data gaps and developing a more comprehensive knowledge of the structure and function of the ecosystem. It is anticipated that workshop participants will identify research needs during the EMI evaluation process. Traditional environmental knowledge and local experience may provide much of the information needed to fill these data gaps.

Chapter 9

Development of Ecosystem Maintenance Indicators for the Peel River Basin

9.0 Introduction

The Peel River is an important transboundary watercourse that drains an area of approximately 109 500 km^2 of north eastern Yukon and north western NWT. From its headwaters in the Ogilvie Mountains, the Peel River flows some 438 km to it confluence with the Mackenzie River, roughly 65 km south of Aklavik (Simpson 1988). Over this distance, it is joined by six major tributaries, including the Ogilvie, Blackstone, Hart, Wind, Bonnet Plume, and Snake rivers. The smaller tributaries that are encompassed within this drainage basin include the Road, Caribou, Satah, and Vittrekwa rivers, and Frog and Stony creeks (Figure 6).

While the Peel River basin is somewhat smaller than the Slave and Liard river basins, it provides a diverse array of benefits to local area residents. The water, fisheries, and wildlife resources produced in this system are utilized to support the traditional culture and subsistence lifestyles of many of the residents within the area (including the Tetlit Gwich'in in Ft. McPherson, the Inuvialuit in Aklavik, and the Nacho Nyak Dun in Mayo). The Gwich'in Comprehensive Land Claim Agreement has identified primary and secondary land use areas within the Yukon portion of the basin (INAC 1992). In addition, the Gwich'in Comprehensive Land Claim Agreement established the Peel River Watershed Advisory Committee to make recommendations to government on land use planning, water management, and special management areas. The First Nation of Nacho Nyak Dun in Yukon consider that most of the Peel River watershed is in their traditional territory. The Nacho Nyak Dun will also be represented on the Peel River Watershed Advisory Committee. The Gwich'in Comprehensive Land Claim Agreement and the First Nation of Nacho Nyak Dun Final Agreement assure that the Gwich'in and the Nacho Nyak Dun will play the lead roles in determining the land use activities that will be permitted within this region.

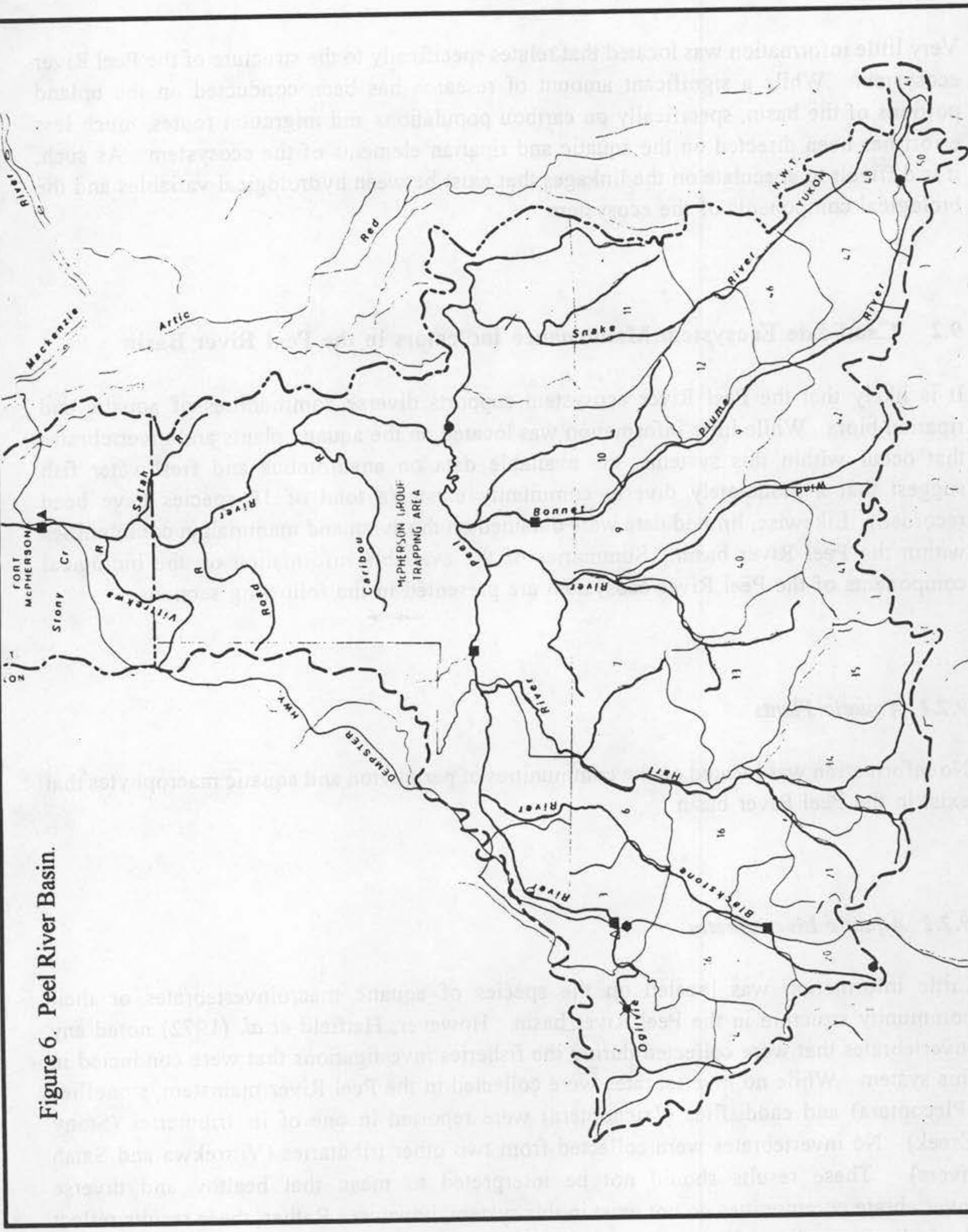


Figure 6. Peel River Basin.

9.1 An Overview of the Peel River Basin

Very little information was located that relates specifically to the structure of the Peel River ecosystem. While a significant amount of research has been conducted on the upland portions of the basin, specifically on caribou populations and migration routes, much less effort has been directed on the aquatic and riparian elements of the ecosystem. As such, it is difficult to speculate on the linkages that exist between hydrological variables and the biological components of the ecosystem.

9.2 Candidate Ecosystem Maintenance Indicators in the Peel River Basin

It is likely that the Peel River ecosystem supports diverse communities of aquatic and riparian biota. While little information was located on the aquatic plants and invertebrates that occur within this systems, the available data on anadromous and freshwater fish suggest that a moderately diverse community exists (a total of 18 species have been recorded). Likewise, limited data were obtained on the avian and mammalian communities within the Peel River basin. Summaries of the available information on the biological components of the Peel River ecosystem are presented in the following sections.

9.2.1 Aquatic Plants

No information was located on the communities of periphyton and aquatic macrophytes that exist in the Peel River basin.

9.2.2 Aquatic Invertebrates

Little information was located on the species of aquatic macroinvertebrates or their community structure in the Peel River basin. However, Hatfield *et al.* (1972) noted any invertebrates that were collected during the fisheries investigations that were conducted in this system. While no invertebrates were collected in the Peel River mainstem, stoneflies (Plecoptera) and caddisflies (Trichoptera) were reported in one of its tributaries (Stony Creek). No invertebrates were collected from two other tributaries (Vittrekwa and Satah rivers). These results should not be interpreted to mean that healthy and diverse invertebrate communities do not exist in this system, however. Rather, these results reflect the lack of sampling effort that has been directed on these rivers.

9.2.3 Fish

At least 18 species of freshwater and anadromous fish utilize habitats within the Peel River basin throughout some portion of their life history (Table 15). These include least cisco, arctic cisco, inconnu, humpback whitefish, broad whitefish, round whitefish, pygmy whitefish, arctic grayling, arctic char, Dolly Varden char, northern pike, burbot, flathead chub, lake chub, longnose dace, longnose sucker, spoonhead sculpin, and slimy sculpin (Hatfield *et al.* 1972; Simpson 1988). Of these species, the least cisco and arctic cisco are probably the most abundant, undergoing large upstream migrations in July and August (Simpson 1988). While in the river, these species and others that migrate into the Peel River during the summer and early fall (including arctic char, inconnu, and burbot) are caught in a domestic fishery that operates nearby Fort McPherson. In recent years, concerns have been raised about the status of arctic char stocks in the Peel, Rat, and Big Fish rivers, with overexploitation frequently cited as the most likely reason for the declining stocks.

Hatfield *et al.* (1972) reported that the Peel River consists of mud banks and is subject to drastic fluctuations in water level and current velocity. This variability in streamflow conditions is reflected in the annual hydrograph (Wedel 1993). Moreover, it carries a high silt load throughout much of the year and it has numerous mud and silt bars along its length. As a result of these observations, Hatfield *et al.* (1972) concluded that the Peel River within the NWT had very limited spawning potential. While some of the northern tributaries have some suitable spawning habitat, it is likely that most of the migratory fish species in this system utilize areas in the vicinity of the Snake and Road rivers for egg deposition and early rearing (Hatfield *et al.* 1972). Arctic char have been observed as far upstream as the Blackstone River (Bodaly and Lindsey 1977). Together, these observations suggest that virtually all migratory species would be severely affected by obstructions that disrupt migrations or alter the natural flow regime of the river (Simpson 1988).

9.2.4 Waterfowl and Shorebirds

No specific information was located on the populations of waterfowl and shorebirds that utilize nesting and rearing habitats within the Peel River basin. As the lower reaches of the Peel River are associated with the coastal plain and are characterized by numerous sloughs and backwater areas, this system undoubtedly provided important breeding and rearing habitats for waterfowl and shorebirds. Simpson (1988) reported that habitats within the Peel River basin are used by significant numbers of Canada geese and ducks. Raptors, such as ospreys, eagles, and falcons, have also been reported in the area (Simpson 1988).

Table 15. List of candidate ecosystem maintenance indicators (EMIs) for the Peel River basin: Aquatic plants, invertebrates and fish.

Candidate EMI	Essential Characteristics		Important Characteristics of EMIs for Their Intended Uses											
	Hydrological Relevance	Result of Preliminary Evaluation	Sensitivity	Measurability	Cost-Effectiveness	Availability of Historic Data	Nondestructiveness	Appropriateness of Scale	Lack of Redundancy	Social Relevance	Interpretiveness	Anticipatory	Timeliness	Total Evaluation Score
Aquatic Plants, Algae, Microbiota, and Invertebrates														
- Macrophytes														
- Periphyton														
- Fungi														
- Bacteria														
- Macroinvertebrates														
Anadromous Fish														
- Arctic cisco														
- Least cisco														
Migratory/Resident Fish														
- Arctic char														
- Dolly Varden char														
- Arctic grayling														
- Round whitefish														
- Pygmy whitefish														
- Humpback whitefish														
- Broad whitefish														
- Inconnu														
- Burbot														
- Northern pike														
- Longnose sucker														

Table 15. List of candidate ecosystem maintenance indicators (EMIs) for the Peel River basin: Aquatic plants, invertebrates and fish (continued).

Candidate EMI	Essential Characteristics		Important Characteristics of EMIs for Their Intended Uses											
	Hydrological Relevance	Result of Preliminary Evaluation	Sensitivity	Measurability	Cost-Effectiveness	Availability of Historic Data	Nondestructiveness	Appropriateness of Scale	Lack of Redundancy	Social Relevance	Interpretiveness	Anticipatory	Timeliness	Total Evaluation Score
Forage Fish/Other Species														
- Lake chub														
- Flathead chub														
- Longnose dace														
- Slimy sculpin														
- Spoonhead sculpin														
Fish Community Metrics														
- Species diversity														
- Species richness														
- Equitability														
- Trophic composition														
- Abundance and condition														
- Index of biotic integrity														

9.2.5 Mammals

Little information was located on the mammals that utilize aquatic and riparian habitats within the Peel River basin. However, the lower reaches of the Peel River are likely to provide abundant habitat for the important furbearers that typify northern river ecosystems. Simpson (1988) reported that these areas were used extensively by muskrat, beavers, mink, marten, and river otters.

9.3 Candidate Physical and Chemical Ecosystem Maintenance Indicators

In addition to the biological EMIs discussed previously, a number of physical and chemical variables could also be utilized to evaluate the health and vitality of the aquatic ecosystem. A list of physical and chemical variables that could be used as EMIs is presented in Table 16. One of the main advantages of these candidate EMIs is that they are typically easier to measure than biological variables. Workshop participants are encouraged to evaluate each of the candidate EMIs presented and identify additional EMIs for the Slave River Basin.

9.4 Potential Ecosystem Maintenance Indicators

In the Peel River basin, arctic char contributes significantly to the domestic fishery in the Peel River (Simpson 1988) and represents an appropriate indicator species for assessing the integrity of the aquatic ecosystem. This species is particularly sensitive to hydroelectric power developments because it utilizes habitat in the upper portions of the watershed for spawning and rearing activities. Hence, dam construction would likely prevent this species from reaching its spawning grounds and could affect the downstream migration of smolts. In addition, this species could be affected by changes in stream temperature, as the eggs are killed at temperatures above 7.8° C (Scott and Crossman 1973).

There are several variables associated with arctic char that could be used as ecosystem maintenance indicators. For example, a reduction in the abundance of adult migrants in the Peel River would be indicative of adverse effects on the ecosystem as a whole. Therefore, the abundance of arctic char (as measured in detailed fisheries investigations or catch per unit effort in the domestic fishery) could be identified as an ecosystem maintenance indicator for this system. However, the smolts of this species do not migrate to the sea until they reach about 150 - 175 mm and an age of 2 - 7 years old (Scott and Crossman

Table 16. List of candidate ecosystem maintenance indicators (EMIs) for the Peel River basin: Physical variables.

	Essential Characteristics		Important Characteristics of EMIs for Their Intended Uses											
Candidate EMI	Biological Relevance	Result of Preliminary Evaluation	Sensitivity	Measurability	Cost-Effectiveness	Availability of Historic Data	Nondestructiveness	Appropriateness of Scale	Lack of Redundancy	Social Relevance	Interpretiveness	Anticipatory	Timeliness	Total Evaluation Score
Flow-related Variables														
- Magnitude of peak discharge														
- Duration of peak discharge														
- Magnitude of low flow														
- Duration of low flow														
- Mean monthly discharge														
- Mean annual discharge														
- Water level														
- Variability in water level														
Ice-related Variables														
- Timing of ice formation														
- Location of river ice														
- Quantity of river ice														
- Stability of river ice														
- Duration of ice cover														
- Timing of river ice break-up														
- Frequency of ice jamming														
- Severity of ice jamming														
- Duration of ice jamming														
Water Quality-related Variables														
- Suspended sediment concentration														
- Suspended sediment loading														
- Nutrient concentrations														
- Nutrient loadings														
- Organic carbon concentrations														
- Organic carbon loadings														
- Trace metal concentrations														

Table 16. List of candidate ecosystem maintenance indicators (EMIs) for the Peel River basin: Physical variables (continued).

Candidate EMI	Essential Characteristics		Important Characteristics of EMIs for their Intended Uses											
	Biological Relevance	**Result of Preliminary Evaluation**	Sensitivity	Measurability	Cost-Effectiveness	Availability of Historic Data	Nondestructiveness	Appropriateness of Scale	Lack of Redundancy	Social Relevance	Interpretiveness	Anticipatory	Timeliness	**Total Evaluation Score**
Water Quality-related Variables (cont.)														
- Trace metal loadings														
- Organic contaminant concentrations														
- Water temperature														
- Dissolved oxygen levels														
Instream Geomorphic Variables														
- Wetted width														
- Stream depth														
- Stream gradient														
- Pool to riffle ratios														
- Wetted area in side channels														
- Depth in side channels														
- Substrate composition														
- Substrate stability														
- Quantity of large organic debris														
- Quantity of instream cover														
- Channel morphology														
Riparian Zone Variables														
- Quality of shoreline habitat														
- Size of delta areas														
- Sedimentation rates in delta areas														
- Quantity of wetlands														
- Extent of flooding														
- Duration of flooding														
- Timing of flooding														
- Frequency of flooding														
- Extent of ice scour														

1973). Arctic char do not mature until they reach 5 to 16 years of age. Hence, the abundance of adult char would not provide a timely indicator of ecosystem integrity.

As disruption of upstream and downstream migration of arctic char could be severely affected by dam construction and operation, the number (expressed as an absolute value or a percent of the total run that enters the river) and condition of fish that reach the major spawning grounds could be used as an ecosystem maintenance indicator for the Peel River basin. These metrics would provide timely information on the present status and trends of arctic char populations. In addition, these metrics could be used as surrogates for the status of other migratory fish species.

9.5 Research Needs

The preliminary evaluation of the candidate EMIs conducted in this study emphasizes the limitation on the existing knowledge base. Future research should be directed at filling these data gaps and developing a more comprehensive knowledge of the structure and function of the ecosystem. It is anticipated that workshop participants will identify research needs during the EMI evaluation process. Traditional environmental knowledge and local experience may provide much of the information needed to fill these data gaps.

Chapter 10

Approaches for Developing Water Quantity Objectives for Maintaining the Structure of Aquatic and Riparian Ecosystems in the Mackenzie River Basin

10.0 Introduction

Ecosystem maintenance indicators provide valuable tools for assessing the health and vitality of aquatic and riparian ecosystems in the transboundary river systems within the Mackenzie River basin. Specifically, these indicators provide a means of evaluating the impacts of changes in the hydrological regime on the important attributes of these ecosystems These attributes were discussed in Chapter 4 and are focused on the maintenance of northern ecosystems, including aquatic life and wildlife communities that utilize these areas. Protection of traditional, navigational, recreational, and aesthetic uses of these areas have also been identified as important management goals. However, establishment and monitoring of ecosystem maintenance indicators does not provide the information required to effectively manage these ecosystems. In addition, information on the hydrological requirements of these indicator species is required to facilitate planning activities by both upstream and downstream jurisdictions.

10.1 Development of Water Quantity Objectives

Currently, the water quantity objectives for the Mackenzie River basin are expressed as a narrative statement which indicated that *there will be no significant change in the flow regime that could affect the aquatic ecosystem*. While this is a reasonable goal for water managers in the river basin, this objective provides little guidance for evaluating the acceptability of developmental activities that are proposed on individual river systems. Therefore, this objective must be supported by physical indicators (such as, mean monthly discharge, water temperature, and water depth) which define the acceptable hydrological conditions. There are a number of approaches that could be used to define the hydrological conditions in the Slave, Liard, and Peel rivers that would be required to conserve the important attributes of aquatic and riparian ecosystems, including:

(i) analysis of historical hydrological and biological data;

(ii) evaluation of case studies from other river systems; and

(iii) utilization of instream flow incremental methodology or similar methods.

Each of these approaches are briefly discussed in the following sections.

10.1.1 Analysis of Historical Data

When available, historical data on the hydrology and biological characteristics could provide valuable information for establishing acceptable hydrological conditions in the transboundary rivers of the Mackenzie River basin. For example, detailed hydrological data are available since 1960 on the Slave River at Fitzgerald (Wedel 1993). These data indicate that significant variability in annual mean flow, annual daily minimum flow and annual peak flow has occurred over this period. If information on muskrat harvest (or other important ecosystem attributes) were also available for part or all of this period, these data could be analyzed to develop relationships between key hydrological variables and trapping success. The strength of this approach is that it would provide site-specific data that apply directly to the Slave River ecosystem. The major disadvantages of this approach are likely to be associated with limitations on the availability of the requisite biological data. In addition, it is possible that the hydrological conditions experienced between 1960 and 1993 were not extreme enough to be associated with adverse biological effects. **It is recommended that the available biological data on the ecosystem maintenance indicator species for the Slave, Liard, and Peel rivers be collected and analyzed, in conjunction with the available hydrological data.**

Alternatively, the requisite biological and hydrological data could be collected on selected EMIs by designing and implementing focused monitoring programs in these river basins. One of the advantages of conducting this type of site-specific monitoring programs is that baseline conditions could be established for assessing the impacts of developments that occur subsequently.

10.1.2 Case Histories

Riverine ecosystems throughout North America have been regulated to generate hydroelectric power, to provide water for irrigation and other water uses, and to reduce flood damage associated with extreme flows. In some cases, stream have even been regulated to increase fisheries production and values (for example, the Big Qualicum River in British Columbia; Mundie and Birt 1986). While little information is available on northern rivers, information on the effects of alteration of the hydrological regime on aquatic and riparian ecosystems provides a powerful management tool. For example, Burt and Mundie (1986) conducted an extensive review of 81 case histories to determine the effects of streamflow regulation on salmonid populations. The results of this investigation indicated that adverse effects were observed in 76% of these cases, with blockage of habitat, sedimentation of habitat, fluctuating flows, and changes in water temperature accounting for the majority of the impacts. In addition to providing useful information for assessing the impacts of streamflow alterations, this study emphasizes the value of utilizing case histories in the impact assessment process. It is possible that further evaluation of these and other case histories could help to define the hydrological conditions that would, generally, protect aquatic organisms.

While general information on the hydrological conditions that are necessary to protect fish and other aquatic organisms may be applicable to the Mackenzie River basin, it would be preferable to establish the requirements of the species that actually reside in the three transboundary rivers. **For this reason, information from appropriate case histories that involved the ecosystem maintenance indicator species that were recommended in Chapters 7, 8, and 9 (or the alternate species that are identified by workshop participants) should be assembled and evaluated.**

10.1.3 Methods for Quantifying Instream Flow Requirements

A number of methods have been developed for quantifying the instream flows that are required to provide adequate spawning and rearing habitats for freshwater fish species. For example, Estes and Orsborn (1986) evaluated four different methods for estimating instream flow requirements to support spawning by chinook salmon in Willow Creek (Alaska). These methods included the instream flow incremental methodology, the Montana method, the maximum spawning area flow method, and the maximum spawning area method. While the results of this study indicated that each method could be used independently or collectively to generate instream flow recommendations, none of these procedures have been demonstrated to be directly applicable to large northern river systems. Likewise, methods, such as the habitat evaluation procedure that has been used in Kansas for recommended minimum desirable streamflow (Layher and Brunson 1992), have not been adequately evaluated. **For this reason, it is recommended that the published methods for quantifying instream flow requirements be evaluated to assess their applicability to large, northern rivers.** In addition, the limitations of these methods in rivers that are dominated by ice should be investigated.

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Appendix 1

MACKENZIE RIVER BASIN TRANSBOUNDARY WATERS MASTER AGREEMENT

BETWEEN:

THE GOVERNMENT OF CANADA as represented by the Minister of the Environment and the Minister of Indian Affairs and Northern Development (hereinafter referred to as "Canada")

AND

THE GOVERNMENT OF THE PROVINCE OF BRITISH COLUMBIA as represented by the Minister of Environment, Lands and Parks (hereinafter referred to as "British Columbia")

AND

THE GOVERNMENT OF THE PROVINCE OF ALBERTA as represented by the Minister of Environmental Protection and the Minister of Federal and Intergovernmental Affairs (hereinafter referred to as "Alberta")

AND

THE GOVERNMENT OF THE PROVINCE OF SASKATCHEWAN as represented by the Minister Responsible for the Saskatchewan Water Corporation (hereinafter referred to as "Saskatchewan")

AND

THE GOVERNMENT OF THE NORTHWEST TERRITORIES as represented by the Minister of Renewable Resources and the Commissioner of the Northwest Territories (hereinafter referred to as the "Northwest Territories")

AND

THE GOVERNMENT OF THE YUKON as represented by the Minister of Renewable Resources (hereinafter referred to as the "Yukon")

Hereinafter referred to collectively as "the Parties".

WHEREAS the waters of the Mackenzie River Basin arise in or flow through British Columbia, Alberta, Saskatchewan, Northwest Territories and the Yukon and are a precious resource;

AND WHEREAS the waters of the Mackenzie River Basin should be managed to preserve the Ecological Integrity of the Aquatic Ecosystem; and to facilitate reasonable, equitable and sustainable use of this resource for present and future generations;

AND WHEREAS cooperative management of the waters of the Mackenzie River Basin requires the application of consistent guiding principles;

AND WHEREAS the Parties have been exchanging information on water related issues, developments and research, and have been undertaking cooperative studies and programs of mutual interest;

AND WHEREAS a cooperative water management mechanism will encourage the assessment of water issues and promote sustainable resource use and management;

AND WHEREAS cooperative water management agreements are the most appropriate means of addressing interjurisdictional water quality and related issues at boundary crossing points;

AND WHEREAS the Governor in Council has pursuant to Order in Council No. _____ dated ___________ authorized the Minister of Environment and the Minister of Indian Affairs and Northern Development to execute this Agreement on behalf of Canada;

AND WHEREAS the Lieutenant-Governor in Council has pursuant to Order in Council No. _____ dated ___________ authorized the Minister of Environment, Lands and Parks to execute this Agreement on behalf of British Columbia;

AND WHEREAS the Lieutenant-Governor in Council has pursuant to Order in Council No. _____ dated ___________ authorized the Minister of Environmental Protection and the Minister of Federal and Intergovernmental Affairs to execute this Agreement on behalf of Alberta;

AND WHEREAS the Lieutenant-Governor in Council has pursuant to Order in Council No. _____ dated ___________ authorized the Minister responsible for the Saskatchewan Water Corporation to execute this agreement on behalf of Saskatchewan;

AND WHEREAS the Northwest Territories Legislative Assembly through the authority of the Water Resources Agreements Act SNWT 1983, c. 9, has authorized the Executive Council Member Responsible for Renewable Resources and the Commissioner of the Northwest Territories to execute this Agreement on behalf of the Northwest Territories;

AND WHEREAS the Yukon Legislative Assembly through the authority of ____________ dated ____________ has authorized the Minister of Renewable Resources to execute this Agreement on behalf of the Yukon.

NOW, THEREFORE, THE PARTIES AGREE AS FOLLOWS:

PART A Purpose

The purpose of this Agreement is to establish common principles for the cooperative management of the Aquatic Ecosystem of the Mackenzie River Basin, to establish an administrative mechanism to facilitate application of these principles, and to make provisions for Bilateral Water Management Agreements.

PART B Definitions

"Aquatic Ecosystem" means the interacting components of air, land water and living organisms including humans, that relate to the Water Resources of the Mackenzie River Basin.

"Basin" means the Mackenzie River Basin as outlined in Schedule "A".

"Bilateral Water Management Agreements" means those agreements between the provinces and the territories (including the Department of Indian Affairs and Northern Development, where the territories are parties to this Agreement) as listed below, which, when signed by the Parties, will be attached to this Agreement as Schedules B, C, D, E, F, G, and H, respectively, and as may be amended from time to time:

British Columbia-Alberta
British Columbia-Northwest Territories
British Columbia-Yukon
Alberta-Northwest Territories
Alberta-Saskatchewan
Saskatchewan-Northwest Territories
Northwest Territories-Yukon

"Board" means the Mackenzie River Basin Board established under Part D, section 1.

"Ecological Integrity" means the condition that the Parties to any of the Bilateral Water Management Agreements determine are necessary to maintain a healthy and diverse Aquatic Ecosystem.

"Fiscal Year" means a period commencing April 1 and ending March 31 of the following year.

"Ministers" means

a. for Canada, the Minister of the Environment and the Minister of Indian Affairs and Northern Development;

b. for British Columbia, the Minister of Environment, Lands and Parks;

c. for Alberta, the Minister of Environmental Protection and Minister for Federal and Intergovernmental Affairs;

d. for Saskatchewan, the Minister responsible for the Saskatchewan Water Corporation;

e. for the Northwest Territories, the Minister of Renewable Resources; and

f. for the Yukon, the Minister of Renewable Resources.

"Secretariat" means the Mackenzie River Basin Secretariat established pursuant to this Agreement.

"Water Resources" means the Mackenzie River and any order tributary to the Mackenzie River including deltas, tributaries of deltas, wetlands and lakes which contribute water to the Mackenzie River, whether in a liquid or frozen state, excluding groundwater except where the Parties tom a Bilateral Water Management Agreement agree to its inclusion.

PART C Principles

The Parties are committed to:

1. Managing the Water Resources in a manner consistent with the maintenance of the Ecological Integrity of the Aquatic Ecosystem;

2. Managing the use of the Water Resources in a sustainable manner for present and future generations.

3. The right of each to use or manage the use of the Water Resources within its jurisdiction provided such use does not unreasonably harm the Ecological Integrity of the Aquatic Ecosystem in any other jurisdiction;

4. Providing for early and effective consultation, notification and sharing of information on developments and activities that might affect the Ecological Integrity of the Aquatic Ecosystem in another jurisdiction; and

5. Resolving issues in a cooperative and harmonious manner.

PART D Administration

1. Mackenzie River Basin Board

a. There shall be established a Mackenzie River Basin Board consisting of no more than thirteen members, eight of which Board members shall be appointed at the pleasure of each Party hereto as follows:

Canada	up to three members
British Columbia	one member
Alberta	one member
Saskatchewan	one member
Northwest Territories	one member
Yukon	one member

b. There shall be a total of five Board members representing Aboriginal organizations, one for Aboriginal organizations in each of British Columbia, Alberta, Saskatchewan, Northwest Territories and the Yukon to be nominated and appointed as follows:

i. The Aboriginal organizations in each such jurisdiction shall nominate one person for appointment to the Board; and

ii. each such nominee shall be appointed by and serve at the pleasure of the Minister representing the jurisdiction from which the nominee was selected.

c. Each member including the chairperson may designate an alternate and shall register that designation with the Board. The alternate may act on behalf of the appointed member during his or her absence whereupon the alternate shall enjoy all the rights conferred upon the member.

d. The chairperson shall be selected from Board members by the full Board membership, at least every two years.

e. A quorum of the Board shall be seven members or their alternates.

f. A two-thirds majority of the members present shall constitute approval of the Board on any question.

g. The expenses of the members representing Aboriginal organizations shall be borne by the Parties in accordance with the costing formula outlined in Part D, section 3, and the Parties will bear the costs of their own members.

2. Duties of the Board

The Board shall act to carry out the purposes of this Agreement in accordance with the principles stated herein by:

a. providing a forum for communication, coordination, information exchange, notification and consultation;

b. identifying, recommending and implementing such studies, investigations, programs and activities as are required to carry out this Agreement;

c. considering the needs and concerns of Aboriginal people through,

   i. the provision of culturally appropriate communication, and

   ii. the incorporation of their traditional knowledge and values;

d. establishing and directing the activities of the Secretariat, which shall carry out the programs approved by the Board and shall comprise such personnel as the Board may direct;

e. recommending uniform objectives or guidelines for the quality and quantity of the Water Resources;

f. establishing and directing technical committees which may be required to support the work of the Board;

g. encouraging consistent monitoring programs;

h. monitoring the progress of implementing the Bilateral Water Management Agreements;

i. administering the dispute resolute process set out in Part E;

j. meeting at least annually;

k. reviewing this Agreement at least once every three years and proposing amendments to the Parties;

l. creating a budget which shall include:

   i. within two years of the signing of this Agreement, developing a five-year expenditure plan,

ii. establishing the annual Board budget within the limits approved by the Parties, and

iii. authorizing expenditures within the limits of approved budgets including, inter alia, expenditures for the staffing and operation of the Secretariat;

m. as required, engaging agencies of the Parties, Aboriginal organizations, or consultants, to undertake such assignments as the Board requires;

n. submitting to the Ministers an annual report, within six months after the end of the Fiscal Year;

o. submitting to the Ministers on the state of the Aquatic Ecosystem within 5 years after the end of the first Fiscal Year and every 5 years thereafter;

p. keeping complete records of all expenditures made pursuant to this Agreement, supporting such expenditures with proper documentation, and making these records and documents available to auditors appointed by the Board or any Party hereto requesting the same;

q. enacting, amending or repealing by-laws for the conduct of the Board and the Secretariat;

r. establishing standards and procedures required for maintenance of order at its meetings; and

s. carrying out such other related duties as all the Parties request in writing.

3. Cost Sharing:

a. Canada, as represented by the Department of Environment, shall assume responsibility for financing all expenditures, in the first instance;

b. the total annual costs eligible to be shared by the Parties pursuant to this Agreement shall not exceed $280,000 or such other amount the Ministers may agree from time to time;

c. eligible expenditures authorized by the Board may include, inter alia, expenditures for the staffing and operation of the Secretariat, and the expenses of the members representing aboriginal organizations but shall not include the expenses of the members of the Parties;

d. total annual eligible costs shall be shared in accordance with the following formula:

i. 1/7 of the total, contributed by each of the following:

The Government of Saskatchewan;
The Government of Alberta;
The Government of British Columbia;
The Government of Yukon;
The Government of Northwest Territories; and

ii. 2/7 of the total, contributed by the Government of Canada, shared equally by the Department of Environment and the Department of Indian Affairs and Northern Development.

e. the provinces and the territories shall pay to Canada, as represented by the Department of Environment, their share of expenditures made by Canada under this Agreement as follows,

i. on or before March 31st of each year, Canada shall prepare and submit to each of the Parties interim statements of their respective shares of monies due Canada for financing the operations pursuant to this Agreement during the current Fiscal Year. Final statements shall be audited and certified by senior officials of Canada prior to submission to the Parties, and

ii. within sixty days after receipt of the statements by Canada, submitted as prescribed in the sub-section next preceding, each of the provinces and each of the territories shall reimburse Canada for their shares of expenditures as provided above;

d. Canada shall reimburse each of the provinces and each of the territories for expenditures made pursuant to this Agreement by any province or territory. Payment for such expenditures will be made by Canada within 60 days after receipt of a claim in a mutually agreed manner and form, any such payments to be then deemed an approved expenditure, which shall be borne by the Parties on the basis provided above; and

e. the Board members shall keep complete records of all expenditures made pursuant to this Agreement, shall support such expenditures with proper documentation, and shall make these records and documents available to auditors appointed by the Board.

PART E Dispute Resolution

1. Any board member may refer a dispute or question under this Agreement, excluding the Bilateral Water Management Agreements, directly to the Board, and the Board, before recommending terms of settlement to the Parties, may, where appropriate, undertake the following actions, as it deems necessary:

   a. studies and investigations;

   b. preparation of a report on the facts and circumstances of the dispute or question;

   c. establish and instruct a panel to prepare the report referred to in b) above, and which may recommend terms of settlement. The panel shall consist of one person designated by each party to the dispute or question together with a chairperson designated by the Board.

2. Where a dispute or question related to a Bilateral Water Management Agreement has not been resolved, it may be referred to the Board by any of the Parties to that Bilateral Water Management Agreement, whereupon the Board shall follow the provisions of section 1 above, insofar as they are applicable.

3. Disputes or questions which have not been resolved in accordance with sections 1 and 2 above, may be referred to the Ministers for the affected jurisdictions by the chairman of the Board acting on the directions of the Board.

PART F Aboriginal and Treaty Rights

Nothing in this Agreement shall be interpreted in a manner inconsistent with the exercise of any existing Aboriginal and Treaty rights as recognized and affirmed in s. 35 of the Constitution Act, 1982, which include rights now existing by way of land claims agreements or which may be acquired under land claims agreements.

PART G Proprietary Rights or Interests

This Agreement and any activity conducted under it shall not derogate from any proprietary rights or interests of the Parties.

PART H Appropriation

Notwithstanding any other provision of this Agreement, the payment of money by the Parties pursuant to this Agreement is subject to:

(a) there being sufficient monies available in an appropriation made in accordance with their respective Financial Administration Acts, to enable the Parties, in any fiscal year or part thereof when any payment of money by the Parties falls due pursuant to this Agreement, to make that payment;

(b) Treasury Board, as defined in those Acts, not having controlled or limited, pursuant thereto, expenditure under any appropriation referred to in subsection (a) of this section.

PART I Amendment

This Agreement, excluding the Bilateral Water Management Agreements, may be amended with the consent of all the Parties to this Agreement.

PART J Duration

This Agreement takes effect when signed by all the Parties, notwithstanding that one or other of the Bilateral Water Agreements hereto may not have been executed, and may be terminated by any Party upon one year's written notice to the other Parties, where upon expiry of the notice period, this Agreement and all Bilateral Water Management Agreements scheduled hereto shall terminate, subject to compliance with the cost-sharing provisions set out in Part D, Section 3.

IN WITNESS WHEREOF this Agreement has been executed on behalf of the Parties by the Ministers and Commissioner of the latest date indicated below.

GOVERNMENT OF CANADA

Witness

Minister of the Environment

Date

Witness

Minister of Indian Affairs and Northern Development

Date

SIGNED on behalf of the Government of the Province of British Columbia by the Minister of Environment, Lands and Parks in the presence of:

GOVERNMENT OF THE PROVINCE OF BRITISH COLUMBIA

Witness

Minister of Environment Lands and Parks

GOVERNMENT OF THE PROVINCE OF ALBERTA

Witness

Minister of Environmental Protection

Date

APPROVED PURSUANT TO THE ALBERTA DEPARTMENT OF FEDERAL AND INTERGOVERNMENTAL AFFAIRS ACT

Minister of Federal and Intergovernmental Affairs

Date

GOVERNMENT OF THE PROVINCE OF SASKATCHEWAN

Witness

Minister Responsible for the Saskatchewan Water Corporation

Date

GOVERNMENT OF THE NORTHWEST TERRITORIES

Witness

Minister Responsible for Renewable Resources

Date

Witness

Commissioner of the Northwest Territories

Date

GOVERNMENT OF THE YUKON

Witness

Minister of Renewable Resources

Date

Appendix 2

DRAFT

YUKON-NORTHWEST TERRITORIES

TRANSBOUNDARY WATER MANAGEMENT AGREEMENT

Prepared By:

Policy and Planning Branch

Yukon Renewable Resources

October 5, 1993

YUKON-NORTHWEST TERRITORIES TRANSBOUNDARY WATER MANAGEMENT AGREEMENT

BETWEEN:

THE GOVERNMENT OF CANADA as represented by the Minister of Indian Affairs and Northern Development (hereinafter referred to as "Canada")

AND

THE GOVERNMENT OF THE NORTHWEST TERRITORIES as represented by the Executive Council Member Responsible for Renewable Resources and the Commissioner of the Northwest Territories (hereinafter referred to as "Northwest Territories")

AND:

THE YUKON TERRITORY as represented by the Executive Council Member Responsible for Renewable Resources (hereinafter referred to as "Yukon")

HEREINAFTER REFERRED TO AS THE 'PARTIES'

WHEREAS the waters of the Mackenzie River Basin arise in or flow through Yukon, British Columbia, Alberta, Saskatchewan and the Northwest Territories and are a precious common resource;

AND WHEREAS the governments of Canada, Yukon, British Columbia, Alberta, Saskatchewan, and the Northwest Territories have signed the Mackenzie River Basin Master Agreement on Transboundary Water Management dated __________;

AND WHEREAS the water resources common to the Yukon and Northwest Territories should be managed to preserve the ecological integrity of the aquatic ecosystem for current and future generations of Canadians in general and residents of Yukon and the Northwest Territories in particular;

AND WHEREAS the Parties recognize that subsistence users are among the first people to be affected by changes to the aquatic ecosystem;

AND WHEREAS the Parties intend that this Agreement be interpreted in a manner consistent with the exercise of any existing Aboriginal and Treaty rights as recognized by way of land claims agreements or which may be acquired under land claims agreements;

AND WHEREAS the Parties following the principles as set out in the Mackenzie River Basin Master Agreement desire to enter into a cooperative water management agreement as contemplated by that Agreement;

AND WHEREAS the Governor in Council has by Order-in-Council no. _____ dated ______, authorized the Minister of Indian Affairs and Northern Development to execute this agreement on behalf of Canada;

AND WHEREAS the Northwest Territories Legislative Assembly through the authority of the Water Resources Agreements Act, S.N.W.T., 1983, c.9 has authorized the Minister of Renewable Resources and the Commissioner of the Northwest Territories to execute this agreement on behalf of the Northwest Territories;

AND WHEREAS the Commissioner in Executive Council pursuant to the Mackenzie River Basin Agreements Act has authorized the Executive Council Member responsible for Renewable Resources to execute this agreement on behalf of Yukon;

NOW THEREFORE, THE PARTIES AGREE AS FOLLOWS:

1.0 PURPOSE

The purpose of this Agreement is to cooperatively manage, protect and conserve the ecological integrity of the aquatic ecosystem of the Mackenzie River basin common to Yukon and the Northwest Territories while facilitating sustainable use of the transboundary waters.

2.0 OBJECTIVES

2.1 To develop and implement ecosystem objectives to protect the ecological integrity of the water resources common to the Yukon and Northwest Territories;

2.2 Work toward prevention, control and minimizing point and non-point sources of persistent toxic substances;

2.3 To prohibit water transfer in or out of the shared portion of the Mackenzie River Basin that could affect the ecological integrity of the aquatic resources;

2.4 To provide opportunities for participation in development planning processes by jurisdictions whose water resources may be affected;

2.5 To foster scientific research and the use of traditional knowledge on water issues in the basin common to the Yukon and Northwest Territories and to identify the implications of potential developments to the aquatic ecosystem;

2.6 To take corrective action as necessary; and

2.7 To promote public information and consultation processes.

2.0 DEFINITIONS

Aboriginal Organizations

In Yukon are the Ross River Dena Council, the Nacho Nyak Dun First nation, the Vuntut Gwitchin Tribal Council and the Dawson First Nation, and

In the Northwest Territories are the Gwich'in Tribal Council and the Inuvialuit Game Council.

Aquatic Ecosystem

The interacting components of the air, land, water and living organisms including humans that relate to the water resources of this agreement.

Ecological Integrity

Chemical, physical, hydrological and biological conditions necessary to maintain a healthy and diverse aquatic ecosystem.

Mackenzie River Basin Board

The Mackenzie River Basin Board established under the Mackenzie River Basin Transboundary Master Agreement.

Ministers

For Canada, the Minister of Indian Affairs and Northern Development; and

For the Northwest Territories, the Member of the Executive Council appointed as the Minister of Renewable Resources; and

For Yukon, the Executive Council Member appointed as the Minster responsible for Renewable Resources.

Mitigative Measures

The elimination, reduction or control of unacceptable deviations from water quality and water quantity objectives. These measures could include restitution for any damage to the ecological integrity of the transboundary waters caused by a project or activity through replacement, restoration, compensation or any other means.

Monitoring Program

The collection, analysis and interpretation of aquatic ecosystem conditions obtained through systematic surveys or studies.

Persistent Toxic Substances

Any substance that can cause death, disease, behavioural abnormalities, cancer, genetic mutations, physiological or reproductive malfunctions or physical deformities in any organism or its offspring, or that can become poisonous after concentration in the food chain, or in combination with other substances and that has a half-life in any medium of greater than eight weeks.

Subsistence User

Any person in the Yukon or Northwest Territories who relies on the harvest of edible fish or wildlife products for sustenance and food, and the use of non-edible by-products of fish and wildlife for such domestic purposes as clothing, shelter or medicine and for spiritual and cultural purposes.

Transboundary Waters

Waters that flow across the boundary between Yukon and the Northwest Territories, or through which the boundary passes.

Water Quality Objectives

Numerical concentrations or narrative statements established under this agreement to support and maintain a designated water use.

Water Quantity Objectives

Numerical values or narrative statements established under this agreement for streamflows, water levels and volumes established under this agreement to support and maintain a designated water use.

Water Resources

The waters of the Mackenzie River and any inland water that is part of the Mackenzie River Basin, including wetlands, deltas, tributaries to deltas, and groundwater, whether in a liquid or frozen state.

3.0 GEOGRAPHIC SCOPE

3.1 The waters of the Mackenzie River Basin common to the Yukon and Northwest Territories are the geographic scope of this agreement as identified and described in Schedule A.

4.0 WATER MANAGEMENT

4.1 The Parties are committed to the management of the trans waters in accordance with the principles established in the Mackenzie River Basin Master Agreement.

4.2 The Parties are committed to the protection, enhancement, conservation and wise use of the water resources to maintain the ecological integrity of the transboundary waters.

4.3 The Parties are committed to achieving the ecosystem objectives for the transboundary waters that are attached as Schedules B and C and which form a part of this Agreement.

4.4 The Parties may develop sub-agreements from time to time to address specific water management issues in individual basins. The sub-agreements may be attached as schedules to and form part of this Agreement.

4.5 Within two years of signing this Agreement the Parties shall undertake monitoring and assessment activities with a view to determining whether the objectives are being met. The Parties shall coordinate monitoring and assessment activities with any related land claims implementation activities.

5.0 ADMINISTRATION

5.1 The Parties may establish a Yukon-Northwest Territories Water Resources Committee on an ad hoc basis to carry out tasks in accordance with terms of reference established by the Parties relating to water management within the scope of this Agreement.

5.2 A Committee shall, within its terms of reference, act to promote the protection, conservation, enhancement and wise use of the transboundary waters.

5.3 The Committee shall provide culturally appropriate communication, incorporate traditional knowledge and values, and where possible, arrive at its decisions by consensus.

5.4 The Committee will consist of no more than eight members appointed by each Party and Aboriginal Organization as follows:

Yukon Government	one member
Canada	two members
Aboriginal Organizations (Yukon)	two members
Aboriginal Organizations (Northwest Territories)	two members
Government of the Northwest Territories	one member

5.5 Members of the Committee will be appointed at pleasure by their respective Ministers or Aboriginal Organizations.

5.6 The Committee shall select from its membership a Chairperson.

5.7 Each member may designate an alternate member to act on their behalf during their absence.

5.8 The expenses of the Aboriginal Committee Members shall be borne by the respective Parties and paid out according to the terms of their appointment. (To be discussed further)

6.0 NOTIFICATION AND COMMUNICATION

6.1 For developments and activities not listed as exclusions under the Canadian Environmental Assessment Act or other environmental assessment legislation, the Parties shall provide opportunities for early consultation and notification of developments and activities that might affect another jurisdiction and share environmental assessment information in a timely and consistent manner.

6.2 Each Party shall provide such technical and other information it possesses to the other Parties for the purpose of enabling the other Parties to assess the probable impact of a development or activity and to determine if new or expanded monitoring programs may be required.

6.3 The Party within whose jurisdiction a development activity is proposed shall afford the responding Parties a sufficient period of time to assess the probable impacts and to determine their monitoring needs.

6.4 Should any Party detect a deviation from water quality or water quantity objectives specified in the Schedules the Party detecting the deviation shall notify the other

Parties in a timely manner. The Party whose jurisdiction the action leading to the deviation has occurred, shall take appropriate mitigative measures.

6.5 If an emergency event occurs which might threaten the ecological integrity of the trans boundary waters, the Party in whose jurisdiction the event has occurred, shall notify the other Parties immediately.

6.6 Each Party shall within its jurisdiction be responsible for any notification of the public and Aboriginal Organizations respecting the matters dealt with in 6.1 to 6.5.

7.0 DISPUTE-RESOLUTION PROCESS

7.1 The Parties shall use their best efforts to resolve any dispute, difference or question respecting this Agreement through direct discussions.

7.2 A Party or an Aboriginal Organization may refer an unresolved dispute, difference or question to the Mackenzie River Basin Board and request the Board to examine and report upon the facts and circumstances. The Board may appoint one or more experts to assist with resolving the dispute. The Board will provide the Parties with its conclusions and recommendations. (To be discussed further)

8.0 AMENDMENTS

8.1 This Agreement may be amended by the Ministers in writing.

9.0 ABORIGINAL AND TREATY RIGHTS

9.1 Nothing in this Agreement shall be interpreted in a manner inconsistent with the exercise of any existing Aboriginal and Treaty rights as recognized and affirmed in s. 35 of the Constitution Act, 1982, which include rights now existing by way of land claims agreements or which may be acquired under land claims agreements.

10.0 GENERAL

10.1 Any requirement of this Agreement shall be performed within the framework of each Party's jurisdiction and within each Party's regulatory schemes in effect from time to time.

10.2 Notwithstanding any other provision of this Agreement, the payment of money by the Parties pursuant to this Agreement is subject to:

(a) there being sufficient monies available in an appropriation made in accordance with their respective Financial Administration Acts, to enable the Parties, in any fiscal year or part thereof when any payment of money by the Parties falls due pursuant to this Agreement, to make that payment;

(b) Treasury or Management Board, as defined in those Acts, not having controlled or limited, pursuant thereto, expenditure under any appropriation referred to in subsection 10.2(a).

10.3 This agreement shall not operate to vest in any Party any proprietary right or interest that it otherwise would not have.

10.4 No member of the House of Commons of Canada, or of the Legislative Assembly of the Northwest Territories or of the Legislative Assembly of Yukon shall hold, enjoy, or be admitted to any share or part of any contract, agreement, commission or benefit arising therefrom.

10.5 This agreement and the attached schedules form the entire agreement.

11.0 DURATION OF AGREEMENT

11.1 This Agreement shall take effect when signed by the Parties and may be terminated by any Party giving one year's written notice to the other Parties.

12.0 SCHEDULES

12.1 The following schedules are attached to and form a part of this agreement:

(a) Transboundary waters

(b) Water quality objectives

(c) Water quantity objectives

IN WITNESS WHEREOF, this Agreement has been executed on behalf of the Parties by the Ministers and Commissioner indicated below on the date so indicated:

IN THE PRESENCE OF

CANADA

______________________	______________________
Witness	Minister of Indian Affairs and Northern Development Date

YUKON

______________________	______________________
Witness	Executive Council Member responsible for Renewable Resources Date

NORTHWEST TERRITORIES

______________________	______________________
Witness	Minister of Renewable Resources Date
______________________	______________________
Witness	Commissioner of the Northwest Territories Date

SCHEDULE A
TRANSBOUNDARY WATERS

Schedule A constitutes a listing of transboundary waters that are common to the Yukon and Northwest Territories. A map is included to illustrate the major transboundary waters.

TRANSBOUNDARY WATERS BETWEEN THE YUKON AND NORTHWEST TERRITORIES IN THE MACKENZIE RIVER BASIN

MAP ID	RIVER BASIN NAME	AREA	CROSSING LOCATION	FLOW
	(km^2)	(Lat and Long)	DIRECTION	
1	PEEL RIVER SUB BASIN	73954.0		
1A	Peel River	70715.5	67° 00' N 135° 00' W	YT to NWT
1B	Vittrekwa River	1668.1	67° 00' N 135° 36' W	YT to NWT
1C	Satah River	1411.9	67° 00' N 134° 27' W	YT to NWT
1D	Old Robert Creek	158.5	67° 00' N 135° 25' W	YT to NWT
2	RAT RIVER SUB BASIN	2401.6		
	Rat River	2401.6	67° 57' N 136° 27' W	YT to NWT
3	BIG FISH RIVER SUB BASIN	2627.7		
3A	Big Fish River	1005.4	68° 30' N 136° 27' W	YT to NWT
3B	Little Fish River	675.9	68° 14' N 136° 27' W	YT to NWT
3C	Almstrom Creek	628.0	68° 7 N 136° 27' W	YT to NWT
3D	Cache Creek	318.4	--	NWT
4	MOOSE CHANNEL	1195.2	68° 47' N 136° 27' W	NWT TO YT

EXPLANATORY NOTES

GENERAL COMMENTS

The trans river basins were delineated on 1:250,000 NTS maps using river channels and height of land. In areas where there was some uncertainty, 1:50,000 NTS maps were used.

The majority of the Yukon and Northwest Territories' border (from 60° N to 67° N) is the height of land and is therefore a drainage divide.

Basins were chosen for all streams that crossed the boundary on the 1:250,000 maps.

The basins were not delineated below 50 feet in the Mackenzie River Delta because of the contorted drainage pattern which prevents any clear definition of the river's mouth.

Only transboundary sub-basins were delineated in order to show greater detail within the basin. The naming convention follows this approach by giving all sub-basins the same number designator and the major sub-basin the letter A (ie. Peel River is 1A which indicates that it is part of the Peel River System and the major sub-basin).

SPECIFIC COMMENTS

Three Cabin Creek flows in two directions and so the basin was divided at Yiditshuu Lake. The northern flow is part of the Satah River Basin while the southern flow is included with the Peel River Basin.

The Moose Channel Basin was delineated by grouping all of the channels and streams that contributed any flow to the channel.

Cache Creek is not a transboundary river but since it completes the western part of the Big Fish River System it was included.

SCHEDULE B

WATER QUALITY OBJECTIVES

The Canadian Council of Resource and Environment Ministers (1987) "Canadian Water Quality Guidelines" are used as the basis for the water quality objectives for this agreement. These water quality objectives may be refined based on monitoring programs or they may be revised to include new or amended water quality objectives developed and accepted by the Canadian Council of Ministers of Environment.

The water quality objectives for this agreement are as follows:

Parameter	Objective	Comments
Inorganic Parameters		
Aluminum[1]	0.005 mg/L	Ph<6.5; [Ca2+]<4.0 mg/L DOC<2.0 mg/L
	0.1 mg/L	Ph≥6.5; [Ca2+]≥4.0 mg/L DOC≥2.0 mg/L
Antimony	ID[2]	
Arsenic	0.05 mg/L	
Beryllium	ID	
Cadmium	0.2 µg/L	Hardness 0-60 mg/L (CaCO3)
	0.8 µg/L	Hardness 60- 120 mg/L (CaCO3)
	1.3 µg/L	Hardness 120-180 mg/L (CaCO3)
	1.8 µg/L	Hardness >180 mg/L (CaCO3)
Chlorine (total residual chlorine)	2.0 µg/L	Measured by amperometric or equivalent method
Chromium	0.02 mg/L	To protect fish
	2.0 µg/L	To protect aquatic life, including zooplankton and phytoplankton
Copper	2 µg/L	Hardness 0-60 mg/L (CaCO3)
	2 µg/L	Hardness 60-120 mg/L (CaCO3)
	3 µg/L	Hardness 120-180 mg/L (CaCO3)
	4 µg/L	Hardness >180 mg/L (CaCO3)
Cyanide	5.0 µg/L	Free cyanide as CN
Dissolved oxygen	6.0 mg/L	Warm-water biota - early life stages
	5.0 mg/L	- other life stages
	9.5 mg/L	Cold-water biota - early life stages
	6.5 mg/L	- other life stages
Iron	0.3 mg/L	

Parameter	Objective	Comments
Lead	1 µg/L 2 µg/L 4 µg/L 7 µg/L	Hardness 0-60 mg/L (CaCO3) Hardness 60-120 mg/l (CaCO3) Hardness 120-180 mg/L (CaCO3) Hardness >180 mg/L (CaCO3)
Mercury	0.1 µg/L	
Nickel	25 µg/L 65 µg/L 110 µg/L 150 µg/L	Hardness 0-60 mg/L (CaCO3) Hardness 60-120 mg/L (CaCO3) Hardness 120-180 mg/L (CaCO3) Hardness >180 mg/L (CaCO3)
Nitrogen		
Ammonia (total)	2.2 mg/L 1.37 mg/L	pH 6.5; temperature 10°C (see Table B.1) pH 8.0; temperature 10°C
Nitrite	0.06 mg/L	
Nitrate		Concentrations that stimulate prolific weed growth
Nitrosamines	ID	
pH	6.5-9.0	
Selenium	1 µg/L	
Silver	0.1 µg/L	
Thallium	ID	
Zinc[3]	0.03 mg/L	
Organic parameters		
Acrolein	ID	
Aldrin/dieldrin	4 ng/L (dieldrin)	
Benzene[3]	0.3 mg/L	
Chlordane	6 ng/L	
Chlorinated benzenes[3]		
Monochlorobenzene	15 µg/L	
Dichlorobenzene 1,2- and 1,3-	2.5 µg/L	
1,4-	4.0 µg/L	
Trichlorobenzene 1,2,3-	0.9 µg/L	
1,2,4-	0.5 µg/L	
1,3,5-	0.65 µg/L	
Tetrachlorobenzene 1,2,3,4-	0.10 µg/L	
1,2,3,5-	0.10 µg/L	
1,2,4,5-	0.15 µg/L	
Pentachlorobenzene	0.030 µg/L	
Hexachlorobenzene	0.0065 µg/L	

Parameter	Objective	Comments
Chlorinated ethylenes[3]		
Tetrachloroethylene	260 µg/L	
Di- and trichloroethylenes		ID
Chlorinated phenols		
Monochlorophenols	7 µg/L	
Dichlorophenols	0.2 µg/L	
Trichlorophenols	18 µg/L	
Tetrachlorophenols	1 µg/L	
Pentachloropheno]	0.5 µg/L	
DDT	1 ng/L	
Dinitrotoluenes	ID	
Diphenylhydrazine	ID	
Endosulfan	0.02 µg/L	
Endrin	2.3 ng/L	
Ethylbenzene[3]	0.7 mg/L	
Halogenated ethers	ID	
Heptachlor + Heptachlor epoxide	0.01 µg/L	
Hexachlorobutadiene	0.1 µg/L	
Hexachlorocyclohexane isomers	0.01 µg/L	
Hexachlorocyclopentadiene	ID	
Phenols (total)	1 µg/L	
Nitrobenzene	ID	
Nitrophenols	ID	
Phenoxy herbicides (2,4-D)	4.0 µg/L	
Phthalate esters		
DBP	4 µg/L	
DEHP	0.6 µg/L	
Other phthalate esters	0.2 µg/L	
Polychlorinated biphenyls (total)	1 ng/L	
Polycyclic aromatic hydrocarbons	ID	
Toluene	0.3 mg/L	
Toxaphene	8 ng/L	

Parameter	Objective	Comments
Physical Parameters		
Temperature		Thermal additions should not alter thermal stratification or turnover dates, exceed maximum weekly average temperatures, and exceed maximum short-term temperatures (see Notes on temperature)
Total suspended solids	increase of 10.0 mg/L	Background suspended solids ≤100.0 mg/L
	increase of 10% above background	Background suspended solids >100mg/L

[1] Concentrations of heavy metals reported as total metal in an unfiltered sample.
[2] ID = Insufficient data to recommend an objective.
[3] Tentative objective.

Table B.1
Recommended Objective for Total Ammonia (NH_3)

	Ammonia concentration (mg/L) at following temperatures (^0C)						
pH	0	5	10	15	20	25	30
6.50	2.5	2.4	2.2	2.2	1.49	1.04	0.73
6.75	2.5	2.4	2.2	2.2	1.49	1.04	0.73
7.00	2.5	2.4	2.2	2.2	1.49	1.04	0.74
7.25	2.5	2.4	2.2	2.2	1.49	1.04	0.74
7.50	2.5	2.4	2.2	2.2	1.49	1.05	0.74
7.75	2.3	2.2	2.1	2.0	1.40	0.99	0.71
8.00	1.53	1.44	1.37	1.33	0.93	0.66	0.47
8.25	0.87	0.82	0.78	0.76	0.54	0.39	0.28
8.50	0.49	0.47	0.45	0.44	0.32	0.23	0.17
8.75	0.28	0.27	0.26	0.27	0.19	0.10	0.11
9.00	0.16	0.16	0.16	0.16	0.13	0.10	0.08

Source: U.S.A. E.P.A. 1985. Ambient Water Quality Criteria for Ammonia - 1984. Criteria and Standards Division, U.S. Environmental Protection Agency, Washington, D.C. EPA 440/5-86-003.

Notes on Temperature

1. **Thermal Stratification**
Thermal additions to receiving waters should be such that thermal stratification and subsequent turnover dates are not altered from those existing prior to the addition of heat from artificial origins.

2. **Maximum Weekly Average Temperature**
Thermal additions to receiving waters should be such that the maximum weekly average temperature is not exceeded.

a) In the warmer months, the maximum weekly average temperature (MWAT) is determined by adding to the physiological optimum temperature (usually for growth) a factor calculated as one-third of the difference between the ultimate upper incipient lethal temperature and the optimum temperature for the most appropriate life stage of the sensitive important species that normally is found at that location and time. Some MWAT values are shown in U.S. EPA (1976).

b) In the colder months, the MWAT is an elevated temperature that would still ensure that important species would survive if the temperature suddenly dropped to the normal ambient temperature. The limit is the acclimation temperature minus 2"C when the lower lethal threshold temperature equals the ambient water temperature.

c) During reproductive seasons, the MWAT meets specific site requirements for successful migration, spawning, egg incubation, fry rearing and other reproductive functions of important species.

d) At a specific site, the MWAT preserves normal species diversity or prevents undesirable growths of nuisance organisms.

3. **Short-term Exposure to Extreme Temperature**
Thermal additions to receiving waters should be such that the short-term exposures to maximum temperatures as calculated in a) and b) are not exceeded. Exposures should not be so lengthy or frequent as to adversely affect the important species.

a) For growth, the short-term maximum temperature is the 24-h median tolerance limit, minus 2^{0}C, at an acclimation temperature approximating the MWAT for that month.

b) The short-term maximum temperature for the season of reproduction should not exceed the maximum incubation temperature for successful embryo survival, or the maximum temperature for spawning.

References:

U.S. E.P.A. 1976. *Quality Criteria for Water.* U.S. Environmental Protection Agency, Washington, D.C. EPA-440/9-76-023.

SCHEDULE C

WATER QUANTITY OBJECTIVES

Water quantity objectives are established to maintain the parameters relating to changes in timing, frequency and magnitude of peak flow, daily, monthly and seasonal flow rates; and annual flow volumes and basin run off yields within prescribed limits at suitable trans boundary locations to maintain the integrity of the ecosystem.

The Interim Water Quantity Objective for this agreement is that there will be no significant change in the flow regime that could affect the aquatic ecosystem.

The variability in hydrologic characteristics that existed prior to this agreement shall be used as a guide to establishing water quantity objectives. The Water Quantity Objectives may be refined based on information from monitoring programs and other sources.