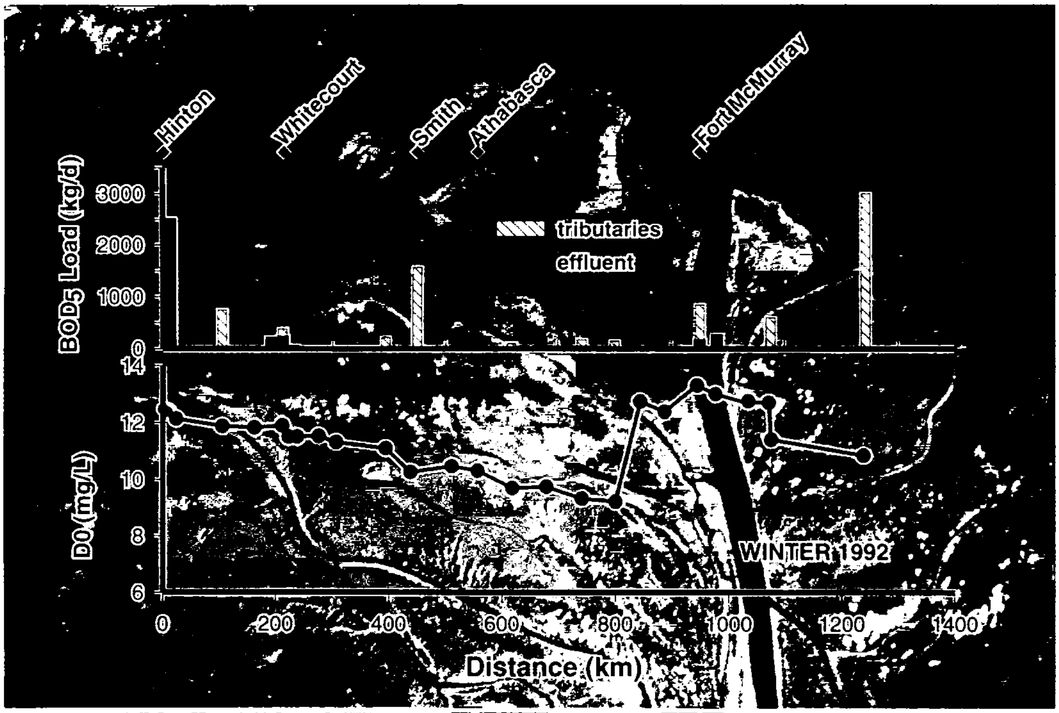
Cumulative Impacts Within The Northern River Basins

11

Synthesis Report



Canada Alberta Northwest Territories

Northern River Basins Study

Scientific Questions

1 a) How has the aquatic ecosystem, including fish and/or other aquatic organisms, been affected by exposure to organochlorines or other toxic compounds?

b) How can the ecosystem be protected from the effects of these compounds?

2 What is the current state of water quality in the Peace, Athabasca and Slave river basins, including the Peace-Athabasca Delta?

3 Who are the stakeholders and what are the consumptive and non-consumptive uses of the water resources in the river basins?

4 a) What are the contents and nature of the contaminants entering the system and what is their distribution and toxicity in the aquatic ecosystem with particular reference to water, sediments and biota?

b) Are toxins such as dioxins, furans, mercury, etc. increasing or decreasing and what is their rate of change?

5 Are the substances added to the rivers by natural and man made discharge likely to cause deterioration of the water quality?

6 What is the distribution and movement of fish species in the watersheds of the Peace, Athabasca and Slave river? Where and when are they most likely to be exposed to changes in water quality and where are their important habitats?

7 What concentrations of dissolved oxygen are required seasonally to protect the various life stages of fish, and what factors control dissolved oxygen in rivers?

8 Recognizing that people drink water and eat fish from these river systems, what is the current concentration of contaminants in water and edible fish tissue and how are these levels changing through time and by location?

9 Are fish tainted in these waters and, if so, what is the source of the tainting compounds (i.e. compounds affecting how fish taste and smell to humans)?

10 How does and how could river flow regulation impact the aquatic ecosystem?

11 Have the riparian vegetation, riparian wildlife and domestic livestock in the river basin been affected by exposure to organochlorines or other toxic compounds?

12 What native traditional knowledge exists to enhance the physical science studies in all areas of enquiry?

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

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

14 What long term monitoring programs and predictive models are required to provide an ongoing assessment of the state of the aquatic ecosystems. These programs must ensure that all stakeholders have the opportunity for input.

Non-Scientific Questions

15 How can the Study results be communicated most effectively?

16 What form of interjurisdictional body can be established, ensuring stakeholder participation for the ongoing protection and use of the river basins?

Cover Photo: LANDSAT Image of Slave River Delta,N.W.T.

NORTHERN RIVER BASINS STUDY
SYNTHESIS REPORT NO. 11

CUMULATIVE IMPACTS WITHIN THE NORTHERN RIVER BASINS

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If you would like:
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- other information regarding the Northern River Basins Study

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■ SUMMARY

The Northern River Basins Study (NRBS) was established in 1991 and represents a joint agreement between the governments of Canada, Alberta and the Northwest Territories. A primary objective of the Study was to advance understanding of how developments within the Peace, Athabasca and Slave river basins have had cumulative impacts on the mainstem and main tributary aquatic ecosystems. The Study also provided the necessary knowledge-base and tools required to assess the potential consequences of future developments. The NRBS and its eight research component areas focussed on gathering and interpreting comprehensive information on water quality, contaminant distribution, fate and effects, benthos, fish and fish habitat, riparian vegetation/wildlife, hydrology/hydraulics, drinking water quality, nutrients, dissolved oxygen, traditional knowledge and use of aquatic resources within this region.

The purpose of this report is to provide an overall synthesis and to address Study Board Questions: what predictive tools are required to determine the cumulative effects of man-made discharges on the water and aquatic environment?, and what are the cumulative effects of man-made discharges on the water and aquatic environment? More specifically this report:

- provides an overview of the key scientific findings of the NRBS in the context of the Study's guiding questions and the eight research components;

- provides an integrated interpretation of the key findings in the context of cumulative effects; and,

- provides research, monitoring and assessment recommendations related to future aquatic ecosystem management.

ACKNOWLEDGMENTS

This report is the result of almost five years of dedication, fortitude and hard work by individuals associated with the NRBS Science Program. In particular, we wish to express our sincerest thanks to the Science Component leaders (Dr. John Carey (Contaminants), Dr. Patricia Chambers, (Nutrients and Dissolved Oxygen), Mr. Sonny Flett (Traditional Knowledge), Dr. Bruce Maclock (Other Uses), Mr. Tom Mill (Food Chain), Dr. Terry Prowse (Hydrology/Hydraulics), Dr. Dan Smith (Drinking Water), and associates (Ms. Lea Bill (Traditional Knowledge), Dr. Brian Brownlee (Contaminants), Mr. Malcolm Conly (Hydrology/Hydraulics), Dr. Ray Hesslein (Food Chain), Dr. Steve Stanley (Drinking Water), Dr. Ross Tallman (Food Chain), Mr. John Thompson (Other Uses)). We also want to express our thanks to the science staff (Mr. Richard Chabaylo, Mr. Jim Choles, Ms. Deborah Kennedy, Mr. Robert Moore, Mr. Greg Wagner) who endured our relentless pressure and timelines.

We also express our appreciation and gratitude to Mr. David Donald for his valuable contribution on fish ecology, the significant efforts of Mr. Mark Ouellette who assisted in all aspects of the preparation of the manuscript and to Mr. Erik Ellehoj who provided the base maps and to Mark Gilchrist who coordinated the printing of the report.

We especially appreciate and value the open and frank dialogue with the non-government organizations carried out over the course of this study. In addition, many members of the community gave their time at public science fora and community gatherings to provide their views and perspective on the scientific direction and findings. We learned much from our interaction with the aboriginal communities and gained insights into the relationship between humans and the ecosystems we studied.

In addition, this report was improved by comments provided by the NRBS Science Advisory Committee, in particular Dr. Peter Larkin (Chairman), and the member agencies of the NRBS Study Board.

We also want to express our sincerest gratitude to our respective families, in particular, Brenda Wrona, Beverley Gummer, Valerie Crutchfield, and Jan Mydynski whose patience and understanding made this report and our involvement in the Northern River Basins Study possible. We finally wish to acknowledge the late Mr. Bev Burns (Co-Chair of the NRBS Study Board) whose wisdom and vision contributed significantly to the evolution of the science program in the context of incorporating societal interests and concerns.

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■ INTRODUCTION


Athabasca River upstream of the town of Hinton (Photo Credit: Cheryl Podemski)

The Northern River Basins Study (NRBS) was established in 1991 and represents a joint agreement between the governments of Canada, Alberta and the Northwest Territories. A primary objective of the Study was to advance understanding of how developments within the Peace, Athabasca and Slave river basins (Figure 1) have had cumulative impacts on the mainstem and main tributary aquatic ecosystems. The Study was also to provide the necessary knowledge-base and tools required to assess the potential consequences of future developments. To achieve this, the NRBS and its eight research component areas (Box 1) focussed on gathering and interpreting comprehensive information on water quality, contaminant distribution, fate and effects, benthos, fish and fish habitat, riparian vegetation/wildlife, hydrology/hydraulics, drinking water quality, nutrients, dissolved oxygen, traditional knowledge and use of aquatic resources within this region. The evolution of the organizational structure and strategic plan of the NRBS is described in the Board's final report and will not be dealt with here.

Box 1: Eight Research Components of the NRBS.

- **Hydrology / Hydraulics**
- **Contaminants**
- **Nutrients**
- **Food Chain**
- **Drinking Water**
- **Other Uses**
- **Traditional Knowledge**
- **Synthesis / Modelling**

Within the biophysical region of the Northern River Basins area, a variety of potential environmental stressors occur (Figure 1). Rather than examining all potential stressors, the NRBS, using AlPac recommendations (see below) as a starting point, established a series of research priorities. This exercise led to a focus on flow regulation and contaminants, particularly pulp-mill effluents, and their effects on the mainstem rivers and major tributaries of the basins.

Details of the NRBS scientific studies are provided in a series of technical and synthesis reports; the purpose of this report is to provide an overall synthesis and to address Study Board Question 13 (Box 2). More specifically this report:

- provides an overview of the key scientific findings of the NRBS in the context of the Study's guiding questions and the eight research components;
- provides an integrated interpretation of the key findings in the context of cumulative effects; and,
- provides research, monitoring and assessment recommendations related to future aquatic ecosystem management.

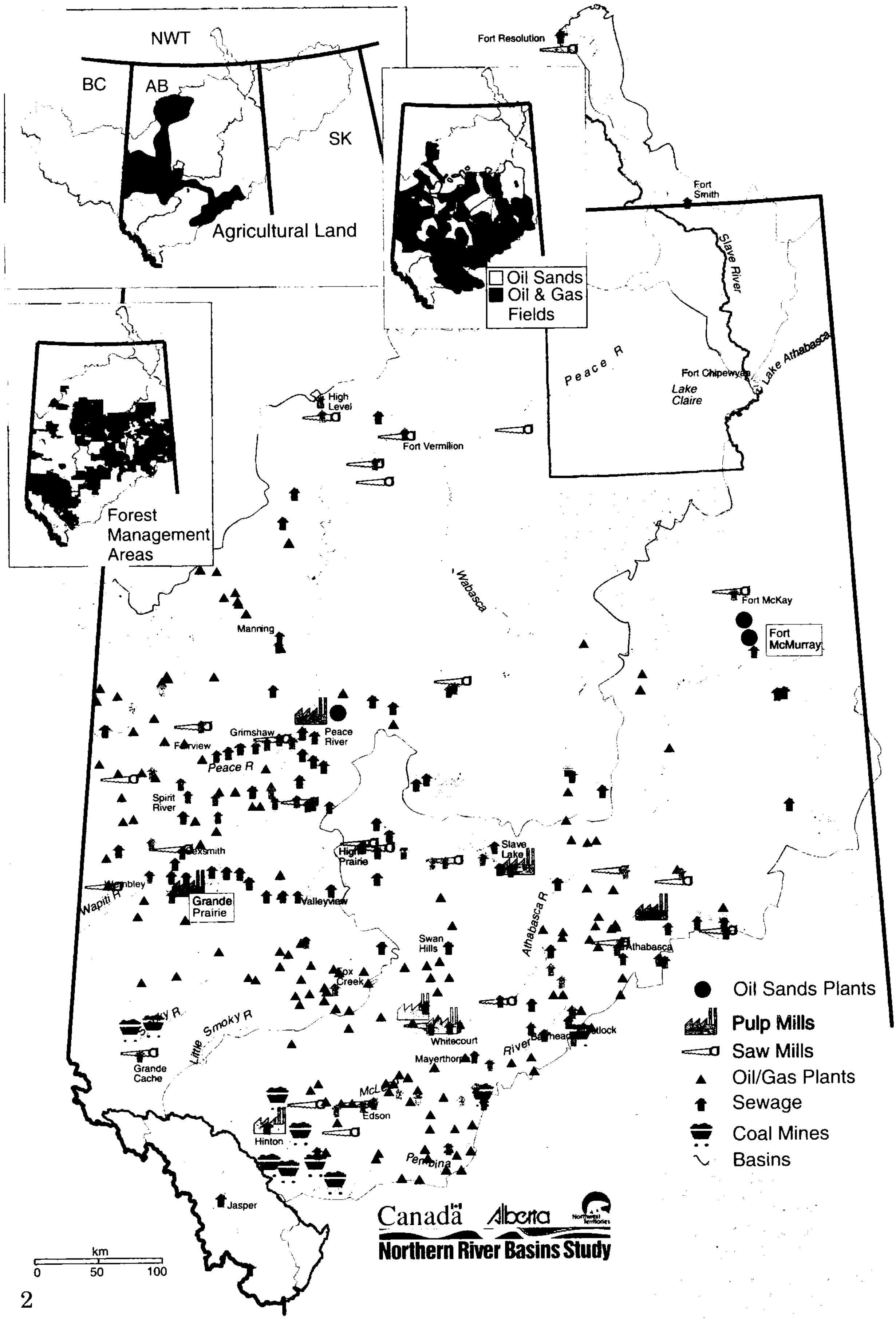
Box 2: NRBS Board Questions Concerned with Cumulative Effects Assessment.

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

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

In the first section, we provide the background and context for the design of the NRBS research program. This section illustrates the state of knowledge at the outset of the NRBS and provides the rationale for the scientific directions taken by the Study. The second

Figure 1: Study Area and Key Stressors in the Northern River Basins.

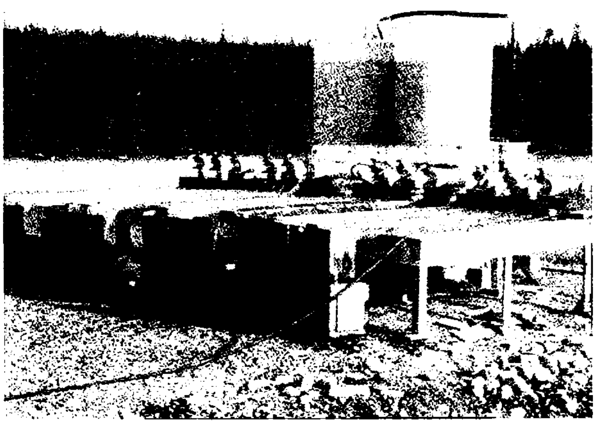


Centrifugation equipment used in the assessment of contaminants in suspended sediment and river water.

section discusses research activities and key scientific findings of the eight research components, while the following section places these findings in a cumulative effects context and provides a "state of environment" assessment of these river ecosystems. In the final section, we provide recommendations on future research and monitoring to ensure the conservation and protection of these ecosystems.

BACKGROUND TO THE NRBS

The twenty years prior to initiation of the NRBS were characterized by increasing public concern and awareness of environmental issues in these basins. For example, the Bennett Dam at Hudson Hope, British Columbia was completed in 1968 and by early 1970 was thought to affect the hydrology and ecology of the Peace-Athabasca Delta. By 1990, forestry-related land clearing was expanding to meet the needs of six active pulp-mills and there were plans for five more mills by 1993. Other than in the Pembina and Paddle River watersheds, agriculture in the Athabasca basin was not perceived as a major land use; however, in the settled areas along the Peace River and its tributaries, agriculture was becoming a dominant feature with most farming confined to a corridor between Grande Prairie and Fort Vermilion and in the High Level area. The Slave River basin, although subject to the effects of flow regulation, remained virtually undeveloped but concerns were expressed about the potential effects of upstream developments, namely, hydropower generation, mining and forestry.



Stream-side equipment used in the nutrient and nutrient-contaminant research. (Photo credit: Cheryl Podemski)

Collection of fish organs for contaminant analysis

The Northern River Basins Study grew out of a general public perception that the ecosystem was increasingly threatened by anthropogenic activity. This perception crystallized in the late 1980s at the time of the proposal to construct the Alberta-Pacific pulp-mill (AlPac) at the town of Athabasca. A primary recommendation of the AlPac Environmental Impact Assessment Hearings in 1990 dealt with the importance of assessing cumulative environmental impacts and underscored the need to obtain an improved understanding of the ecology of the basins placed within the context of societal concerns and objectives.

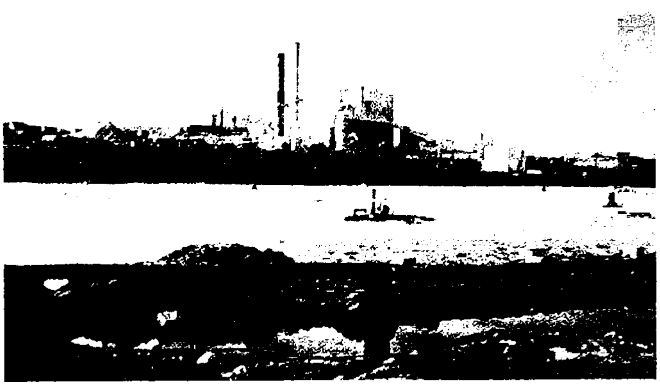
At the outset of the NRBS, only limited information was available on a variety of key ecosystem components and processes including: fish ecology; the response of aquatic biota to effluent exposure; the presence, distribution, fate and effects of contaminants; drinking water quality; and the consequences of flow regulation. This situation was further complicated by the fact that existing information resided with a variety of different government agencies, universities and industries. Hence, a major challenge for the NRBS was to assemble and integrate this information and use it to design research activities within the NRBS.

What follows is an overview of a few of the important studies undertaken prior to NRBS (1991) which have contributed significantly to knowledge about aquatic ecosystems for each of the three basins.

- **Athabasca River Basin**

Prior to the NRBS, the most comprehensive environmental study conducted in the Athabasca River basin was the federal-provincial Alberta Oil Sands Environmental Research Program conducted in the period 1975 to 1980. This program focused on the effects of oil sands development on atmospheric, terrestrial, and aquatic systems, and on human use of the oil sands area. As a consequence of this program, monitoring programs were expanded to obtain ongoing information on hydrology, water quality and fish ecology. In 1989 the Panel for Energy Research and Development (PERD) began to research hydrocarbons and their pathways in the lower reaches of the Athabasca River. Concurrently, Alberta Pacific Forest Industries Inc. proposed a pulp-mill at Athabasca that was subjected to a joint federal-provincial environmental review process.

The assessments undertaken by the AlPac environmental review board and its recommendations identified several deficiencies particularly with respect to pulp-mill contaminants, fish ecology, dissolved oxygen, tainting of fish and drinking water, and cumulative effects of developments. The findings of the board led directly to a "state of knowledge" assessment by the governments that acknowledged there was a lack of fish and fish related information for much of the Peace, Athabasca and Slave River basins, especially in the areas of species distribution, relative abundance, life



Weldwood pulp mill on the Athabasca River at Hinton. Photo credit: Cheryl Podemski)

Box 3: Athabasca River Basin – Status of Knowledge at the Onset of NRBS.

	Basin-wide	Reach-Specific
Chemical		
General water chemistry		
Organochlorine compounds	■	■
Metals	■	■
Dissolved oxygen	■	■
Physical		
Water levels		
Hydrologic processes		
Ecological		
Fish Ecology	■	■
Benthic community ecology	■	■
Nutrient enrichment	■	■
Ecological processes	■	■
Ecological response to stress	■	■
Human Use		
Drinking water	■	
Water supply/demand		
Human health	■	■
Cumulative Effects	■	■

Legend: Darker indicates greater deficiencies in the database history, predator-prey relationships, habitat use, fish health, and fish requirements of dissolved oxygen. The deficiency was so great the assessment further concluded there were insufficient data to focus and prioritize future research.

Box 4: Peace River Basin – Status of Knowledge at the Onset of NRBS.

	Basin-wide	Reach-Specific
Chemical		
General water chemistry		
Organochlorine compounds	■	■
Metals	■	■
Dissolved oxygen	■	■
Physical		
Water levels		░
Hydrologic processes	░	░
Ecological		
Fish Ecology	■	■
Benthic community ecology	■	■
Nutrient enrichment	■	■
Ecological processes	■	■
Ecological response to stress	■	■
Human Use		
Drinking water	■	
Water supply/demand	░	░
Human health	■	■
Cumulative Effects	■	■

Legend: Darker indicates greater deficiencies in the database

Other issue-specific studies are worth noting: Spring Creek Experimental Watershed Study (1964-1988), which assessed the effects of deforestation on the hydrological cycle; The Tri-Creeks Watershed Research Study (1965-1986), which examined the impact of timber harvesting on fish populations; and the Athabasca River Black Fly Control Program (1974-77), which examined the use and effects of the insecticide methoxychlor on aquatic organisms. In addition to the above noted studies, Alberta Environmental Protection (AEP) and Environment Canada (EC) have conducted routine monitoring and assessment of water quality (mainly general chemistry), water quantity and biological community structure at various locations throughout the basin over the last 25 years. Finally, specific industries have conducted environmental impact studies which contain valuable information, and they have routinely monitored effluent quality and selected ecological parameters immediately downstream from their discharges as part of their regulatory requirements. The assessments related to Slave Lake Pulp, Alberta Newsprint and Miller Western pulp mills are particularly relevant.

Box 3 summarizes the state of knowledge for the Athabasca basin at the beginning of the Study on a basin-wide and reach-specific scale. While general data on chemical and physical parameters were available, specific information was lacking on contaminants (e.g., organochlorine, metals) concentration and distribution. There were also significant gaps in our understanding of ecological structure and function within this basin, and in our knowledge of patterns of human use and interaction. Alberta fish consumption guidelines exist for various reaches of the Athabasca River concerning mercury, dioxins and furans.

• Peace River Basin

Unlike the Athabasca River Basin, one of the major anthropogenic impacts on the Peace River system is from flow-regulation caused by the construction of the W.A.C. Bennett Dam. The Peace-Athabasca Delta Project (1971-1972) investigated the ecological changes caused by the construction of the dam and included an analysis of water uses by local people. This project was the first to recognize the importance of naturally occurring ice-dams on the Peace River and their implications for the management of water levels in the delta.

In the two decades following the construction of the Bennett Dam, four pulp mills in the B.C. portion of the Peace River and three mills in Alberta (one each in 1973, 1988 and in 1990) were built. However, it was not until the 1980s that legislation required rigorous environmental impact assessments by industry; and only recently has legislation of both federal and provincial governments begun to reflect the need for understanding cumulative effects. As in the Athabasca Basin, Alberta Environmental Protection and Environment Canada have conducted routine monitoring and assessment of water quality (limited in scope), water quantity and biological community structure at various locations throughout the basin over the last 25 years. Industries historically monitored effluent quality for a limited number of mainly physical-chemical variables and only recently have begun to adopt more of a multi-media approach. In 1990 Proctor and Gamble Cellulose Ltd. began a study of water quality and fish health and habitat on the Wapiti and Smoky river systems. A fish consumption advisory concerning dioxins and furans exist for the Wapiti and Smoky river systems.

Box 4 outlines the state of knowledge for the Peace Basin at the beginning of the Study on a basin-wide and reach-specific scale. The pattern is similar to that observed in the Athabasca Basin in that while there were adequate data for many of the chemical and physical parameters, there was a much poorer understanding of ecological issues and cumulative effects.

- **Slave River Basin**

The Slave River system from, its confluence with the Peace River and Riviere Des Rochers to Great Slave Lake, a distance of about 440 km, is the least developed, and perhaps the least studied, of the three basins. A Slave River Hydro Feasibility Study conducted by Alberta in the early 1980s contributed greatly to knowledge of Slave River fisheries, water quantity and water quality, mainly north of 60° latitude. The Slave River Monitoring Program (1988 to present) conducted by federal and territorial agencies provided a baseline understanding of selected contaminants in

Box 5: Slave River Basin – Status of Knowledge at the Onset of NRBS.

	Basin-wide	Reach-Specific
Chemical		
General water chemistry		
Organochlorine compounds	■	■
Metals	■	■
Dissolved oxygen	■	■
Physical		
Water levels		
Hydrologic processes		■
Ecological		
Fish Ecology	■	■
Benthic community ecology	■	■
Nutrient enrichment	■	■
Ecological processes	■	■
Ecological response to stress	■	■
Human Use		
Drinking water	■	■
Water supply/demand		
Human health	■	■
Cumulative Effects	■	■

Legend: Darker indicates greater deficiencies in the database

Box 6: Areas of Information Deficiency Identified at the Outset of NRBS.

- Environmental presence, abundance, distribution and trends of contaminants
- Exposure and response of fish to pulp mill contaminants
- Exposure of humans to contaminants in drinking water and fish
- Nutrient enrichment of mainstem river systems and associated productivity
- Dissolve oxygen requirements of various life stages of fish
- Effects of flow regulation on the aquatic ecosystem
- Fish distribution and habitat
- Cumulative effects of developments and overall state of water quality in the basins based on science and observations of the basins' residents
- Long-term monitoring

water, sediment and fish in the Alberta-Northwest Territories transboundary waters. However, by 1990, the state of the Slave River Delta and the fate of environmental contaminants entering the system via the Peace River or Lake Athabasca were as yet unexplored. As with the other basins, significant information gaps remain respecting both ecological structure and cumulative effects (Box 5).

THE NRBS RESEARCH PROGRAM


Dissolved oxygen sampling on the Pembina River.

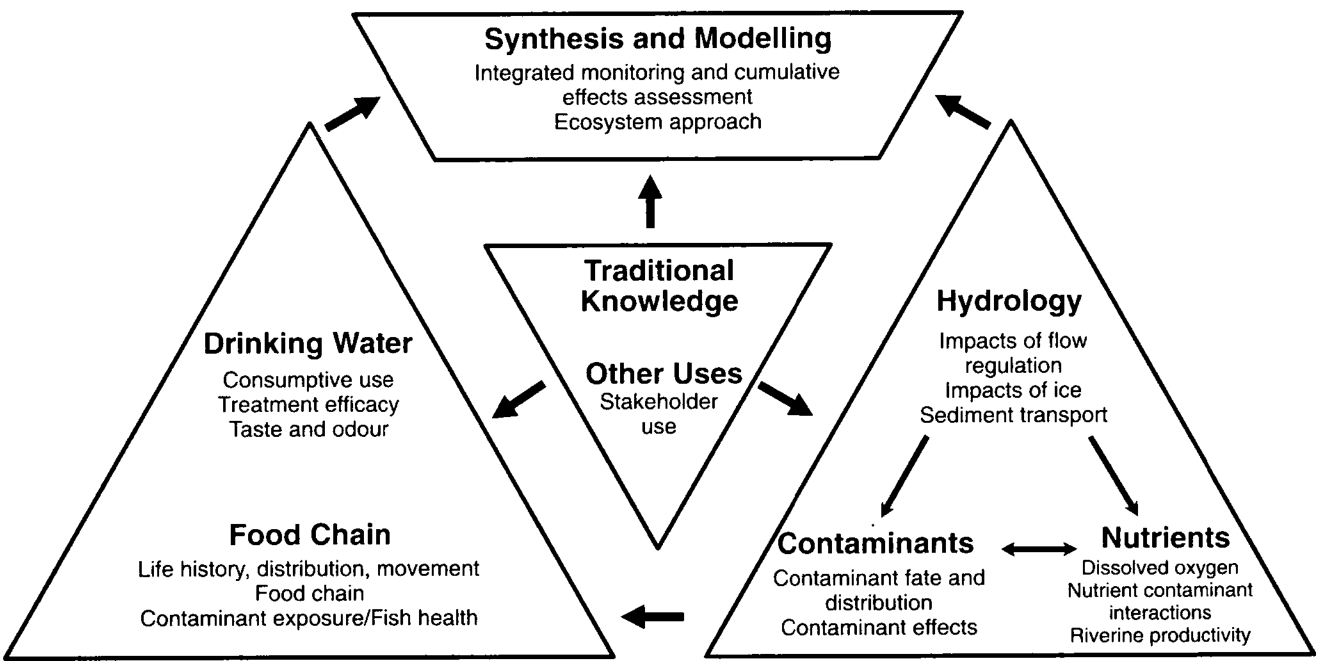
The NRBS developed sixteen guiding questions (see inside front cover) to provide scope and focus for the research. These questions and the research program were structured to address information deficiencies (summarized in Box 6), and to build upon the existing knowledge base for these basins. Implicit in the guiding questions was the need to adopt an ecosystem-approach to the study of environmental stressors and to implement a cumulative effects philosophy in the design and interpretation of the research. The objectives of the research program were to identify and quantify the multiple and diverse stressors acting on the Athabasca, Peace and Slave river basins and to assess the ecological consequences of exposure to those stressors. NRBS did not have a mandate to investigate human health implications but it undertook to provide findings to the proper authorities for their consideration and use. It was recognized at the outset that various ecosystem components are strongly linked and inter-dependent. Thus, the effects of multiple stressors (e.g., nutrient additions, contaminants, changes in river flow) operating simultaneously on the ecosystem may be difficult to assess and predict. This is further complicated by the synergistic and antagonistic effects of multiple stressors (e.g., nutrient/contaminant interactions) and by the effects manifested at a variety of spatial (e.g., reach-specific versus basin-wide), temporal (within- versus among-years) and organizational (e.g., the individual, population community, ecosystem) scales. Although individual NRBS research components focussed on specific issue areas, their respective programs were designed to integrate information across ecosystem components. There was, consequently, a necessary overlap among the research components. The Synthesis/Modelling Component was created to provide an overall integration of the individual studies. Figure 2 delineates the relationships among the eight research components of the NRBS and highlights the inter-relationships among them. The Traditional Knowledge and Other Uses components provided important sociologically-based information to all other areas, particularly in relation to identifying issues and geographic areas of concern for human populations in these basins.

■ KEY RESEARCH ACTIVITIES AND FINDINGS

The following sections present the key activities and findings for each of the eight component research areas. The Study Board's guiding questions relevant to each of the components are highlighted. The purpose of this section is to provide a general overview of NRBS activities and findings that form the basis of the cumulative effects assessment given in the following section. Readers requiring more detailed information and/or reference to specific technical reports are referred to the appropriate synthesis reports (see references).

Although much of the data discussed below was collected and interpreted as part of the NRBS science program, other agencies kindly provided data and/or logistical support to the NRBS study. These agencies include Alberta Environmental Protection, Environment Canada, the governments of the North West Territories, British Columbia and Saskatchewan and several municipalities and industries located within the basins.

Figure 2: Relationships Among NRBS Research Components.



HYDROLOGY / HYDRAULICS AND SEDIMENT RESEARCH

The primary focus of the Hydrology Component was to assess the effects of flow regulation on the hydrology and ecology of the Peace and Slave River Basins and their associated deltas (Box 7). In addition, the Component provided information on the general hydrology of the basins, time-of-travel and dispersion characteristics of contaminants in the river systems, insights into processes affecting sediment transport and deposition, and impacts of ice formation and break-up. Information provided by this component (Box 8) linked directly to the research activities of the Contaminants and Nutrients components, particularly in relation to their research on the underlying processes affecting contaminant fate and distribution and on nutrient/dissolved oxygen effects. In addition, hydrology research provided information concerning instream flow needs for fish, thereby linking to both the Food Chain and Other Uses research components. Traditional Knowledge research findings were also integrated into several areas of the hydrologic research.

Box 7: Study Board Questions Addressed by the Hydrology Component.

Q10.

How does and how could river flow regulation impact the aquatic ecosystem?

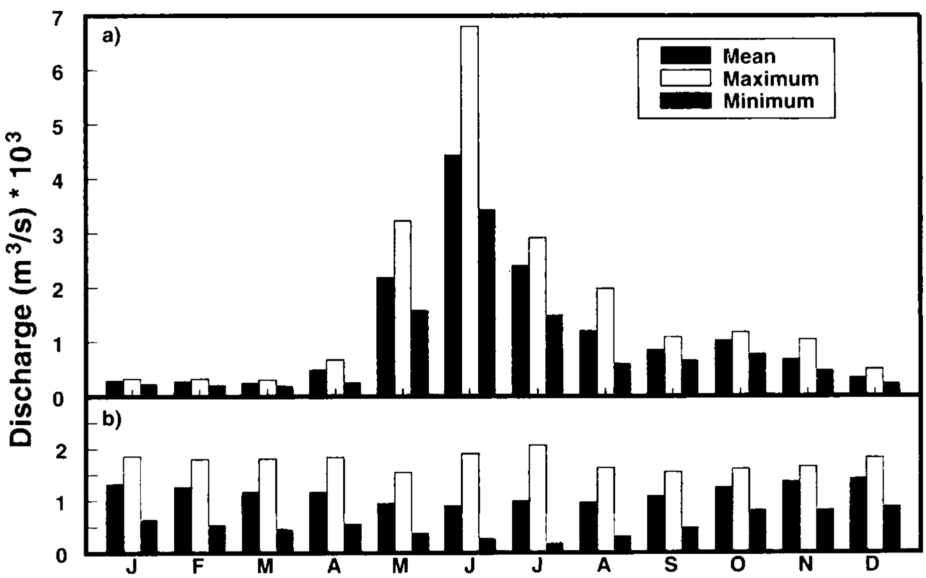
Q13a.

What predictive tools are required to determine the cumulative effects of many made discharges on the water and aquatic environment?

Box 8: Research Activities of the Hydrology Component.

- Evaluation of the hydrologic and hydraulic effects of flow regulation in the Peace and Slave rivers and their associated deltas.
- Assess the affects of flow regulation on sediment regimes, water chemistry, channel geomorphology, ice formation and riparian habitat in the Peace River.
- Development of sediment transport models.
- Assessment on in-stream flow needs (IFN) methodologies.

Figure 3: Comparisons of (a) Pre- and (b) Post- Bennett Dam Hydrograph for Peace River at Hudson Hope, British Columbia. (NRBS Synthesis Report No.1).



• River Flow Regimes

Flow regulation of the Peace River has changed the pattern and amplitude of the seasonal hydrograph of both the Peace and Slave Rivers (Box 9). This effect diminishes downstream as tributary flow now becomes more important to the total discharge. Not only have the average seasonal high flows been reduced but their timing has shifted, particularly in the reaches closest to the dam (Figure 3). High flows now occur in December whereas formerly they occurred in June. The average low flow now occurs in June rather than March, but at four times the former volume. Thus, summer flows are now lower, winter flows higher, and peak flows diminished. As a consequence, tributary flow contributes relatively more to total flow in summer while the reverse is true in winter.

Since the 1970s, the extent of the snowpack in the Smoky and other tributary basins has diminished. Climate variability has exacerbated the effects of flow regulation by decreasing the snowpack in the headwaters of the tributaries, and, ultimately, reducing levels of spring run-off.

• Sediment Transport and River Morphology

Discharges from the Bennett Dam contain low sediment loads and are representative of pre-regulation conditions. The Smoky and Wapiti rivers have been and continue to be, the major sources of sediments in this part of the basin. The erosional force of the Peace River downstream of the dam has been reduced as a result of changes in flow regime. The net effects are increased sediment deposition, channel narrowing, abandonment of secondary channels, and in-channel shoaling. Sand and silt deposit along channel edges and former back-channels now provide new habitat for semi-aquatic shoreline and riparian vegetation.

• Ice Formation and Timing

Reservoirs behave as heat sinks; therefore, the temperature of their discharges in winter is higher than would have normally occurred. As a consequence, river ice formation and timing are affected (Box 10). Ice now rarely forms in the area immediately below the Bennett Dam to the town of Peace River. Ice forms intermittently at the town of Peace River where there has been a significant change in the initiation of freeze-up and the length of the ice season since the construction of the dam. Further downstream this effect is lessened, until in the Slave River system, the timing and duration of ice cover are unaffected. Consolidated ice-cover and higher than normal ice-cover elevations are a consequence of higher winter flows. Together these factors can supercharge groundwater systems, causing flooding of basements, as has occurred in the town of Peace River.

• Effects of Flow Regulation on Deltas

In cooperation with the Peace-Athabasca Delta (PAD) technical studies, NRBS examined the relationship between ice-jams and water levels within the Delta. The Peace-Athabasca Delta has experienced significant ecological impacts (Box 11) that are primarily attributable to flow regulation and changes in the flow regime (Figure 4).

Within the Delta, the periodic formation of ice jams during spring break-up serves to flood the perched basins and prevents drying and associated changes in plant communities. Hydrometric analysis confirmed local knowledge that backwater flooding during ice break-up is responsible for filling the Delta's perched basins and that the frequency of such flooding has declined since the construction of the Bennett Dam. Higher winter flows and freeze-up elevations resulting from flow regulation have had major consequences for the occurrence of break-up ice jams. Smaller tributary snowpacks (e.g.,

Box 9: Research Activities of the Hydrology Component.
(post-compared to pre-Bennett Dam).

- flood peak at Hudson Hope, B.C. is 66%.
- flood peak at Peace Point is 15% lower
- summer flows at Hope, B.C. are 50% lower
- winter flows at Hope are flour times higher
- at Peace Point, summer flows are 33% lower
- at Peace Point, winter flows are 2.5 times higher
- during the winter, tributary flows used to double the flow between Hudson Hope and Peace Point, now

Box 10: Bennett Dam Has Influenced Ice Formation And Timing.

- open water exists during winter from the dam to Peace River
- ice cover characteristics and quality have changed; ice is weaker and coarser and its formation is delayed in places
- in steeper reaches of the Peace River, ice is thicker and a rougher consolidated cover at elevated stages
- enhanced staging of ice occurs in the Vermillion Chutes area

in the Wapiti-Smoky basins) further reduce the probability of ice-jam formation.

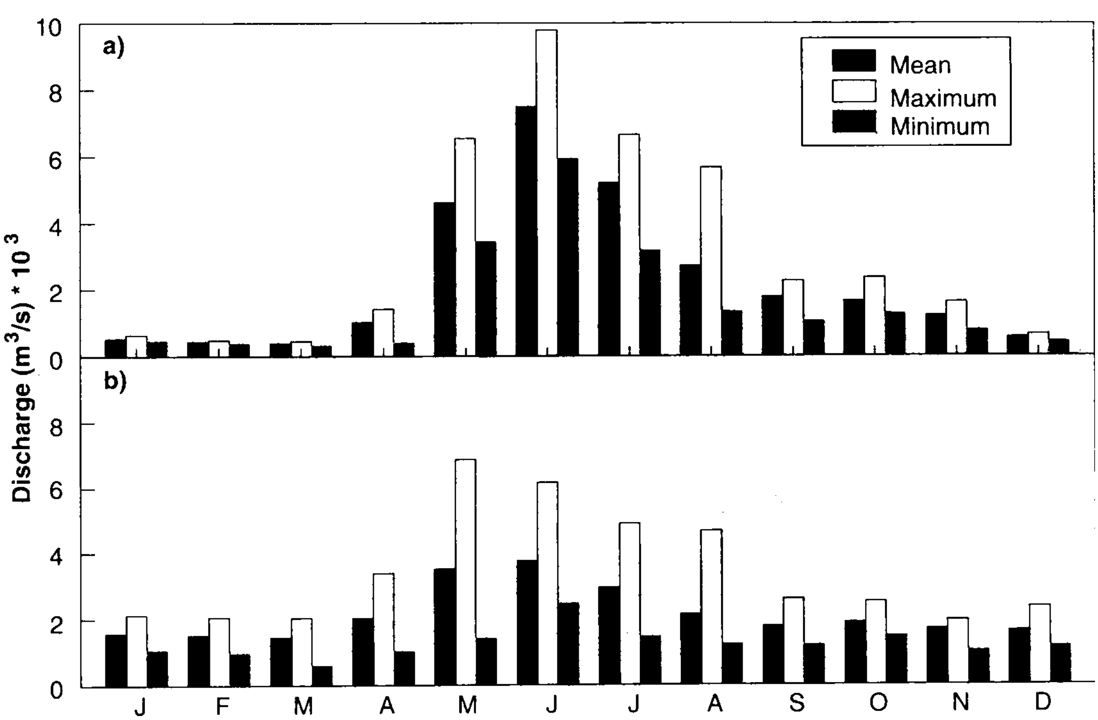
All major ice-jam floods that occurred in the 1960s, prior to regulation, were associated with large runoff events from the main tributaries (e.g., Smoky River). Moreover, backwater flooding used to occur on a biennial basis in the 1960s prior to regulation, and has only occurred three times since, including the major flood in 1974.

Box 11: Flow Regulation Effects On The Basins' Deltas.

- A commonly held view was that reduced flows due to regulation were responsible for the reduction in ice jams. NRBS confirms that tributary flows play a critical role in forming these ice jams.
- The major effect of regulation on the occurrence of break-up ice jamming near the PAD is related to the higher flows and freeze-up elevation of the ice cover throughout the winter period.
- Hydrometric analysis coupled with local knowledge confirms that backwater flooding during ice break-up has historically inundated the delta's perched basins.
- Major ice-jam floods that occurred in the 1960s prior to regulation were associated with large runoff events from the main tributaries (e.g., Wapiti-Smoky Rivers).
- Backwater flooding used to occur on a biennial basis in the 1960s prior to regulation and has only occurred three times since, including the major flood in 1974.
- Changing the timing of Bennett Dam releases to coincide with tributary spring flows may increased probability of creating ice-jams.
- Although the outer limits of the Slave River Delta are showing slowed sediment deposition it is uncertain if this is due to flow regulation upstream or to other factor such as interaction with the lake.
- Coupling of hydraulic river and delta models provides a useful tool for assessing effects of flow regulation on hydrologic regime of river and delta systems.

The direct effects of flow regulation on the Slave River Delta are less certain. Although the outer perimeter of the Slave River Delta is showing slowed sediment deposition, it is uncertain if this is related to flow regulation or to other hydrologic influences from Great Slave Lake.

Figure 4: Comparisons of (a) Pre- and (b) Post- Bennett Dam Hydrograph for Peace River at Peace Point, Alberta. (NRBS Synthesis Report No. 1).



CONTAMINANTS

The key findings of the Contaminants Component's research are highlighted in three sub-sections: sources, environmental distribution and fate, and environmental effects. In addition to providing information to answer the Study Board's contaminant-related questions (Box 12), Contaminant research also adapted analytical models to predict the fate and distribution of contaminants in the environment and their uptake in the food web. Given the complexities of contaminant-related issues, several projects required joint involvement of the components. The Synthesis and Modelling Component provided collaborative research on environmental indicators, biomarkers and ecotoxicology and the development of the cumulative effects framework; the Food Chain Component provided for the collection of fish specimens and food web characterization; the Hydrology Component provided research support on the sediment mechanisms and dispersion of contaminants; and the Nutrients Component examined contaminant-nutrient interactions. The research activities of the Contaminants Component are identified in Box 13.

Box 12: Study Board Questions Addressed by the Contaminant Component.

- Q 2. What is the current state of water quality in the Peace, Athabasca and Slave river basins, including the Peace-Athabasca Delta?
- Q 4a. What are the contents and nature of the contaminants entering the system and what is their distribution and toxicity in the aquatic ecosystem with particular reference to water, sediments and biota?
- Q 4b. Are toxins such as dioxins, furans, mercury, etc. increasing or decreasing and what is their rate of change?
- Q 5. Are the substances added to the rivers by natural and man made discharge likely to cause deterioration of the water quality?
- Q 8. What is the current concentration of contaminants in water and edible fish tissue and how are these levels changing through time and by location?
- Q 13a. What predective tools are required to determine the cumulative effects of man made discharges on the water and aquatic environment?

• Sources of Organic and Metal Contaminants

Key point sources of pollution entering the river basins include effluent discharges from pulp mills, municipalities, and oil sands refineries, while non-point sources include atmospheric deposition, and land-use-related runoff from forestry and agriculture.

With respect to organochlorines, the primary contaminants identified in Bleach Kraft Mill Effluent (BKME) (Weyerhaeuser Canada Limited at Grande Prairie; Daishowa-Marubeni International Ltd. at Peace River; Weldwood of Canada Ltd. at Hinton; and, Alberta- Pacific Forest Industries Inc. at Athabasca) are chlorinated dimethylsulphones, chlorinated aromatics (includes dioxins and furans), chlorophenolics and chlorinated terpenes. Non-chlorinated compounds identified include terpenes, hydrocarbons and sulphur containing compounds. Effluents from thermal mechanical pulp mills (TMP) and chemical thermal mechanical pulp mills (CTMP)

Contaminant mixing / time of flow study using dye tracer.

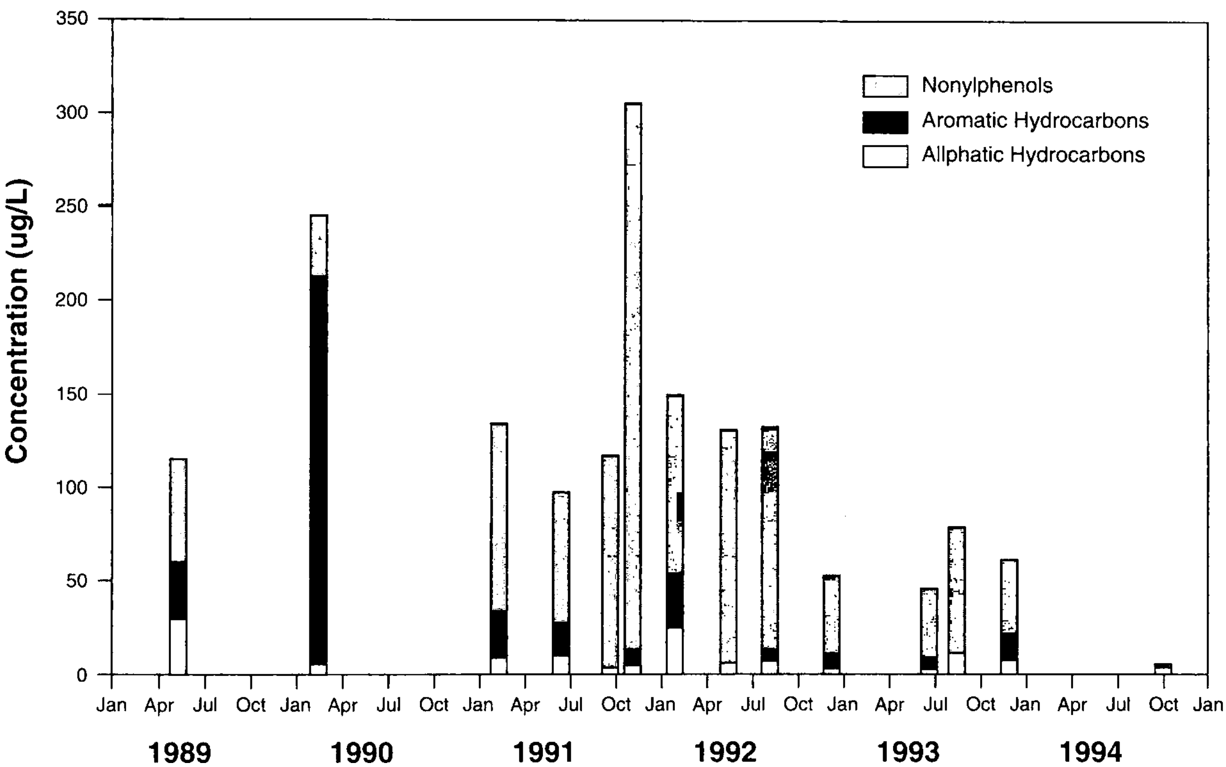
Box 13: Research Activities of the Contaminant Component.

- characterize contaminant sources
- assess presence and distribution of contaminants in the aquatic ecosystem
- determine ecological processes important to the contaminant fate and pathways
- assess effects of contaminants on aquatic ecosystem (e.g., physiological responses and gross pathology

(Alberta Newsprint Company at Whitecourt; Millar Western Pulp Ltd. at Whitecourt; and Slave Lake Pulp Corporation at Slave Lake) contain fewer chlorinated compounds but a variety of natural compounds such as terpenes, aromatics, phthalate acid esters, alkyl benzenes and benzothiazoles.

Concurrent with the NRBS, pulp mills introduced new treatment technologies resulting in a reduction of chlorinated organic contaminants into the aquatic environment (Figure 5). Improvements involved the elimination or reduction in the use of elemental chlorine in the bleaching processes and upgrades to effluent secondary treatment. The proportions of contaminants in effluents have also changed with these advances, resulting in proportionately higher levels of the chlorodimethylsulphones in the chlorinated fractions. In the hydrocarbon fraction, nonylphenols, although reduced since 1992 in the Hinton combined effluent, now constitute a larger proportion of the hydrocarbons (Figure 5). Despite the reduction in chlorinated phenolics, taste and odour compounds (such as terpenes) are still present, albeit at much lower levels, for hundreds of kilometres below Hinton.

Figure 5: Chlorinated Compounds in the Hinton Combined Effluent, 1989-1993.



New analytical approaches, such as broad spectrum analysis, have provided a comprehensive characterization of pulp mill, municipal and oil sands-related effluents, as well as ambient river water of the Athabasca and Peace rivers. Analyses of sewage plant effluent identified a variety of previously unrecognized organic compounds. These "finger prints" provide a baseline against which to compare organic complexity of future samples.

As part of the 1992 Reach Specific Survey, the Hinton combined effluent (HCE) was examined for metal contamination. Metal contaminants in the HCE existed at background, low or non-detectable levels, although unusually high levels of aluminum, manganese and zinc were noted in the liquid phase and high levels of cadmium were detected in suspended sediment below the mill.

Core samples from Lake Athabasca, Great Slave Lake and several reference lakes were used to evaluate atmospheric non-point source contaminant inputs to the basins. Polyaromatic hydrocarbons, often associated with forest fires, the insecticide toxaphene, and other organic contaminants such as hexachlorobenzene, polychlorinated biphenyls, chlorinated phenolics, hydrocarbons, and various dioxin and furan congeners were present in the cores. While measured concentration were low, and atmospheric input was found to be a dominant source of these contaminants in selected areas, chemical markers of pulp mill effluents were observed at very low levels in both Lake Athabasca and Great Slave Lake. The last observation indicates that contaminants produced by pulp mills can be transported hundreds to thousands of kilometres downstream.

• Environmental Distribution of Contaminants

Very early in the study it was determined that the contaminants of interest were less likely to be found in water than in sediment and biota. Therefore, contaminant investigations were re-focussed to sample and test the "environmental compartment" thought to be most affected.

Perhaps the most important findings of the NRBS relate to the levels rather than the presence of contaminants. It was known at the outset of the Study that dioxins, furans and many of the organic contaminants would be present in the system. However, NRBS research indicates low levels of environmental contamination, particularly compared to other systems in Canada and elsewhere in the world. In addition, contaminant loads in biota generally conform to guidelines for both aquatic and human health; although, levels of dioxins, furans, PCBs and mercury in sediment and/or biota did exceed guidelines at certain times and in certain locations. As will be discussed below, all fish data should be reviewed and assessed by health authorities in the context of human consumption patterns.

During the course of the NRBS investigations, a large number of samples were collected (Box 14) for a variety of contaminant analysis (Box 15). On the basis of these results, it is clear that pulp mills are responsible for the presence of several classes of contaminants, namely, dioxins, furans, chlorophenolics, and chlorinated resin acids.

The study has confirmed that for a distance of about 50 km below Hinton, the river bed contains pulp mill induced aggregates (floc) of sediment and sediment-bound contaminants. Under low-flow conditions these aggregrates settle out. This area and as far downstream as below Emerson Lakes would appear to have the highest levels of dioxins, furans, chlorinated phenols and chlorinated resin acids in both sediment and fish. NRBS has found that the river bottom within the 50 km of the HCE discharge is not always a depositional area. Under extremely high flows such as during spring

Box 14: The Number of NRBS Samples Tested for Contaminant Analysis.

Sample Type	Number Tested
Effluents	49
Water	190
Sediment	
bottom	300
suspended	37
cores	45
Benthos	65
Fish	3356
Mammals	
Mink	29
Muskrat	30
Waterfowl (ducks)	37

Box 15: Further Statistics on Contaminants

- Trace levels of the few organic contaminants detected in muskrats (PAD), mink and waterfowl (PAD) appear to meet human health consumption guidelines
- Of 20 organochlorine pesticides tested (including toxaphene) in water, none was detected above a level of 0.01 ug/L.
- TCDD/TCDF in sediments were less than detection 1994 except for one site below Hinton (Emerson Lakes) and another on the Peace River above the Smoky confluence
- Radionuclides in fish of Lake Athabasca were found to be typical of background
- Chlorinated resin acids were significantly higher in sediments of the Athabasca River than the Peace River
- Di- and tri-chlorodibenzofurans in deep cores confirm pulp milk contaminants reach Athabasca and Great Slave Lakes.
- TCDD toxic equivalents in burbot livers declined from 33.1-68.5 pg/g wet wt. in 91/92 to 3.8 pg/g in 1994
- Toxic equivalents for caddisfly larvae from the Weldwood Bridge site exceeded the Canadian guideline in 1992

runoff when the shear stresses are highest, these sediments are expected to break up and re-disperse in the river downstream.

With improvements in the pulp mill bleaching processes, many of these chlorinated organics are expected to decline in effluent emissions and in the ecosystem; NRBS has provided evidence that this is indeed happening. Given that the half-life of 2,3,7,8-TCDD in fish is in the order of 120 days (D. Muir personal communication) one would expect to see declines in fish tissue certainly within a year of significant technology improvements. NRBS has determined that the levels of TCDD and TCDF in burbot liver of the Peace River have decreased by from one half to ten fold since 1992 (Figure 6).

Figure 6: Concentration (pg/g) of: (a) TCDD-2378, and (b) TCDF-2378 in Burbot Livers in the Northern Rivers Basins, Autumn of 1992 and 1994.

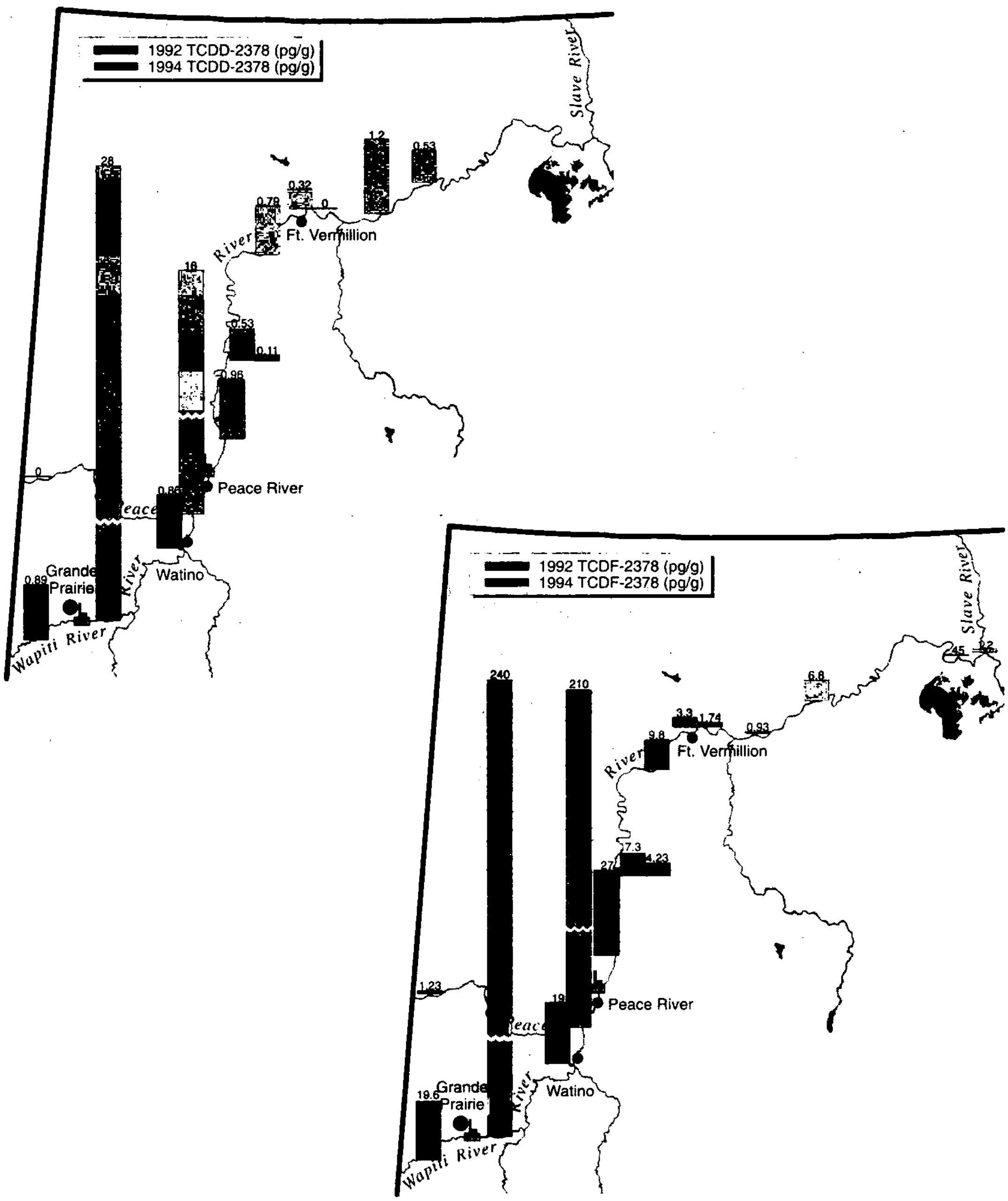
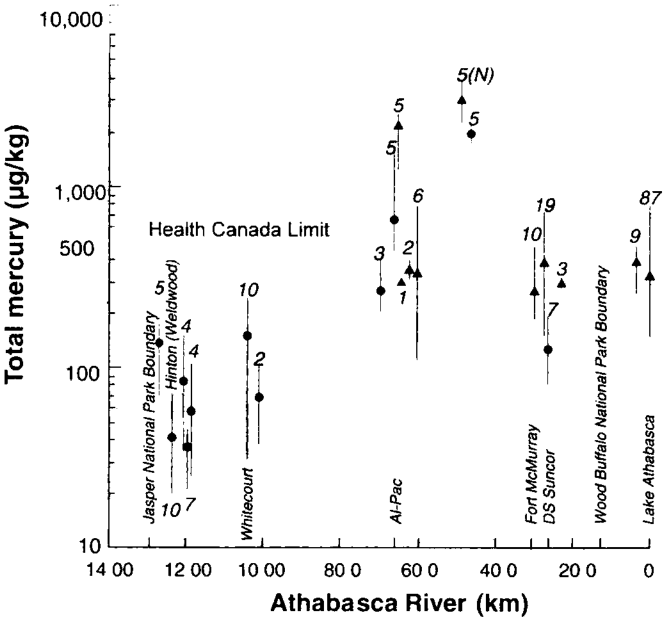


Figure 7: Mean Total Mercury in Walleye (▲) and Longnose Sucker (●) Muscle Tissue, Athabasca River 1977-1992. Sample size (N) is indicated for each value. (After Donald and Craig 1996).



Installing radio-transmitter for the Fish Study of Movement

Resin acids, which occur naturally, exist at relatively high levels in pulp mill effluents. Of particular interest are the chlorinated resin acids (CL-RA) that can be formed during the chlorination process of pulp mills. Several chlorinated resin acids, particularly chlorinated dehydroabietic acid, were determined to exist in both fish and sediments below the mills. Again, improved pulp mill treatment technologies are believed to have resulted in decreases in chlorinated resin acids. Residual levels still exist in fish and sediments.

Higher levels of PCBs, CL-RA and PAHs were found in the Peace River upstream of the confluence of the Smoky River. There was no significant spatial trend in PCB concentrations in sediments of either the Athabasca or Peace Rivers; however, the results suggest a possible PCB source in the upper Peace River (Many Islands). The high levels of sediment-associated chlorinated and nonchlorinated organic contaminants in this reach of the Peace River are somewhat perplexing given that the nearest pulp-mill source is about 250 km upstream at Taylor, British Columbia and there are no other major industrial developments on the system until Grande Prairie. Highest levels of PCBs in fish were found in the Wapiti-Smoky rivers and the Peace River above its confluence with the Smoky. Moreover, between 1992 and 1994 there was an approximate doubling in the concentrations of PCBs in burbot liver collected in the Wapiti River near Grande Prairie and in the Notikewin and Ft. Vermilion areas of the Peace River. The lowest levels of PCBs were found in fish collected from tributary locations (e.g., Athabasca River: Pembina, Clearwater, and McLeod Rivers; Peace River: Wabasca River).

Mercury deserves special attention because of the existing fish consumption guidelines for the lower Athabasca River. The large fish collections of NRBS have provided the best mercury database to date for re-examining the need for such guidelines. In addition, the Traditional Knowledge and Other Uses components have provided specific details about the fish consumption habits of people within the basins. As shown in Figure 7, mercury levels in large walleye, a predatory fish, tend to be high in the lower end of the Athabasca River. In contrast, a special winter 1994/95 subsistence fish investigation in the Peace-Athabasca Delta revealed that all the fish tested contained less than 350 µg/kg, all less than the Health Canada limit for the commercial sale of fish.


Athabasca River near Emerson Lakes

• Environmental Effects of Contaminants

Fish Biomonitoring

Physiological Biomarkers

The term "physiological biomarkers" refers to a class of physiological or biochemical responses to stress exposure (Table 1). These responses are measured at the level of the individual and represent the first level of response to stress. Consequently, biomarkers are being evaluated for application in environmental biomonitoring as "early warning" indicators of stress exposure. It is important to distinguish between biomarker response and ecological consequence. For the purposes of NRBS an ecological response is a change in growth, fecundity or survival of the individual. Some biomarkers provide early warning of this type of response, while others, though they represent stress, may not result in an observed ecological effect. It is thus necessary, to define the link between biomarker response and the ecological consequences of that response. In addition, different physiological biomarkers are diagnostic of different types of stresses (e.g., heavy metals versus hydrocarbons) and no single biomarker will provide information on all types of stress.

Table 1: Physiological Biomarkers Assessed in the NRBS as Responses to Different Classes of Contaminants.

	MFO Induction	Retinols	Metallothionein	Seroid Hormones
Toxic metals			✓	
PAHs	✓			✓
PCBs	✓	✓		✓
CL-RA, CPs		✓		✓
PCDDs/PCDFs	✓	✓		✓

NRBS explored the utility of a suite of physiological biomarkers as indicators of environmental stress. The results of these studies are discussed below.

Sex Steroids

A growing body of evidence suggests environmental chemicals may be associated with endocrine (hormonal) disruption in biota. This disruption may lead to reduced reproductive success or even to reproductive failure. For instance, prolonged depressions in male (11-ketotestosterone) and female (17ß-estradiol) hormones are linked to potential reproductive impairments in fish.

The 1994 NRBS basin-wide fish survey identified a potential geographic association between measured hormone levels in sexually mature burbot and their proximity to point-source pulp mill inputs. In female burbot and longnose sucker at near-field sites (<100 km downstream from a pulp mill discharge), measured levels of plasma17ß-estradiol were significantly lower than measured values at reference and far-field (>100 km downstream from a pulp mill discharge) locations (Figure 8). However, there was no evidence that these lower levels affect reproductive development as measured by relative female gonad size (GSI), oocyte size, or fecundity. In male burbot, 11-ketotestosterone at near-field sites was significantly lower than measured values at reference locations (Figure 8) but there were no observed histopathological aberrations in male gonad tissue. These data indicate the presence of physiological stress but also illustrate the need to better understand the link between observed hormone levels and reproductive response as well as the link between hormone level and exposure to pulp mill effluent.

The 1994 basin-wide fish survey also showed that in burbot, the sexes were not evenly distributed throughout the basins. Females accounted for 70% of fish caught at reference locations, but only 40% at near-field locations and 34% at far-field locations.

NRBS also assessed hormone levels in smaller fish species with restricted distributions and very small home ranges. In the fall of 1994, measured levels of testosterone and 17ß-estradiol in spoonhead sculpin were higher in fish collected downstream of the Hinton combined effluent discharge relative to fish collected upstream of the discharge; however, this difference was not apparent in the spring of 1995. In both the of fall of 1994 and in the spring of 1995, fish collected below the discharge were older, heavier, fatter, and had larger gonads and liver weights relative to fish collected at the reference sites, probably in response to increased nutrient loadings and subsequent higher productivity. Spoonhead sculpin collected from the near-field north bank (outside the effluent plume) showed responses intermediate between those observed for reference fish and near-field south bank (inside the effluent plume).

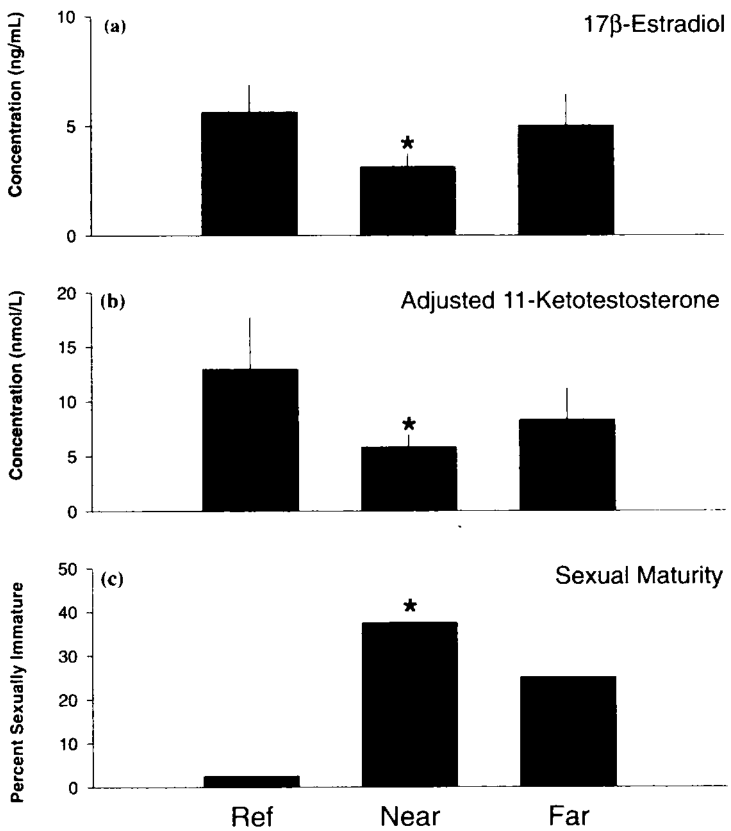
Numbers of Sexually Mature Fish

In addition to measuring hormone levels in sexually mature fish, the 1994 NRBS basin-wide fish survey also compared the proportions of sexually mature and sexually immature fish at different locations. The immature fish were not juveniles, rather they were of the same age, size and condition as mature fish but did not possess developed gonads at the time they were sampled. Immature fish accounted for less than 10% of the burbot collected at reference sites (Figure 8); however, the proportions of immatures in near-field sites were 27% (Athabasca River), 62% (Peace River) and 35% (Smoky River) and averaged 38% across all basins. A similar pattern, albeit, with lower sample sizes was observed for longnose suckers. Higher incidences of sexually immature fish in some locations may be a reflection of their natural distribution and ecology. Alternatively, these observations might be evidence of reproductive disorder, and in those cases an increase in the proportion of immature fish is usually associated with reductions in size, growth rates and poorer condition. Interestingly, such an association was not observed in this study; for example, burbot from the Slave River Delta were in the best condition and possessed the largest oocytes but the lowest fecundity; in addition no immatures were observed in this collection. The underlying causes for the observed distribution of sexually mature versus immature fish (as well as the distribution of sexes) require further investigation.

Mixed-Function Oxidase

Measurement of hepatic mixed-function oxidase (MFO) activity has received considerable attention as a biomarker for exposure to environmental stress. MFOs facilitate the excretion of contaminants from the body, and elevated levels of MFO activity are thus interpreted as evidence of exposure to those contaminants. Relative to other sites in northern Canada, MFO activity in burbot liver (1994 basin-wide survey) was elevated at only two sites in the basins: Ft. McMurray and Wabasca oil sands areas. Near-field and far-field analyses indicated these elevated MFO levels were not related to pulp mill discharges. In 1992, elevated MFO levels in mountain white fish and longnose suckers were highly localized and restricted to areas immediately downstream of pulp mills. Similarly, spoonhead sculpin exposed to pulp-mill effluent showed significantly higher levels of liver MFO activity than did fish collected from upstream reference sites. Elevated levels of MFOs were also observed 21 km below the Hinton outfall, but were not apparent 48 km downstream.

Figure 8: Mean Concentration of (a) 17ß-Estradiol, (b) 11-Ketotestosterone (Adjusted) and Proportion of Sexually Immature Fish from the 1994 Burbot Collection in the Northern River Basins. Ref sites are located above pulp mills, Near sites are within 100 km downstream of pulp mills and Far sites are between 100 and 200 km downstream of pulp mills. * denotes significant difference.



Semi-permeable membrane devices (SPMDs)

In addition to direct measures of MFO induction in fish tissue, the NRBS also assessed the utility of semipermeable membrane devices (SPMDs) as passive measures of the average concentrations and bioavailability of organic contaminants in water. These devices, made of thin-walled, low-density polyethylene tubing filled with a neutral lipid such as triolein, passively accumulate organic compounds. Accumulated organics are subsequently extracted and added to cell culture to test for physiological effects such as MFO induction (NRBS Contaminants Synthesis Report No. 2). Results indicate that pulp-mill effluents do not contribute significant levels of MFO inducers to the Athabasca or Peace river. Levels of induction observed for mills in this system were significantly lower than those observed at mills elsewhere in Canada using the same techniques. Of all the effluents sampled, the highest levels of induction were observed in Suncor effluent. In river water samples, the highest levels of induction were observed in the Athabasca River both upstream and downstream of the Suncor discharge and in the Clearwater and Steepbank rivers.

Hepatic Vitamins

Hepatic vitamins (Vitamin A and Vitamin E) are important in a variety of physiological processes; hence, the amount of stored hepatic vitamins, or retinoids can be used as an indicator of general fish condition. In the 1994 basin-wide fish survey, the type of storage retinoids was found to differ among burbot, longnose suckers and northern pike; however, observed levels were generally high in all species and fell within ranges observed elsewhere in non-impacted populations. The one exception to this pattern was observed immediately upstream of Ft. Vermillion where significantly higher levels of free retinoids and significantly lower levels of tocopherol were observed in male and immature burbot. The cause of this vitamin imbalance is unknown but is not related to overall condition.

Metallothionein

Metallothionein (MT) refers to a group of proteins produced when animals are exposed to heavy metals, such as cadmium and mercury. These proteins bind to the metals and assist in their removal or in their development of tolerance to their toxicity. As with the biomarkers discussed above, elevated levels of MT may thus serve as an indicator of exposure to contaminants. In the 1994 basin-wide fish survey, measured levels of MT in the gills and intestines of longnose sucker were not significantly related to pulp mill discharge; however, liver MT levels at near-field sites were higher than those at reference sites and measured kidney levels were higher at far-field sites than at reference sites. Measured levels of MT in burbot tissues were not significantly related to pulp mill discharges; however, intestine levels were significantly higher at far field sites relative to those at near field sites. Observed levels of MT in burbot kidney were approximately 8X higher in fish captured in the Slave River Delta; however, these fish had the best condition of any collected in the basins. Relative to other sampling locations, fish in the Pembina River consistently showed elevated levels of MT. Overall, observed MT levels tend to increase from upstream to downstream on the Peace River and on the lower Athabasca River but there was insufficient evidence to conclude that fish from near-field locations experienced generally higher MT levels than did fish from reference or far-field locations.

External Abnormalities

As part of the of the NRBS sampling protocol, captured fish were routinely checked for external abnormalities, including the presence of tumors, lesions, scars, injuries skin discoloration or deformities. Nearly 23,000 fish (most of which were then released) were checked in this manner and while the overall incidence of abnormalities was less than 1% certain species from certain locations showed a much higher incidence. In some cases a higher frequency of external abnormalities may result from physiological or behavioral changes associated with spawning; however, the Food Chain Component obtained evidence of a higher incidence of abnormalities in fish captured immediately downstream of pulp-mills. These qualitative results are difficult to interpret but suggest that the frequency of external abnormalities in fish merits further investigation.

Fish Population / Community Responses

Although considerable time and effort have been invested by NRBS and other fish studies in the collection and analysis of data relating to distribution and abundance of fish populations and community structure within these basins, major information gaps remain, particularly with respect to quantifying overall fish community structure. The primary reasons for this lack of information relate to a historical bias in fish inventory assessments (i.e., a focus on those species important to sport or commercial fisheries) and the difficulties associated with both defining and adequately sampling the entire fish community in large rivers. For these reasons it was recommended that measures of entire fish community structure could not be effectively used as a biomonitoring tool in the northern river basins (Cash et al. 1996).

It is possible to replace measures of the entire fish community with measures of some subset of the same community. Individual- (e.g., growth, fecundity, morphometrics and meristics) and population- (e.g., distribution, age/size-class structure, rate of increase) based measures taken on a variety of fish species are commonly used ecological indicators and provide valuable insight into the ecological structure and integrity of riverine systems. As discussed above, the NRBS has employed fish species with restricted distributions to examine the population effects of pulp-mill exposure, and in the Peace-Athabasca Delta, the catch-per-unit-effort of goldeye in late June has been developed as an indicator of overall population status.

Macroinvertebrate Biomonitoring

Ecotoxicology of Sediments

In order to assess the toxicology of sediments, four species of benthic invertebrates were reared in sediment samples collected from various locations throughout the basins. The survival, growth and fecundity of these species were then measured over a 28-day period. While, in general, no significant sediment toxicity effects were observed using this approach, the Emerson Lakes area of the Athabasca River emerged as a region containing sediments that could impair fecundity in at least one of the species tested. Although substrate type (i.e., the extent of sand) may have influenced this observation it should be noted that macroinvertebrate contaminant body burdens in this reach of the river exceeded Canadian Water Quality Guidelines.

External Abnormalities

As in fish, the frequency of external abnormalities among macroinvertebrates may provide valuable insight into the effects of contaminants on biota. The Modelling and Synthesis Component conducted a preliminary study investigating the relative frequency of mouth-part deformities in a dominant macroinvertebrate group (the chironomid worms or midges) in the Hinton area of the Athabasca River. Results of this study suggest that the frequency of deformity is higher among chironomids living immediately downstream of the pulp-mill discharge relative to those living in reference locations or further downstream. As with physiological biomarkers, knowledge of the frequency of deformity in this group may provide an early warning of ecological effects of contaminant exposure.

Macroinvertebrate Population / Community Response

The population/community response of macroinvertebrates to contaminant exposure was explored by assessing in situ community structure (NRBS Synthesis and Modelling Component Synthesis Report No. 10) and by the deployment of river-side artificial stream experiments designed to distinguish between the effects of nutrients and contaminants contained in a single effluent (NRBS Nutrient Component Synthesis Report No. 4).

Measures of benthic macroinvertebrate community structure indicated that communities both upstream and downstream of pulp mills were numerically dominated by midges, oligochaete worms and mayflies. Observed differences among sites upstream and downstream of any particular pulp mill were generally a function of changes in relative abundance of taxa rather than a result of the disappearance or addition of specific taxa. Exposure to pulp-mill effluent did not produce significant and consistent changes in overall benthic macroinvertebrate community structure; a finding consistent with studies conducted by the Province of Alberta and by various industries operating within the basins. Artificial stream experiments demonstrated a significant positive effect on the growth of certain invertebrate taxa exposed to pulp-mill effluent. However, this effect was a consequence of exposure to the nutrients contained within the effluent and there was no evidence to suggest that contaminants within the effluent affected macroinvertebrate growth.

NUTRIENTS RESEARCH

The Nutrients Component addressed Study Board Questions 2, 5, 7 and 13a (Box 16) with a focus on nutrient sources, trends, and nutrient productivity relationships. Dissolved oxygen responses to spatial and temporal factors were also investigated.

Box 16: Study Board Questions Addressed by the Nutrients Component.

Q 2. What is the current state of water quality in the Peace, Athabasca and Slave river basins, including the Peace-Athabasca delta?

Q 5. Are the substances added to the rivers by natural and man made discharge likely to cause deterioration of the water quality?

Q 2. What concentrations of dissolved oxygen are required seasonally to protect the various life stages of fish, and what factors control dissolved oxygen in the rivers!

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

- **Nutrient Trends and Effects**

In the Athabasca River, total phosphorus (TP) and total nitrogen (TN) concentrations are lowest around Jasper and, during spring, fall and winter, increase downstream of Jasper, Hinton, Whitecourt and Fort McMurray.

During summer high flows, higher non-point source loadings of TP often mask any impacts of point-source nutrient loading. Twenty percent of TP samples from the Athabasca River exceeded the Alberta Surface Water Quality Objective (Alberta Environment 1977) for TP of 0.05 mg/L P. Most of these levels occurred during summer and were probably due to natural high particulate P concentrations. Only 2% of the samples exceeded the TN objective of 1.0 mg/L N. On an annual basis, continuously-discharging industrial and municipal sources contribute 3 to 10% of the TN load and 17% of the TP load in the Athabasca River, with a higher contribution during winter.

In the Wapiti-Smoky rivers, TN and TP concentrations increase downstream of the Grande Prairie sewage treatment plant and again, below the Weyerhaeuser of Canada Ltd. outfall. Concentrations remain elevated to the mouth of the Wapiti River and, during periods of low flow, increase the receiving water concentrations of the Smoky River. Of the 27 TP measurements at the mouth of the Wapiti River, 74% of the samples exceeded the Alberta Surface Water Quality Objective for TP of 0.05 mg/L P, suggesting that TP from the City of Grande Prairie and Weyerhaeuser of Canada Ltd. effluents contributed to this non-compliant situation. Importantly, these two sources contribute 23% of the annual TP loading to this system and under low-flow conditions this figure exceeds 40%. The objective for TN was exceeded by 19% (n=26) of the samples from the Wapiti River near the mouth compared to no TN samples (n=21) exceeding the objective upstream of Grande Prairie, again suggesting the influence of nutrient loading from the Grande Prairie sewage treatment plant and pulp mill.

Elevated nutrient concentrations have increased periphyton biomass and benthic invertebrate densities on the Athabasca River downstream of Jasper, Hinton, Whitecourt and Fort McMurray and on the Wapiti River downstream of Grande Prairie; and, for the Athabasca River downstream of Hinton, have increased the length and body weight of spoonhead sculpin.

Enrichment studies conducted with nutrient diffusing substrata in fall 1994 in the Athabasca and Wapiti-Smoky rivers showed that periphyton growth was not nutrient limited immediately downstream of Jasper, from downstream of Hinton to upstream of Whitecourt and in the area downstream of Fort McMurray. Periphyton growth was nitrogen limited from downstream of the Alberta Newsprint Co. to the confluence of Lesser Slave River and in the mouth of the McLeod River. In the Wapiti-Smoky rivers, periphyton growth was nitrogen and phosphorous limited upstream of the Weyerhaeuser Canada Ltd. (even in the reach receiving Grande Prairie sewage), not nutrient limited in the reach downstream of the mill, and N-limited in the Smoky River.

Studies conducted in artificial streams showed that periphyton biomass and growth of the mayfly Ameletus and capniid nymphs increased in response to both nutrient and 1% effluent addition, with no significant difference between the two treatments. These results indicate that the response to effluents at a community or population level is one of nutrient enrichment not toxicity.

- **Dissolved Oxygen**

DO concentrations less than the Alberta Surface Water Quality Objective of 5 mg/L DO do not routinely occur in the mainstem of the Athabasca River (Figure 9). DO concentrations of less than 5 mg/L have rarely been observed in near-shore areas or zones where effluent mixing was not complete. In the case of the Wapiti, Smoky, Peace and Slave rivers, DO concentrations less than the 5 mg/L objective have never been recorded.

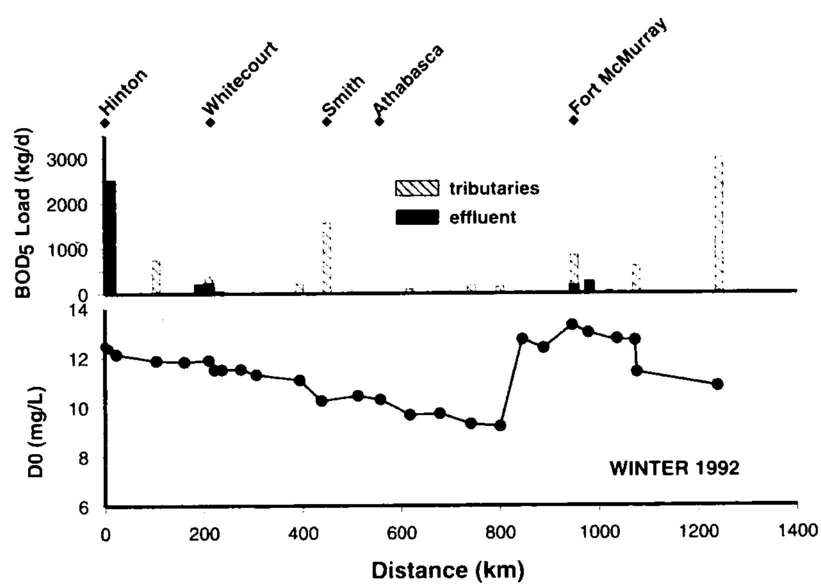
Historical data from 1958-1995 for the Athabasca River and 1966-1992 for the Wapiti-Smoky rivers indicate that late winter DO concentrations in the Athabasca River downstream of Hinton were lowest during the 20-years following the 1957 start-up of the Hinton mill and have since increased significantly at both Whitecourt and Athabasca. In the Wapiti-Smoky rivers, winter DO concentrations upstream of Grande Prairie have remained constant before and after the 1973 start-up of the Proctor and Gamble Cellulose Ltd. Mill but have decreased significantly in the Smoky River since 1973.

In an attempt to develop quantitative predictions of under-ice DO levels, an analytical model, DOSTOC, was adapted for use in the Athabasca basin (NRBS Dissolved Oxygen Synthesis Report No. 5). Input parameters for DOSTOC were tested and validated for their applicability to the Athabasca River and gave a reasonable fit to the data trend observed for recent (1990-1993) winters.

Box 17: Research Activities of the Nutrients Component.

- Identification and quantification of point and non-point sources of nutrient loading to the basin and assessment of long-term trends in water chemistry.
- Identification of reaches in which primary production was limited by nutrient availability.
- Examination of the interaction of nutrients and contaminants with respect to invertebrate growth and community structure.
- Identification and quantification of late-winter dissolved oxygen patterns in the Athabasca and Wapiti-Smoky rivers
- Adoption of analytical models to predict dissolved oxygen levels in the Athabasca River
- Assessment of low dissolved oxygen effects on fish eggs and larvae and on invertebrate behavior and survival

Figure 9: Spatial Variation in Dissolved Oxygen and BOD5 for the Athabasca River, Winter 1992. Re-aeration occurs at Grand Rapids. (NRBS Dissolved Oxygen Synthesis Report No. 5).



Dissolved oxygen concentrations of 5 mg/L at temperatures of 2-3°C had no effect on egg survival of either mountain whitefish or bull trout, although mountain whitefish eggs took longer to hatch and bull trout alevins were less well developed. DO concentrations of 5 mg/L stressed mayflies, leading to altered positioning behavior, reduced feeding rate, and decreased survival. Given that mayflies and the early life stages of fish live at or in the surface layers of the riverbed and that DO concentrations can differ by 3 mg/L DO between the water column and the sediment-water interface, water-column DO concentrations of 6-8 mg/L would be needed to protect these organisms (NRBS Dissolved Oxygen Synthesis Report No. 5).

FISH ECOLOGY RESEARCH

The Food Chain Component addressed Study Board Question 6 (Box 18) and provided new or confirmatory information on distribution and movement patterns of selected fish species within the basins. This component identified critical fish habitats, assessed patterns of pathological abnormalities, and provided important insights, through the use of stable isotope analyses, into potential food chain pathways and routes of exposure of selected contaminants (Mill et al. 1996; Tallman 1996). This information provided an important basis for the Contaminants Component in their assessment of fish contaminant trends and effects.

Although many fish species spawn primarily along tributaries, several mainstem reaches have also been identified as providing particularly important spawning and/or overwintering habitat (Figure 10). In the Athabasca River, the Jasper Park reach and its associated tributaries contain a remnant population of pygmy whitefish and large numbers of spawning mountain whitefish, while the Mountain and Cascade rapids provide important spawning habitat for lake whitefish and longnose sucker. In the Peace River, the area downstream of Fort Vermillion provides critical over-wintering habitat for over one million goldeye; while inconnu spawn in the lower and middle reaches of the Slave River and at the Rapids of the Drowned. The Peace-Athabasca and Slave River deltas provide critical spawning and rearing habitat for a variety of species including norther pike, burbot, walleye and goldeye.

Burbot, longnose suckers, and northern pike were shown to have basin-wide distributions (Figure 10), making them suitable candidates as bioindicator species. In addition, lake chub and spoonhead sculpins showed promise as potential bioindicators for local (i.e., reach-specific) biomonitoring applications.

Radio telemetry studies confirmed extensive spawning movements of mountain whitefish, walleye, goldeye, bull trout, and inconnu and proved to be an effective technique for understanding fish movement patterns in large rivers; however, major gaps still exist in our general understanding of fish movement, habitat use and ecology. Several geographic reaches were identified or confirmed as critical

Box 18: Study Board Questions Addressed by the Food Chain Component.

Q 6. What is the distribution and movement of fish species in the watersheds of the Peace, Athabasca and Slave rivers? Where and when are they most likely to be exposed to changes in water quality and where are their most important habitats?

Q 7. What concentrations of dissolved oxygen are required seasonally to protect the various life stages of fish, and what factors control dissolved oxygen in the rivers?

Q. 8. What is the current concentration of contaminants in water and edible fish tissue and how are these levels changing through time and by location?

Box 19: Research Activities of Food Chain Component.

- assess the basin-wide distribution and relative abundance of selected fish species
- assess fish movement patterns using radio telemetry and tagging methodologies.
- obtain a more comprehensive understanding of potential exposure patterns in relation to point-source and non-point source contaminant inputs
- use stable isotope analyses to describe the aquatic food chain for selected fish species and identify potential biomagnification pathways for contaminants

fish spawning or overwintering habitat within the basins and deep-hole overwintering habitats were found in the Peace River system. In addition, a threatened species, the pigmy whitefish, was found to be resident in the Athabasca River within Jasper National Park.

In the 1992 reach-specific survey of the Athabasca River, fish collected in the spring below the Hinton Combined Effluent showed overall poorer condition than those collected upstream. In addition, a higher incidence of external abnormalities was observed in fish collected below the Whitecourt pulp mill discharges as compared to other areas of the basins. In addition, some fish species under a Human Health Consumption Advisory on the Athabasca River were found to move more upstream seasonally into Jasper National Park.

Stable isotope analyses were employed to describe food web structure in the Athabasca Basin and revealed a relationship between fish body burden levels of dioxins and furans and the feeding habits of those fish. These results indicate that for fish in this basin a primary route of exposure to pulp mill contaminants is through the food chain; however, the results also indicate that the extent to which fish are exposed to pulp mill contaminants is largely dependent on the extent to which they feed on mainstem sources of carbon. Fish whose isotope signatures suggested they fed primarily on tributary-based carbon sources (i.e., material produced in the tributaries, or washed into the mainstem from the tributaries) tended to display lower contaminant body burden levels relative to those that relied on mainstem carbon sources (i.e., primary production in the mainstem of the river).

DRINKING WATER RESEARCH

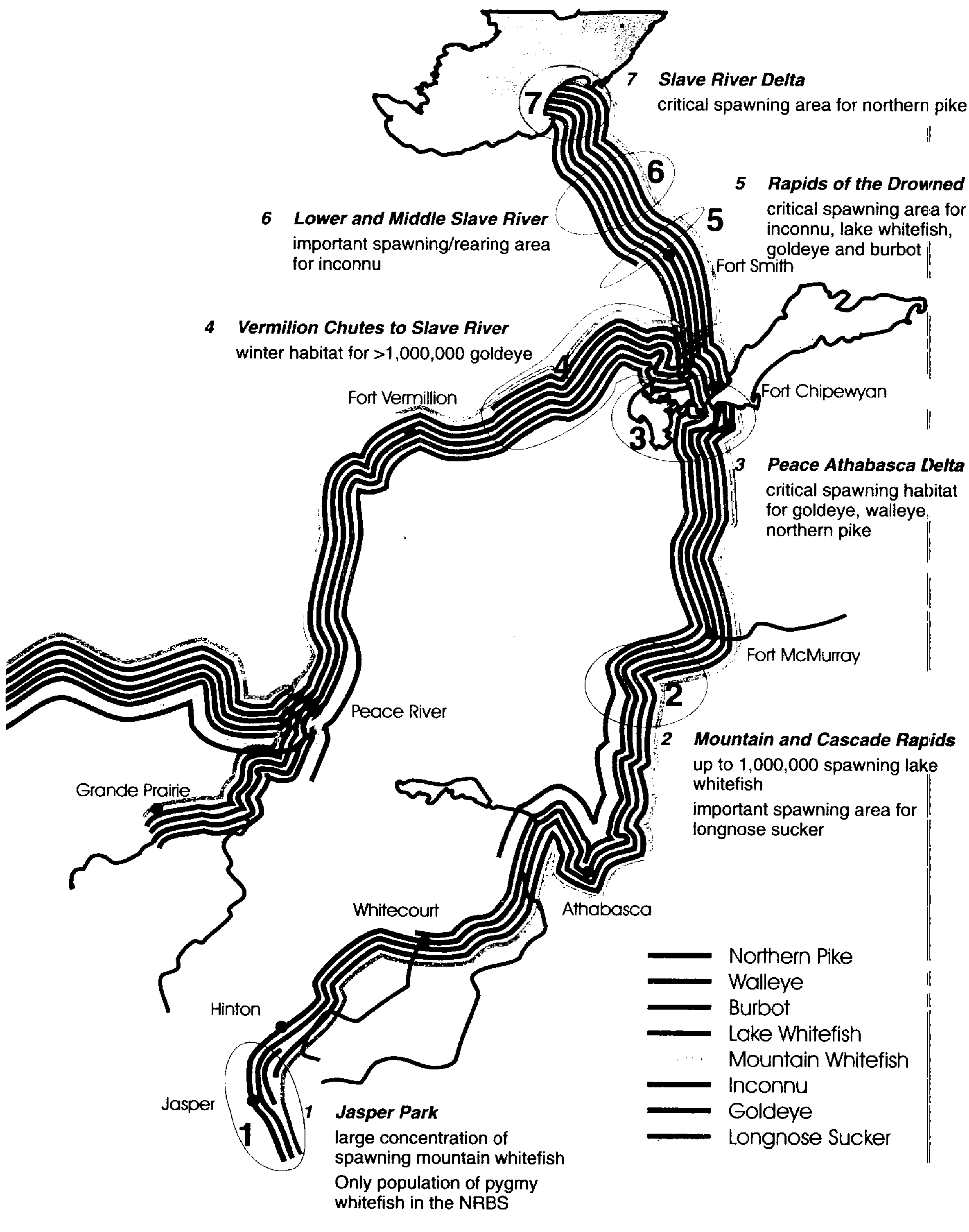
Box 20: Study Board Questions Addressed by the Drinking Water Component.

Q. 8. Recognizing that people drink water and eat fish from these river systems, what is the current concentration of contaminants in water and edible fish tissue and how are these levels changing through time and by location?

The drinking water investigations of NRBS focussed on reviewing and assessing existing drinking water quality data as well as collecting new information from site visits and interviews. The conclusions of the drinking water assessment are also based on ancillary information provided by surveys conducted in the Other Aquatic Uses Component and the Traditional Knowledge Component. These assessments have significantly added to the identification and understanding of drinking water problems encountered in the basins.

NRBS investigations revealed that the quality of drinking water throughout the basins is, for the most part, of exceptional quality. This is especially true of water obtained from conventional treatment systems. The quality of drinking water is dependent on the quality of the raw water source but is also very much dependent upon the efficiency of the water treatment facility and its ability to treat high levels of turbidity and coliform bacteria. NRBS reports that non-conventional drinking water users are more vulnerable to contacting waterborne diseases such as giardiasis ("beaver fever") than are those using water from large municipal treatment systems. Even some of the portable treatment alternatives available to non-conventional drinking water users are suspect in terms of meeting their stated chemical or microbial contaminant removal efficiencies. The major industrial contaminants originally suspected of being in the raw water supplies have been determined to exist at very low or non-detectable levels. As well, these contaminants tend to be associated with sediment particles and can therefore be removed by standard coagulation and filtration processes. Taste and odour issues were a primary research interest of the Drinking Water Component; NRBS confirms that taste and odour associated with the Hinton Combined Effluent in 1992/93 could be detected in the river as far as 1100 km downstream. Distinctive smells have been identified also for the AlPac and Suncor effluents although their role in the taste and odour issue for drinking water and fish remains unresolved.

Figure 10: Distribution of Selected Fish Species and Critical Fish Habitat on the Mainstems of the Peace, Athabasca and Slave Rivers, and the Wapiti-Smoky System Below Grande Prairie.



Several of the compounds (e.g., Di-, tri- and tetrachlorophenol, guaiacols, catechols, syringols and vanillins) that cause many of these off flavours and odours fall into a group of chemical compounds commonly referred to as phenolics. With the advancements in pulp mill treatment processes, many of the chlorinated phenolics have decreased during the course of the study; however, taste and odour issues remain and may be attributable to low levels of anisoles, terpenes and many sulphur containing compounds. Pre- and post-AlPac taste and odour studies were unable to identify conclusively an effect attributable to AlPac, for at least two reasons: background odors from the Hinton Combined Effluent, and dilution by the river.

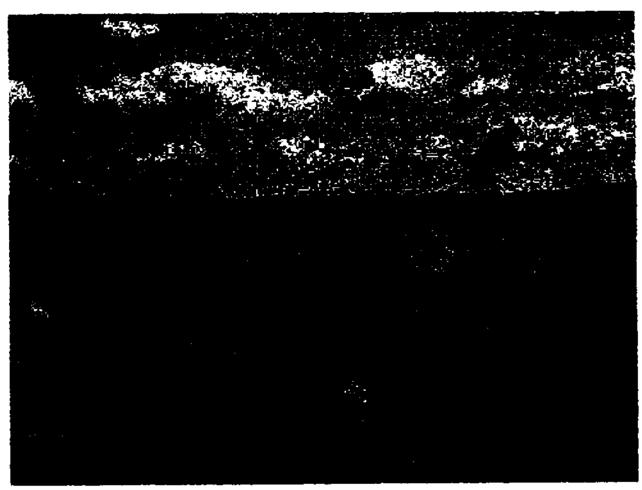
The NRBS investigations conclude that there are many "challenges" to providing safe drinking water quality in the basins. Although surface and ground waters are generally of good quality there are water quality issues associated with the smallest communities (< 500). The Drinking Water Quality Component has advanced approaches for consideration by drinking water authorities including: changes to the water monitoring program and improvements in the training and certification process of those who have direct responsibility for maintaining treatment facilities.

Box 21: Research Activities of the Drinking Water Component.

- Assessment of existing drinking water quality relative to drinking water quality guidelines
- Taste and odour of drinking water (aesthetics): causes and prevalence including pre- and post-AlPac
- Assessment of non-conventional and conventional drinking water supplies in terms of physical-chemical and microbial quality
- Review and assessment of treatment efficiencies related to both non-conventional and conventional water supplies
- River model for predicting time-of-travel of spills, ambient concentrations of contaminants and notification scheme for communities

Box 22: Drinking Water Use Statistics.

- 214 conventional drinking water facilities
- 25-50% of basins' people use unconventional treated water: wells/springs (31%), dugouts (4.4%), bottled water (4.4%), river water (2.8%), lake water (2%)
- Bottle water use highest on McLeod, Wapiti and Wabasca Rivers (2-7% of people surveyed)



Non-conventional drinking water sources.

SYNTHESIS AND MODELLING RESEARCH

The Synthesis and Modelling Component addressed Study Board Questions 13a, b and 14 (Box 22), and further integrated the findings of other components to develop a more complete understanding of the state of the ecosystem, allow identification of ecosystem indicators, and provide a framework for integrated environmental monitoring and cumulative effects assessment. This Component was also involved in studies of ecotoxicology, development of ecological indicators for the Peace-Athabasca Delta and evaluation and synthesis of modelling exercises conducted by the NRBS.

• Ecosystem Approach to Environmental Management and Ecosystem Health

The NRBS has recognized the need to adopt an ecosystem approach to the management of these basins. This approach focuses on the collection and synthesis of integrated knowledge of ecosystems and emphasizes a holistic perspective, linking systems at different organizational levels within the ecosystem. As well, it attempts to develop management strategies that are ecological, anticipatory and ethical and recognizes that human populations are part of, and not separate from, the ecosystem.

Implicit in the concept of an ecosystem approach is the desire to maintain the ecosystem at some adequate level of function, or health. Both "ecosystem" and "health" are difficult concepts to define. Ecosystem boundaries are, of necessity, somewhat arbitrary and the constraints imposed by these boundaries should be recognized. Although there exist a variety of approaches to the assessment of ecosystem health, the pragmatic approach is the only one that explicitly combines the best available scientific understanding of the ecosystem with the priorities and concerns of the human populations living in those ecosystems. The pragmatic approach thus offers the greatest utility for researchers and managers (NRBS Synthesis and Modelling Component Synthesis Report No. 10).

An important dimension of the pragmatic approach to ecosystem health is the development of ecosystem-specific indicators that adequately reflect societal concerns and scientific knowledge. The process of indicator development involves statements of societal concern followed by the refinement of those concerns into specific management objectives and the selection of particular indicators to satisfy those objectives. Societal participation in all aspects of indicator development and in ongoing environmental monitoring is critical.

Box 23: Study Board Questions Addressed by the Synthesis and Modelling Component.

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

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

Q. 14. What long term monitoring programs and predictive models are required to provide an ongoing assessment of the state of the aquatic ecosystems?

• Integrated Monitoring and Cumulative Effects Assessment

The NRBS has recognized that monitoring within the basins is, and will continue to be, conducted by a variety of agencies and for a variety of purposes. Given these circumstances, a considerable benefit would be realized by integrating all monitoring efforts appropriately. Such an integration would serve to identify priorities, avoid duplication, redirect efforts and allow for monitoring at a basin scale. Quality assurance and quality control practices as well as procedural standardization must be incorporated into all aspects of these monitoring activities and any such program must have a rigorous scientific basis. Issues of particular concern include: (i) basic ecology, (ii) study design, (iii) scale and, (iv) research.

Various approaches to cumulative effects assessment exist but all share three components: 1) the identification of the potential cause(s), 2) understanding how ecosystem structure and process(es) are influenced, and 3) developing the capability to predict future effects. The overall science program in the NRBS was designed to provide insights into each of these components of cumulative effects assessment. Cumulative effects assessment is closely tied to integrated monitoring and represents a major advance over traditional site specific environmental impact assessments in that it is the only approach that explicitly considers multiple impacts from a variety of point sources.

• Model Evaluation

Evaluation of NRBS modelling exercises generally indicates that analytical models can be usefully employed to predict trends in under ice dissolved oxygen levels (the DOSTOC model), contaminant

Box 24: Research Activities of the Synthesis and Modelling Component.

- Development of an ecosystem approach to the assessment of ecosystem health and the development of ocosystem indicators.
- Development of an integrated management framework that emphasizes cumulative effects assessment and stakeholder participation at all levels.
- Critical evaluation of analytical modelling efforts conducted in the NRBS.
- Development of specific ecosystem indicators for the Peace-Athabasca Delta.
- Evaluation of pulp-mill and sediment toxicology employing chironomid deformities, the TRIAD approach and analyses of benthic community structure.

fate (the WASP model) and the transfer of contaminants through the aquatic food web. . However, before these models can be made truly effective, data are required to parameterize and verify them adequately (McCauley 1996). In many cases the success of the modelling exercise was compromised not by the model itself, but rather by the quality and availability of data to feed into the model.

The DOSTOC model was investigated by the Nutrients Component and was found to successfully predict "large-scale" trends in available oxygen concentrations, particularly in years with higher discharge. The model was less successful in predicting "small-scale" changes in oxygen concentration that occurred downstream of some pulp mills in the 1988-1989 period but enjoyed greater success in the 1990-1993 period. Dissolved oxygen levels declined linearly with distance in regions of the Athabasca River receiving pulp mill effluent. Although the rate of decline differs among river segments, it does not differ among years within a segment. A comparison of data from these basins with those from other ice-covered rivers suggests dissolved oxygen concentrations can be predicted from a knowledge of effluent concentration and river discharge.

The WASP model, developed by the Contaminants Component, adequately simulated configuration and flow conditions in the Athabasca and Wapiti-Smoky systems. Descriptive simulations of total suspended solids (TSS) adequately captured changes in water column concentrations in the Athabasca and Wapiti-Smoky systems. The model also adequately simulated spatial and temporal variation in 2,3,7,8-TCDF in all media. If loads are adequately defined, the WASP model provides a reliable simulation of dissolved water column concentrations in the Athabasca and Wapiti-Smoky systems. Simulated bed concentrations in the Wapiti-Smoky system were overestimated for all chemicals except 2,3,7,8-TCDF. Calibration was not possible for resin acids in suspended solids from the Athabasca River. For some chemical species (e.g., Phenanthrene) available data are so sparse, or conflicting, that it is not possible to evaluate the calibration of WASP.

In general, the WASP food chain modelling results support the hypothesis that consumption of filter-feeding invertebrates feeding on suspended solids represents the primary exposure pathway of mountain whitefish to TCDF. This relationship was further confirmed by the stable isotope analyses conducted by the Food Chain Component. A lack of data on processes affecting uptake and excretion of resins acids and chlorinated phenolics resulted in overestimation of the concentrations of these chemicals in fish species. The lack of fit between predicted and observed values was attributed to two potential sources: (1) environmental variability in concentrations of organic contaminants in various environmental media and; (2) variation in biota within and among locations, including migratory movements of fish. While these modelling efforts greatly improve our understanding of contaminant fate and distribution in the system, they are not yet sufficiently developed to allow for quantifiable predictions as to specific concentrations of contaminants in various media. Future research in this area should focus on obtaining baseline data required to adequately parameterize these models.

TRADITIONAL KNOWLEDGE RESEARCH

Land is vital to traditional users of the northern river basins. It is a source of spirituality, livelihood, sustenance and balance. In recent years, residents of the basins have observed changes in the quality and quantity of water, and this has affected the traditional northern lifestyle, residents' livelihood, self esteem, traditions and future.

A perception of many basin residents is that researchers, managers and decision makers often fail to consider the realities of those who "live off the land;" they also often fail to consider traditional knowledge about the state of the ecosystems and causes and effects

Box 25: Study Board Questions Addressed by the Traditional Knowledge Component.

Q. 12. What traditional knowledge exists to enhance the physical science studies in all areas of the enquiry?

of change. The NRBS endeavored to correct this perception by creating the Traditional Knowledge Component with a mandate to gather and document indigenous peoples' knowledge on matters relating to the Board's areas of interest. The traditional knowledge research addressed Study Board Question No. 12 (Box 24) and related information to all other study components (Box 25).

Box 26: Scope of Research Activities for the Traditional Knowledge Component.

- Gather, store and process knowledge of traditional users
- Develop protocols to acquire traditional knowledge
- Form partnerships to assist in collecting of traditional knowledge
- Analyze results within traditional and scientific contexts.

A community endorsed survey process, developed by the Traditional Knowledge Component, used interviews and questionnaires to obtain information on a range of topics including an identification of past and present patterns of resource use, trends in environmental change, identification of significant environmental features or observations (e.g., fish spawning areas, location of ice dams, direction of flood flows). Box 26 summarizes some of the key findings obtained by this Component, which are fully discussed in the NRBS Traditional Knowledge Synthesis Report No. 12.

In 1994, the Northern River Basins Study interviewed approximately 220 elders and traditional users from a total of 9 communities. Project managers, interviewers and interviewees were selected in consultation with community elders, leaders and organizations. Each interviewee was regarded by the Study as a traditional scientist. The observations of northern residents serve as a human testimony to the changes within the river basins. Participating communities included Fort Smith, Fort Fitzgerald, Fort Resolution, Tall Cree, Fort McMurray, Garden River, Fox Lake, Jean D'Or Prairie, Fort Vermilion, Fort Chipewyan and Fort Smith.

All information in the form of tapes and transcripts have been returned to each community for safekeeping. A detailed summary of trends in each community is contained in the Traditional Knowledge Synthesis report, an extensive document released in March 1996. As well, a 30 minute video has been produced that provides an overview of Traditional Knowledge findings.

The following are general trends as described by the Component:

Throughout all the communities visited, development is perceived as a destructive force against the traditional relationship to the land, water and wildlife and, therefore, to a traditional northern lifestyle. Many users say that development disrupts the natural balance between the land and its inhabitants.

- Sixty three percent of those interviewed regard the water resource as vital to the future health and balance of the northern river basins.
- All communities have seen changes in the quality of water. Forty percent see it polluted, dirtier, muddy and oily. Ten per cent noted increases in algae and weeds.
- Twenty eight percent noted decreased water levels over the entire basin. Changes in the character of the rivers have been observed as has the drying up of wetlands and some tributaries.
- Increased incidence of diseases and disorders such as cancer, diabetes, asthma, respiratory ailments and birth defects.
- An overall reduction in the numbers of fur bearing animals such as beaver, lynx, muskrat and rabbit and in numbers of moose, caribou, water foul, songbirds.

Box 27: Traditional Knowledge Key Findings.

- Water quality has diminished
- Climate has changed
- Perceptions of contamination are directing decisions
- Marked change in water levels within last 15 years
- Water more turbid and for longer periods
- Diminished quality of ice
- Reduced seasonal flooding
- Increase in the frequency and velocity of winds
- Longer interval between cyclic highs and lows of lynx and hare
- Reduced presence of song birds
- Fish habitat use has changed and the size of fish has become smaller
- Significant redistribution of the aboriginal tribes with "European" settlement, significant cultural changes
- 50% of future development concerns relate to pulp, paper, logging, followed by mining

The Traditional Knowledge Component Group noted that a basin wide concern exists over the future of water, "the life giver." It adds that residents are concerned human interference in the natural balance of nature, unless rectified or reversed, may have devastating effects on future generations.

Community gathering provided scientists with local perceptions

OTHER USES RESEARCH

The Other Uses Component primarily addressed Study Board Question 3; however, it also provided research support to the Hydrology Component in relation to Question 10 (Box 27). The Component also assisted the Board to address Question 16 and understand values of the basins residents. The objective of the component was to obtain sociologically-based information relating to the inhabitants of the basin, their consumptive and non-consumptive use of water resources, and their priorities and concerns with respect to environmental issues in the basins (Box 28).

During the first three months of 1995, 1350 households and 602 stakeholder groups were given a 100 question survey to complete. The response rate for households was 53% (n= 718) while 30% (n=183) of the stakeholder groups choose to participate. The high number of responses reflects the overall interest of basin residents regarding the river system. The survey touched on a variety of areas dealing with how residents and user groups view development and the environment. The questionnaire also sought to gather information about who river users are and how they use the river system.

The Other Uses household / stakeholder survey revealed a general perception that contamination of surface water is a problem within the basins and that effluents should be reduced through tighter monitoring and better enforcement. Water quantity was also identified as an issue, particularly by those who rely on the wetlands in the Delta for their livelihood and for transportation along the river. Key findings of the household surveys include:

- More than 75% of households throughout the basin felt that water contamination is a major problem, and that some industries or municipalities should be forced to reduce effluent discharges even if that means closing some operations.
- More than 80% of households, and over 75% of user groups agreed that no further effluent discharges be allowed until a river basin plan has been completed.

Box 28: Study Board Questions Addressed by the Other Uses Component.

Q 3. Who are the stakeholders and what are the consumptive and non-consumptive uses of water resources in the river basin?

Q. 10. How does and how could river flow regulation impact the aquatic ecosystems?

Box 29: Research Activities of the Other Uses Component.

- Identify users and uses
- Determine stakeholder values and expectations
- Determine the general resource capacity
- Characterize the basin setting
- Assist the integration of traditional knowledge and scientific investigation

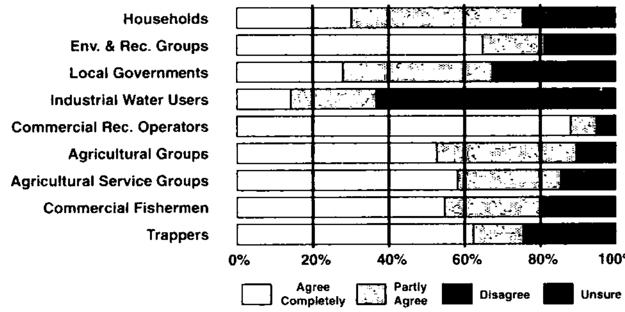
- Pulp mills were identified as the most important factor affecting water quality during the last 10 years in the northern river basins. Nearly 39% of surveyed households listed pulp mills as a threat to water quality and 83% of those households supported tighter control of pulp mills.
- Other factors identified by residents as affecting water quality included municipal sewage, non pulp mill industry, logging, runoff from livestock operations, agricultural chemicals and dams.
- More than 70% of households believe that oil and gas industry should be better regulated in terms of environmental effects.
- Nearly 40% stated that governments should be responsible for northern river basins monitoring. About 30% suggested that an independent agency should perform this role. About 3% felt industry should be responsible for monitoring.

Householders and stakeholders were asked to list up to three recommendations they felt should be made by the Study Board. The top five recommendations of those who responded are:

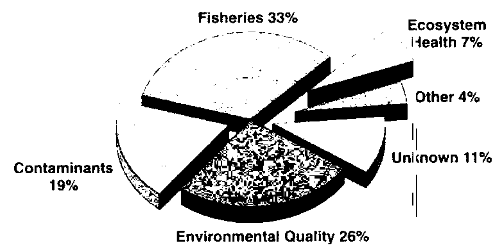
- Reduce effluent loads (23% of households)
- Monitor industrial activities (21% of households, 23% of trappers)
- Enforce pollution laws (17% of households)
- Stop selected activities such as clear cutting and additional industrial discharges (12% of households)
- Develop a river basin management plan

In ranking 11 potential solutions, households showed preference for reducing industrial effluent. Enforcing pollution control laws and developing a basins' management plan ranked second and third, respectively. While no consensus emerged as to how to satisfy water quality expectations, many basin residents supported the notion that those responsible for the degradation of water quality should be required to provide improvement and/or remediation. Government was expected to continue to have an important role in ensuring water management expectations are met.

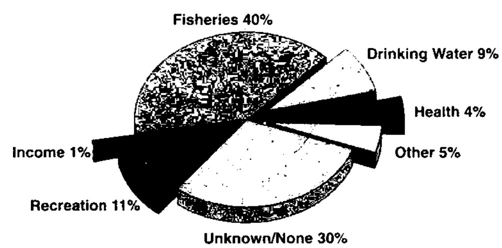
Agreement with Statement "Water Contamination is a Major Problem"



Environmental Effects of Pulp Mills
(According to Household Survey Respondents)



Effects of Pulp Mills
(According to Household Survey Respondents)



Box 30: Some Household Survey Findings.

- Industrial and municipal contamination of surface water is a problem
- Pulp mills are perceived to be the most important source of the problem
- Reduce effluent loads needed to protect water
- Closer monitoring by governments is necessary
- Better enforcement is needed
- Increased regulation should be used to control activities
- Current regulations do not interfere with economic development

■ THE STATE OF THE NORTHERN RIVER BASINS - AN ASSESSMENT OF CUMULATIVE EFFECTS

Despite their ecological importance, our understanding of how large rivers function and respond to human activities is limited. In a global sense, large rivers have been little studied compared to small streams and lakes. This is related in part to logistics involved in sampling but has resulted in a weak theoretical or scientific basis for how large river ecosystems operate and respond to anthropogenic stress.

In the past, the Athabasca, Peace and Slave river systems served as important food and water sources and transportation routes for the people living in the basins' area. Over time, increased developments within this region have placed greater and often conflicting demands on the use of the aquatic resources. For instance, the rivers are used as "sinks" and conduits for waste products, and yet are also valued as ecosystems of aesthetic, cultural and spiritual interest.

As can be seen from the key findings section, the NRBS research program has used a variety of techniques and approaches to gain insight into the ecology and response of these systems to anthropogenic stress. Perhaps the most daunting task is to examine the scope of this information in a cumulative effects context and decide how the findings might be applied to the future study and management of these rivers. In the context of the NRBS, cumulative effects refers to the additive or synergistic effects of multiple environmental stresses acting at different temporal (time) and spatial (geographic) scales and explicitly considers human perceptions relating to the impact of these stresses. For example, contaminant concentrations in depositional sediment sampled in the tar sands area are a function not only of the "local" contributions from the oil sands deposits and related industrial inputs, but also of upstream discharges from municipalities and pulp-mills. Similarly, changes in tributary snowpack, as identified by the Hydrology Component, serve to exacerbate contaminant, nutrient and dissolved oxygen effects (identified by the Contaminants and Nutrients Components) of the Weyerhaeuser pulp-mill effluent on the Wapiti-Smoky system. Thus, a focus on single point sources or ecosystem component (e.g., flow, nutrients) will not provide the context necessary for a proper cumulative effects assessment.

In assessing the information from a cumulative effects perspective, several key questions emerge:

> ***What is the present ecological state of these river systems? Is the ecosystem improving, deteriorating, or maintaining its structure and function?***
>
> ***How have environmental stressors related to changes in hydrology and climate, the levels of contaminants entering these systems, and changes in resource use, cumulatively altered the ecological functioning of these basins?***
>
> ***Which areas of the basins are at highest risk from current and future levels of developments?***
>
> ***What impacts will future environmental stressors have on the residents and their use of the aquatic resources?***

Our assessment of cumulative effects involved identifying and evaluating the types of events that contribute to cumulative change, conducting research that provided a better understanding of the complex inter-relationships operating on and influencing ecosystem structure and function, and finally, in key areas, enhancing the capability to predict and assess future environmental effects (Synthesis/Modelling Synthesis Report 10). In the following sections we highlight the observed cumulative effects on the health and integrity of Peace, Slave and Athabasca rivers and discuss the implications of these effects in the context of ecosystem health and use of aquatic resources.

CHALLENGES OF CUMULATIVE EFFECTS ASSESSMENT

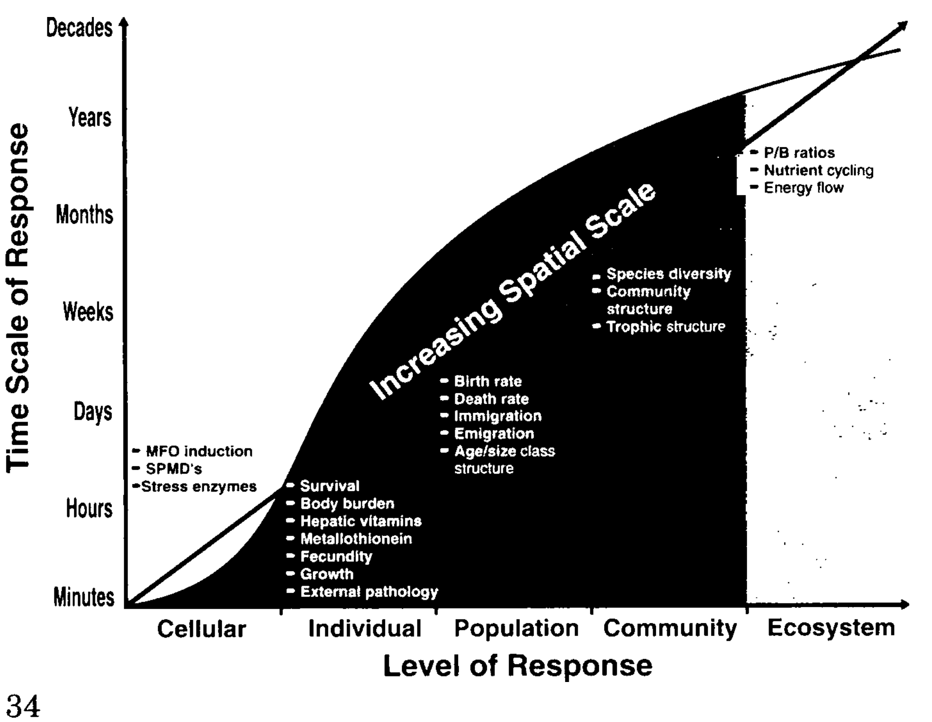
Developing an understanding of the cumulative environmental impacts in the Northern River Basins is a major departure from historical practices that have assumed that water protected from chemical contaminants through guidelines and regulations assures chemical, physical, and biological integrity. From a basin perspective, the potential degradation of this ecosystem begins in the headwaters and upland areas of the watershed and is progressively influenced by downstream developments including industrial and municipal point-source pollution, non-point source effects from land-use practices, and farther reaching effects related to climate change and atmospheric transport of contaminants. These stressors affect the aquatic ecosystem by influencing one or more primary classes of variables (Box 30).

Within the biophysical region of the Northern River Basins area, cumulative environmental impacts are occurring at a variety of interacting spatial (e.g., localized versus basin-wide geographic ranges), temporal (seasonal, among year, and decadal time-frames) and organizational (e.g., cellular, individual, population community levels) scales (Figure 11). The assessment of cumulative environmental effects is complicated by the range of point- and non-point anthropogenic stressors influencing these basins, the complexity and dynamic nature of the ecological pathways and processes involved, the range in possible types of biological and ecological responses that can occur and by several key changes that have occurred over the course of NRBS in the process technology and effluent treatment of pulp-mills in the basins.

Box 30: Primary Classes of Ecosystem Variables Subject to Cumulative Environmental Effects.

- ***Water Quality & Quantity:*** temperature, turbidity, dissolved oxygen, organic and inorganic chemicals, toxic substances, nutrients, water depth, volume, sediment type and transport
- ***Habitat Structure:*** spatial and temporal complexity of in stream physical habitat, riparian and delta habitat
- ***Biological/Ecological Responses:*** fish distribution & abundance, health of biota, trophic interactions
- ***Human Uses of the Ecosystem:*** fish consumption, drinking water supplies and consumption, transportation, aesthetic values, economic development

Figure 11: Relationship of Response to Spatial, Temporal and Organizational Scales.



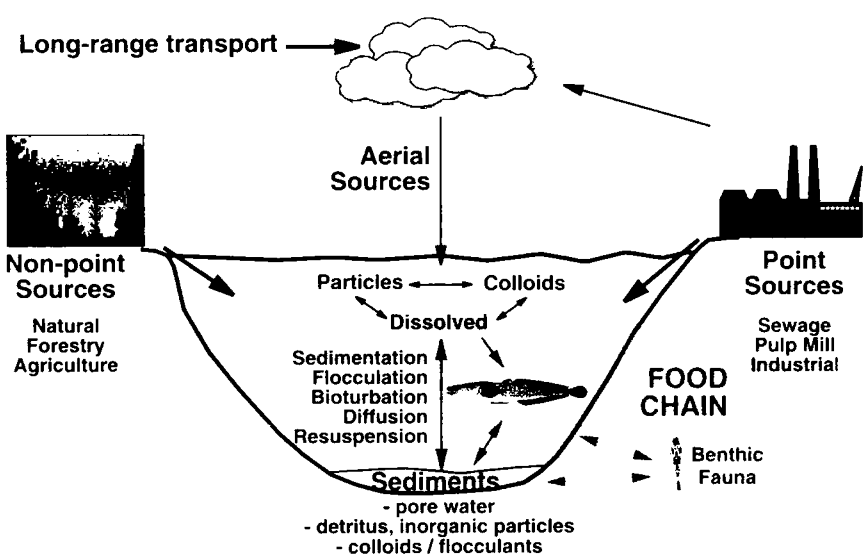
ECOSYSTEM HEALTH

From a cumulative effects perspective, issues relating to ecosystem health can be categorized into five major groupings: 1) effects of chemicals; 2) consequences of changes in flow regime, 3) effects of nutrients and dissolved oxygen; 4) health of aquatic biota; and 5) implications for human populations. In the following discussion, all human populations are considered to be part of the ecosystem and not separate from it. Such a view of human populations is an essential component of the ecosystem approach (Synthesis/Modelling Synthesis Report 10). Each of the general issue areas will be dealt with below.

- **Cumulative Effects of Chemicals**

Chemical inputs of interest to NRBS are described in the Contaminant and Nutrient Synthesis reports and include major cations and anions, nutrients (e.g., phosphorus, nitrogen), oxygen and contaminants such as chlorinated organic compounds (e.g., polychlorinated dibenzo-p-dioxins (PCDDs), polychlorinated dibenzofurans (PCDFs), polychlorinated biphenyls (PCBs), chlorophenols (CPs) and chlorinated resin acids (Cl-RA)), non-chlorinated organic compounds (e.g., polyaromatic hydrocarbons (PAHs)), and heavy metals (e.g., mercury, cadmium, zinc). In addition, NRBS has broadened the definition of contaminants to consider the occurrence and effects of microorganisms and other pathogens on water quality and use. In this report we focused cumulative effects assessment to consider those chemicals with known toxicological and/or deleterious ecological effects having linkages to human health or affecting usage of aquatic resources.

Figure 12: Sources, Fate and Potential Routes of Exposure of Aquatic Biota to Contaminants.



An understanding of the fate, movement and levels of contamination associated with sediments formed an important component of assessing cumulative effects. The assessment of sediment-contaminant relationships within the river ecosystems provided the ability to link the potential sources of contaminants to the rivers (e.g., aerial, point and non-point land sources) to potential routes of exposure and responses in various biota, including fish and macroinvertebrates (Figure 12). In addition, spatial and temporal sediment and biological analyses helped provide a better understanding of the movement and fate of various classes of contaminants within and among biotic and non-biotic components of these riverine ecosystems.

One of the primary cumulative effects issues addressed by the science program was the temporal and spatial trends of persistent organochlorines and other contaminants within the basins and their measured effects on the biota. Of highest concern were PCDDs and PCDFs, both of which are extremely toxic to many organisms. In general, all planar halogenated hydrocarbons such as PCDDs/PCDFs and selected congeners of PCBs have a common mode of potential toxicological action and ecological effect, including; mixed function oxidase (MFO) induction, immune suppression, reproductive impairment, weight loss, hormonal alterations, and induction of cancerous tumours.

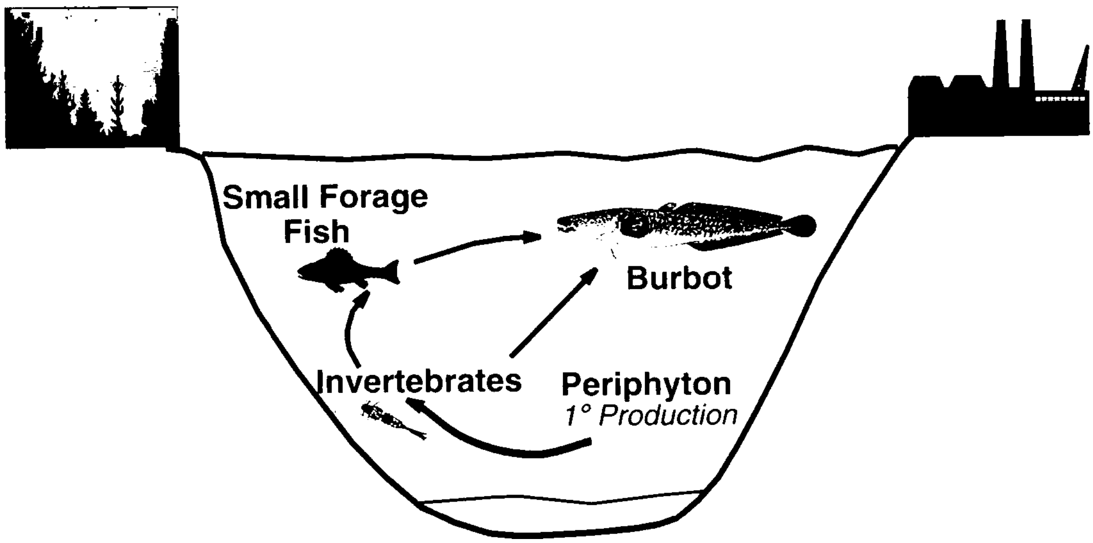
Overall, in the Athabasca and Peace River basins environmental concentrations of chlorinated organic compounds such as PCDDs, PCDFs, CL-RA and CPs have declined since the late 1980s; however, these contaminant classes still occur in detectable levels in sediments and/or fish in the basin (Figure 6). In general, highest concentrations of these chlorinated compounds occur in reaches immediately below pulp-mill effluent inputs and are consistent with the results of biomarker tests such as sex steroid levels. The observed decline in the concentration of these toxic contaminants in sediments and fish is probably a consequence of improvements in the bleaching process technology and effluent treatment by the pulp-mills in the basin area. However, the decline in ambient environment concentrations is not simply related to decreased effluent loadings.

Natural sediment transport and deposition processes are also operating simultaneously in fluvial systems and observed decreases in sediment concentrations and bioavailability of contaminants are further augmented by cumulative dilution with uncontaminated sediments and/or their resuspension and redistribution within the system. Sediment-related processes such as these are likely to be of greater importance in affecting measured contaminant concentrations in erosional and depositional areas of the basins. For example, the highest levels of organochlorine compounds associated with sediments were observed in the Emerson Lakes reach of the upper Athabasca river. This reach also exceeded CCME guidelines (see Appendix 1) for macroinvertebrate body burdens and displayed benthic ecotoxicological responses, and a relatively high incidence of external abnormalities in fish. Sediment transport and hydrology studies confirm this reach of the Athabasca is primarily depositional and further influenced by pulp-mill effluent-sediment flocculation processes. Thus, independent lines of evidence, taken together (i.e., the weight of evidence approach) indicate this region of the Athabasca River is particularly susceptible to the cumulative effects of environmental stresses and warrants further attention.

Another contaminant-related cumulative effects concerns PCBs. Atmospheric deposition of PCBs is known to occur within the basin, but the fact that observed PCB concentrations vary spatially suggests additional point-sources. In particular, anomalously high levels of PCBs were observed in burbot collected in the Wapiti-Smoky rivers, and in the Athabasca River downstream of Hinton, in sediments in the Wapiti-Smoky, and in the Peace river above the confluence of the Smoky. A possible explanation for the observed spatial differences in PCB concentrations in fish tissues (described in Section 2), particularly in burbot, might be related to site-specific differences in trophic biomagnification, primary and secondary production levels, and contaminant bioavailability.

First, the higher body burdens of PCBs observed in burbot livers as compared to mountain whitefish, longnose sucker and northern pike, may be related to their trophic position and high fat (lipid) content. As burbot grow and mature, they display a shift in diet with age. That is, with increasing age and body size, burbot become progressively more piscivorous (fish eating). Since PCBs are concentrated 10 fold across each trophic level, it is hypothesized that the observed higher body burdens from fish collected in the Wapiti River below Grande Prairie and in the Smoky River could, in part, be explained by burbot feeding at a higher trophic level. In other words, burbot feeding exclusively on forage fish may experience an exposure to PCBs that is 10X higher than that experienced by burbot feeding one trophic level lower (i.e., on invertebrates) (Figure 13). Second, higher concentrations of PCBs in burbot liver from the Wapiti-Smoky rivers and Athabasca River may be related to point-source inputs of PCBs, such as from spills.

Figure 13: Biomagnification of Contaminants in Burbot.



The oil sands area of the Athabasca and Peace basins acts as a source of hydrocarbon and PAH contamination, possibly heightened by related oil extraction operations. Several independent physiological biomarker studies (1994 basin-wide fish survey; 1994, 1995 semi-permeable membrane bioassays) confirm the highest level of MFO induction observed in these basins occurs in the oil sands area (Wabasca River, Athabasca River downstream from Ft. McMurray, mouth of Clearwater and Steepbank rivers). As with the Emerson Lakes and the Wapiti-Smoky system, the oil sands area represents a zone of concern that deserves further investigation.

Within the Northern River Basins, mercury is the heavy metal of greatest concern; however, the distribution, fate and effects trends observed for mercury are somewhat different than those observed for chlorinated organic contaminants. In general, measured mercury concentrations in sediments and fish tissues have remained relatively constant throughout the basins since the late 1980s. Based on the 1994 fish survey, there is no evidence to suggest mercury levels in burbot change as a function of sampling location in the basins. Samples of walleye collected in the lower Athabasca Basin indicated that in some cases observed levels for this species exceed Health Canada guidelines and that consumption advisories in this region should be continued.

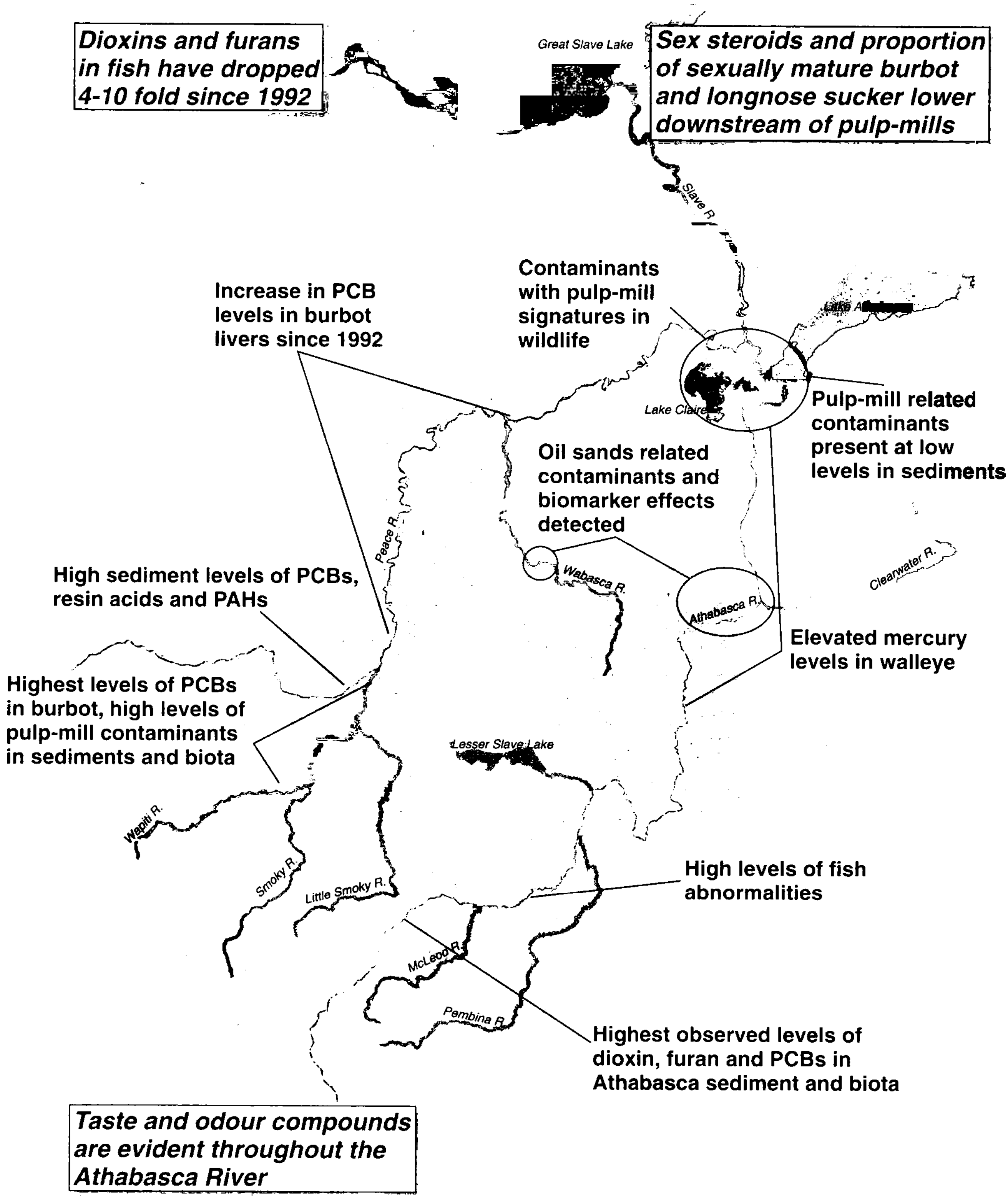
In contrast to the observed pattern for mercury, there is some evidence to suggest a downstream increase in metallothionein (MT) levels in fish, particularly burbot. High MT tissue concentrations also occurred in burbot collected from the Slave River Delta.

Figure 14 summarizes the key contaminant issues and findings on a basin-wide scale.

- **Cumulative Effects of Changes in Hydrology and Climate**

Understanding the cumulative effects of flow regulation and climatic variation for the Peace River ecosystem presents a complex challenge. Regulation has changed the natural hydrograph of the Peace and Slave River systems. Effects are most pronounced immediately downstream from the W.C. Bennett dam and diminish with river distance. Winter flows have been

Figure 14: Summary of Key Contaminant Issues and Findings on a Basin-Wide Scale.

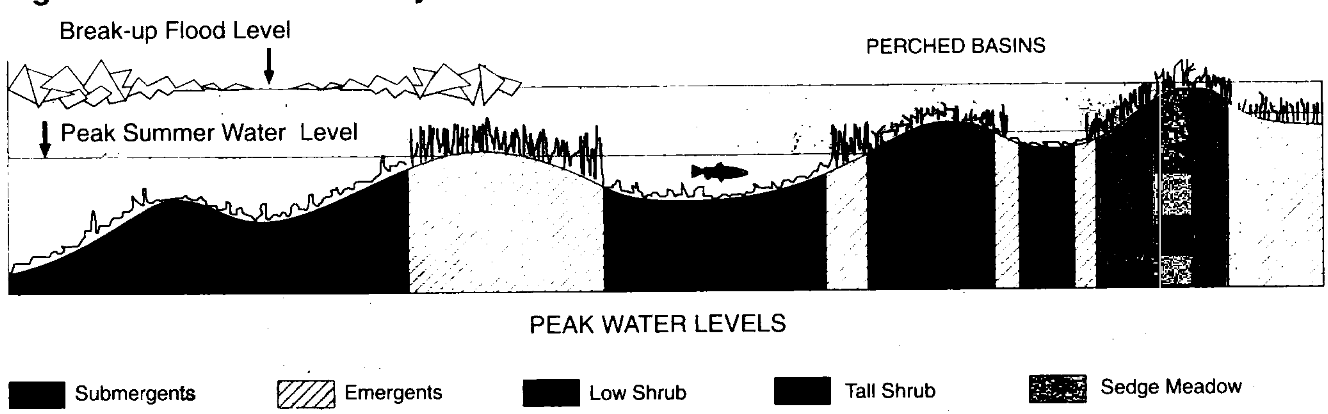


accentuated and summer flows diminished as water is placed into storage in the reservoir. In addition, thermal alterations caused by the warmer water releases from the reservoir now keep the Peace river ice-free most of the winter as far as the town of Peace River. Downstream of Peace River, ice formation occurs later in the year, at higher stage, and involves a change in the quality of ice. This is confirmed by aboriginal people who have observed the higher staging and generally poorer quality of ice.

Vegetation encroachment into the Peace River channel (Photo credit: M.Church)

Peak flows important to the rejuvenation of riparian habitat and to the natural scouring of the river channel have been significantly reduced immediately downstream of the dam. Flooding of the Peace-Athabasca Delta (PAD), historically a regular event, has been virtually eliminated since the construction of the dam. The elimination of regular ice-jam flooding has had a profound influence on the ecology of the PAD and the people who depend on the Delta for subsistence living. The drying up of the channels, perched lakes and marshes has directly affected fish ecology: both wintering and spawning habitat have been altered or lost. The physical structure of the delta and mainstem has been changed by the formation of new sand bars and related habitat. Delta lakes formerly supporting high densities of wildlife, including muskrat, are now dry. Birds have shifted their migratory patterns westward perhaps in response to improved feeding opportunities in the agricultural areas but also because of the significant reduction in breeding and staging habitat in the delta. The observed decline of wood bison in the PAD is implicated by the aboriginal people as being a result of drying in the delta. Corresponding successional changes in plant communities resulting in increased willow and forested areas, along with a reduction in sedge meadow habitat, are believed to provide more moose habitat at the expense of bison habitat.

Figure 15: Plant Community Structure in Perched Basins (from Prowse *et al.*1996).



Climatic variation has complicated flow issues since recent reductions in tributary snow pack have reduced the volume and timing of peak tributary flows entering the Peace River. The reduction in tributary flow further reduces the probability of ice-jam formation and consequent overland flooding of the deltas. Conversely, these tributaries now make a greater relative contribution to summer flows in the Peace River because of the retention of water by the dam.

The cumulative effects of flow regulation and climatic change have had profound impacts on the ecology and peoples in the Peace basin. During the winter months, higher water levels during freeze-up serve to cap areas with ice which might have otherwise remained open. While not directly assessed by NRBS, this has the potential to affect over-wintering areas for fish by removing natural areas of re-aeration. Increased river winter flows may remove natural barriers to fish movement. Again while not quantified, there is a re-occurring observation by the people who live along the Peace River that the abundance of fish has declined. Changes in flow and sediment transport regimes has influenced channel morphology and associated in stream and riparian habitat. For instance, vegetation encroachment and changes in plant communities along the river banks are evident from satellite imagery and confirmed by traditional knowledge in the Fort Vermilion and Fox Lake areas. Within the river channel, sand bars are developing during the open water period and vegetation is being established in some of these new sedimentation zones.

Because human communities living along the river and delta depend on these systems for spiritual and cultural needs, subsistence, economic opportunities and transportation, it is not surprising that the alteration of the Peace and Slave River flow regimes would surface as one of the most important factors affecting their perspectives on the quality of the ecosystem. The quality of drinking water and the production of muskrat and other wildlife are inextricably linked to basin hydrology. In a cumulative context, the people in the lower end of the Peace River and in the PAD and Slave Delta have been most affected in social, economic, cultural and spiritual terms

Traditional knowledge has provided important insights into how fisheries habitat has been impacted by flow regulation. Some traditional fishing sites located along the mouths of creeks and rivers no longer exist. For example, the now dry "fish hole" on the Rat River, the lack of fish at the rapids on the Peace River below the Horse River, and the observed reduction in access to Delta spawning areas are all documented effects of alterations to flow regime in this area.

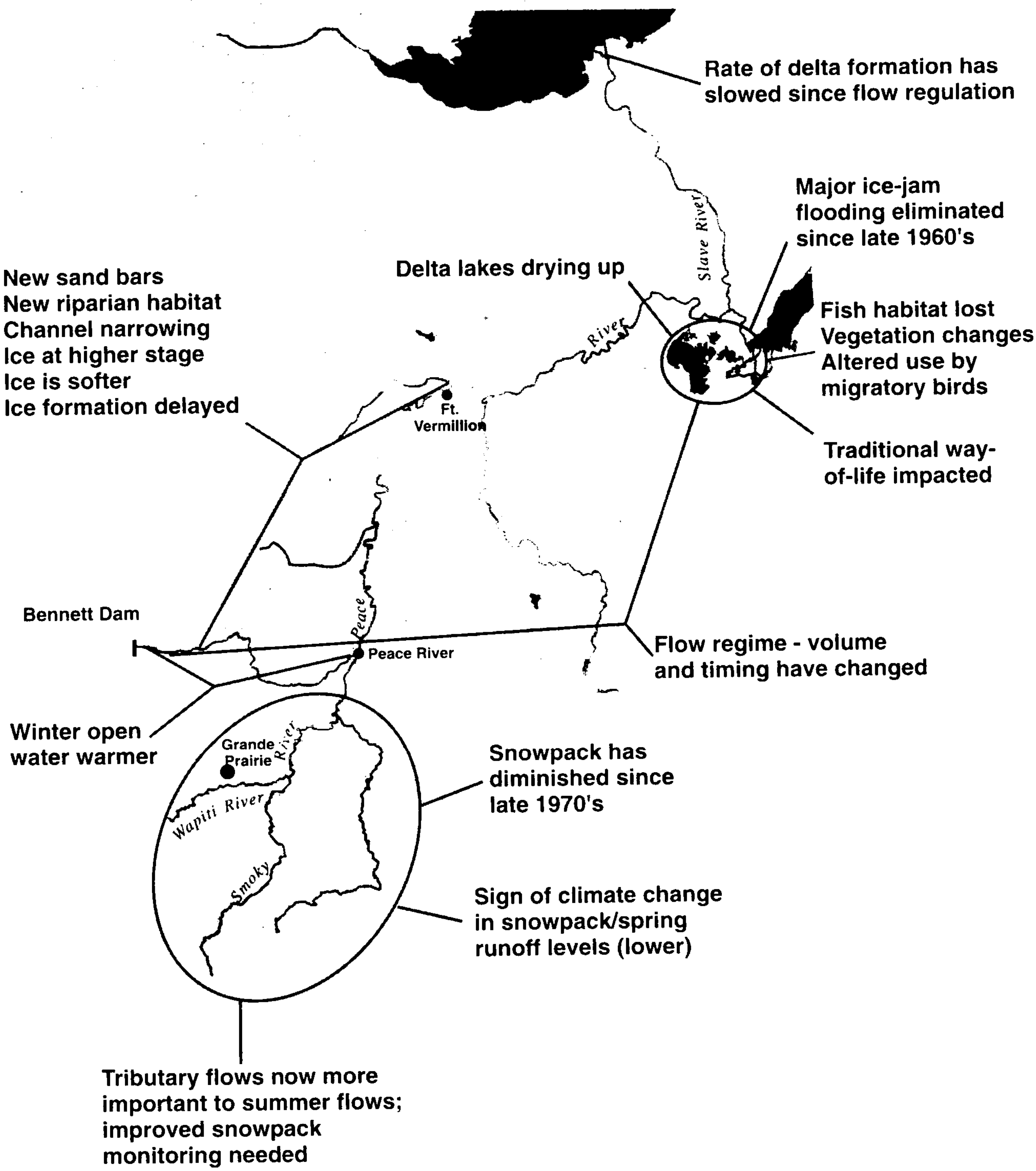
The increase in winter sediment loads and distribution is apparent in the observations from the communities of Fort Vermilion, Fox Lake, Fort Chipewyan, Fort Fitzgerald, Fort Resolution and Fort Smith. Increased turbidity in drinking water has been noted and this may indicate that the conventional drinking water treatment facilities may, at times, have treatment capacity and efficiency problems. Those who use the non-conventional sources of water such as surface water from the Peace, have also observed increased turbidities.

In summary, considering the weight of evidence from past studies and from the NRBS, it is apparent that the ecosystem has been altered by the cumulative effects of flow regulation on the Peace River and by climate variability (Figure 16). Although effects have been documented by both scientific research and traditional knowledge, the precise extent of the effects is not yet clear and requires further investigation.

- **Cumulative Effects of Nutrient / Dissolved Oxygen Stress**

Before considering the cumulative effects of nutrient additions and associated changes in dissolved oxygen, it is first necessary to understand and describe nutrient (Figure 17) and dissolved oxygen (Figure 18) dynamics independent of anthropogenic inputs. Northern rivers such as these are intrinsically oligotrophic (i.e., nutrient poor) and will experience reductions in dissolved oxygen levels during ice-covered periods. Nutrient additions from anthropogenic sources have two potentially important effects. First, they serve to "fertilize" the river, thereby increasing primary production (i.e., increased algal growth) with corresponding increases in secondary production (i.e., benthic invertebrates and fish). Secondly, this increase in

Figure 16: Summary of Key Hydrologic Issues and Impacts on the Peace and Slave River Basins.



biological (BOD) and sediment oxygen demand (SOD) and may ultimately serve to reduce dissolved oxygen levels during ice conditions when re-aeration is limited.

An additional complexity in understanding the effects of nutrient additions to these systems is the potential higher order effects related to nutrient-contaminant and nutrient-dissolved oxygen-contaminant interactions. Effluents containing nutrients could increase primary productivity and, consequently, food availability for fish and aquatic insects; however, these same effluents may produce contaminant effects and lower dissolved oxygen levels that separately or synergistically act as a stress to the biota. Cumulative interactions might result in a variety of observed endpoints, including a reduction in productivity, an increase in productivity, or a lack of change. In this example, the net cumulative effect on

Figure 17: Sources, Fate and Potential Effects on Aquatic Biota of Nutrients.

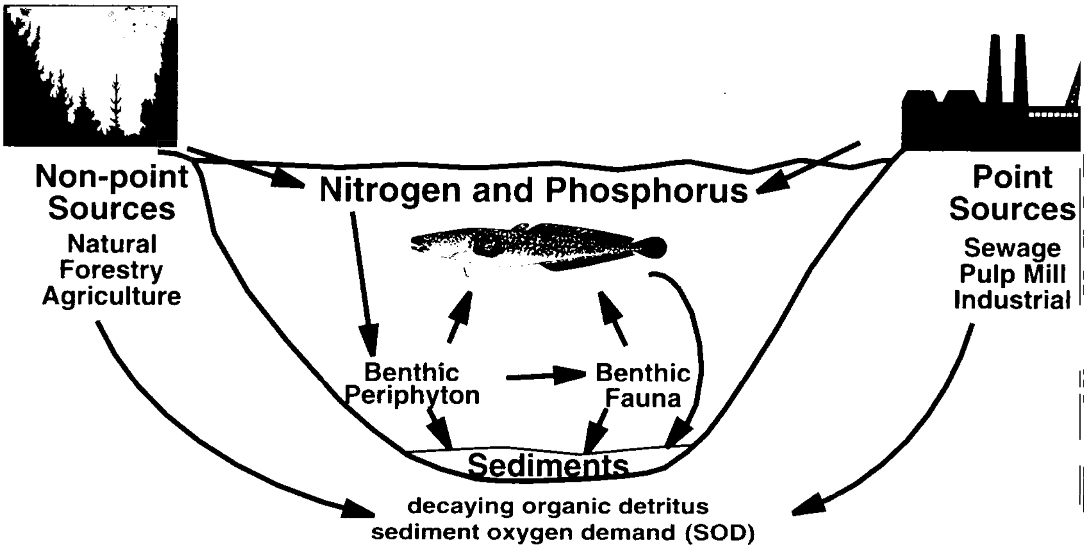


Figure 18: Sources and Effects of Low Under-Ice Dissolved Oxygen Levels on Aquatic Biota.

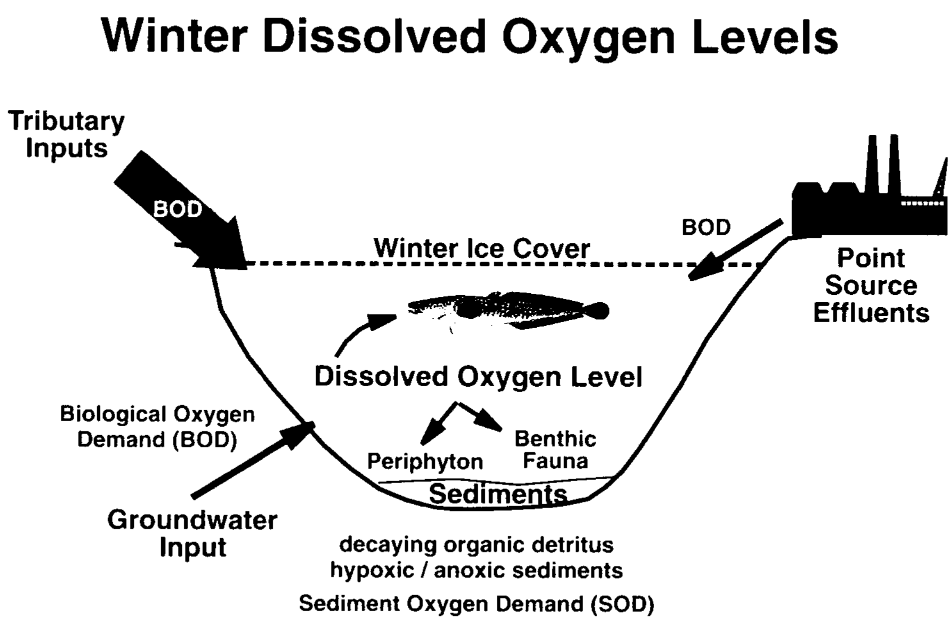
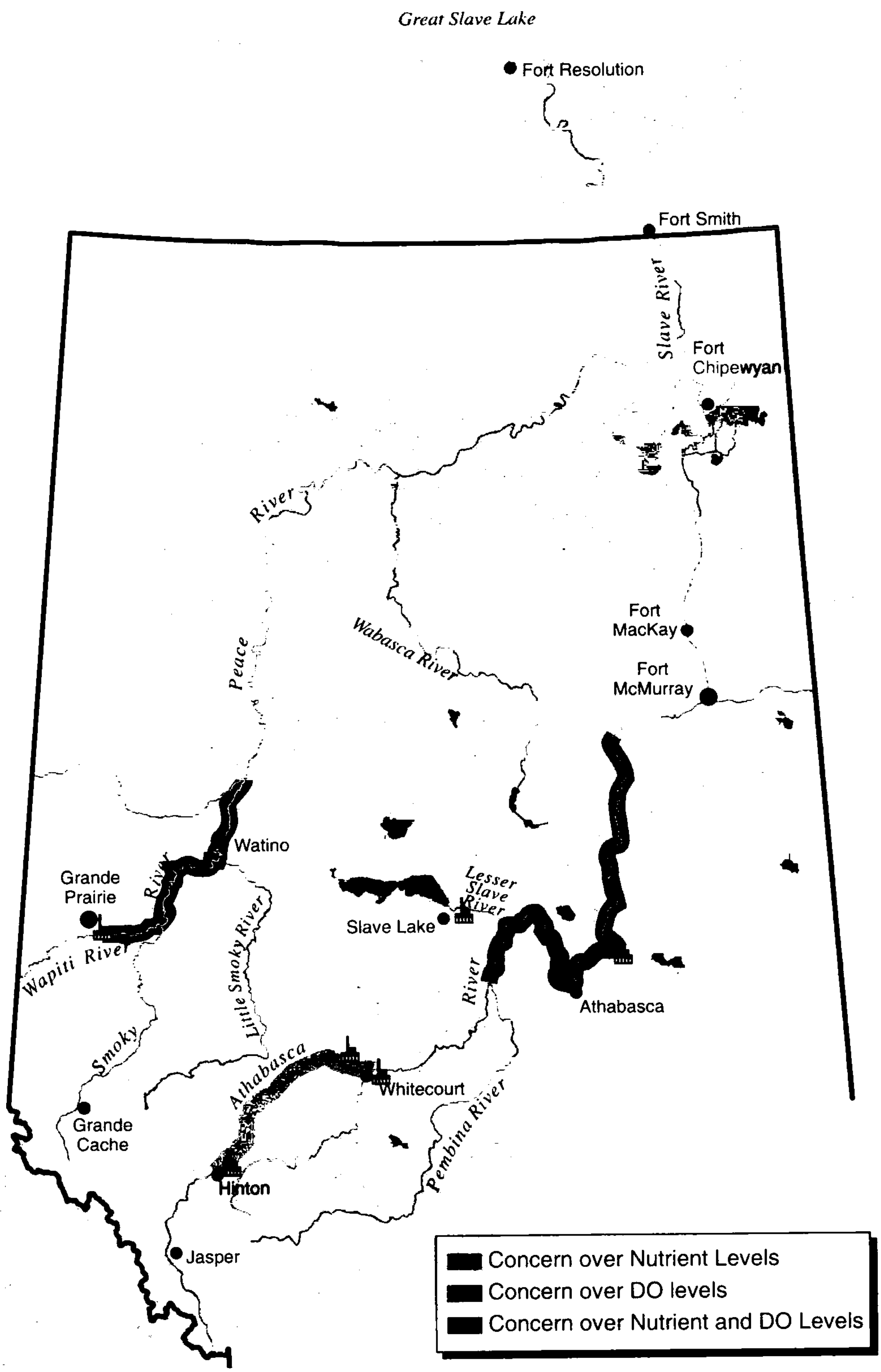


Figure 19: Zones of Concern With Respect to Nutrient / Dissolved Oxygen Issues.

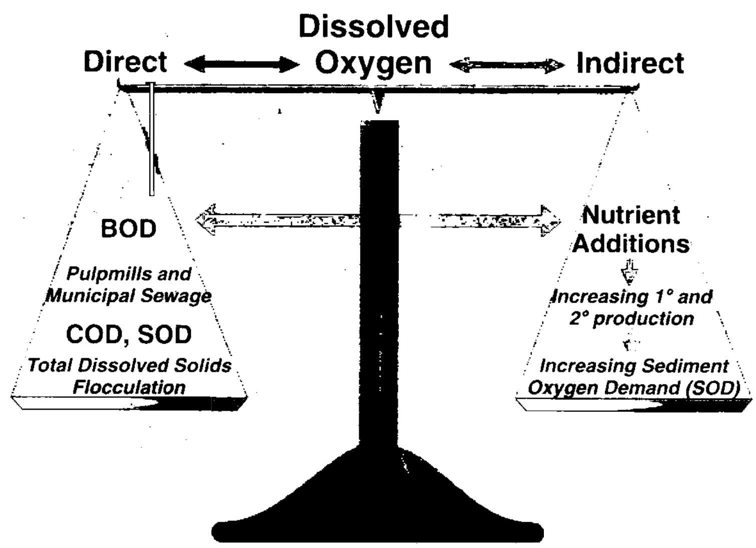


macroinvertebrate growth depends on the interaction between increased food availability as a result of nutrient addition and the depression in feeding rate caused by low dissolved oxygen levels resulting from the same nutrient additions.

Using a weight-of-evidence approach, the results of these studies indicate that while anthropogenic discharges to the rivers certainly affect nutrient limitation, observed increases in primary productivity were limited to reaches immediately downstream of major point source discharges. Given current levels of nutrient addition, the cumulative impact immediately downstream from point-source discharges appears to be primarily an aesthetic one (i.e., an increase in the amount of algae, or "green slime", on rocks downstream of discharges), and does not result in the loss of any macroinvertebrate or fish species, or in any reduction in overall production. It is important to note that while nutrient addition may result in increased algal growth other factors, including light and water temperature, will also limit primary production.

With respect to cumulative impacts from low dissolved oxygen levels, concern is focused on the ice-covered period because any oxygen consumed by oxygen-consuming effluent and river biological processes (BOD and SOD) and chemical processes (COD) cannot be replaced by re-aeration. In the Athabasca, Wapiti and Smoky rivers, DO concentrations decrease along the length of ice-covered river with sags in DO occurring below some pulp mill discharges in certain winters (Figure 19).

Figure 20: Linkage Between Nutrient Addition and Demands on Dissolved Oxygen.



Pulp-mills attempt to limit their contribution to reduced dissolved oxygen levels by adding nutrients to their treatment process thereby reducing BOD levels. NRBS has demonstrated that the addition of nutrients also serves to increase primary and secondary productivity and ultimately SOD, which could actually serve to further reduce dissolved oxygen levels. Since both increased BOD and SOD will result in lower dissolved oxygen levels, the challenge is to describe the link between nutrient additions and increased SOD better and to determine what level of nutrient additions simultaneously minimize both BOD and SOD so as to minimize the impact on dissolved oxygen levels (Figure 20).

One of the critical knowledge gaps identified by NRBS is the cumulative impact of continued, and probably increased loadings of nutrients from point and non-point sources. Can the river system continue to receive these nutrients loadings without suffering substantive effects on factors such as the aesthetics of the systems and related under ice dissolved oxygen levels? While the information obtained through the NRBS is not adequate to answer the question, the Study has identified the issue, furthered our knowledge, and provided direction for future investigation in this area.

- **Health of Aquatic Biota**

Fish health in the NRBS was assessed using a suite of biomarkers and measures of general condition. Of more than 23,000 fish examined in the three river basins (most of which were subsequently released), less than 1% showed evidence of external abnormalities such as tumours, lesions, scars, injuries, skin discolouration or deformities. However, higher incidences (27-60%) of such abnormalities were noted in specific reaches and below pulp-mills. Of particular concern was the higher incidence below Whitecourt in the Athabasca, and in the Wapiti-Smoky reaches.

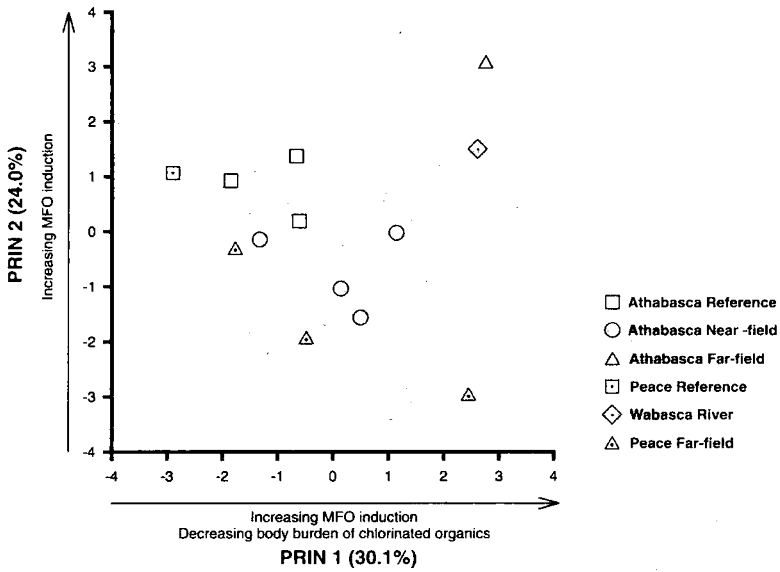
These observations are supported, in part, by the observed reduction in sex steroid levels in the these areas, and by the possibility of a higher frequency of sexually immature fish (burbot, longnosed sucker) in near field reaches below pulp-mills. However, there was no evidence linking lower steroid levels to reproductive development as measured by relative gonad size, egg size, or fecundity.

Traditional users report a decline in the quantity and quality of fish from the lower Peace and Athabasca rivers, and from the Peace-Athabasca Delta. These changes may be a consequence of any number of factors including: contaminant exposure, a reduction in the availability of critical spawning and rearing habitat (resulting from changes in flow regime and flooding frequency), and/or over-fishing.

The weight of evidence indicates that many of the fish in these basins exhibit signs of physiological stress. Of particular concern is the finding that sex hormone levels in burbot and longnosed sucker collected from near-field pulp-mill locations are significantly depressed, and that numbers of immature fish in these same locations are unexpectedly high and more likely to show external abnormalities. In addition, there is a perception that fish in the lower reaches of the Peace-Athabasca basins and in the deltas are of lower quality. Biomarkers have proven to be a valuable tool in assessing fish health; however, a better understanding of the quantitative and qualitative relationships between stress exposure, biomarker responses and ecological effects is required. For example, the relationship between observed depression in burbot sex steroid levels, the duration of that depression, and resulting fecundity is not known. Levels of depression observed in this study may serve as early warnings of future reproductive impairment or may represent physiological variation that has no reproductive consequences. Thus a better linkage must be established between biomarker responses and higher-level effects at the population and community levels.

Multivariate analyses were performed on burbot collected as part of the 1994 Basin-wide survey. This analysis simultaneously considered measures of general condition, biomarker response and contaminant burden. Results of this analysis are presented in Figure 21 and reveal several interesting trends. The first axis represents increasing levels of MFO induction and decreasing levels of dioxins and furans. Interestingly, this result indicates that dioxin and furan levels are not strongly associated with increased MFO induction, at least with respect to this sample. It is apparent that most sites, regardless of their position relative to pulp-mills, group together in ordination space. This suggests that when all burbot traits are considered simultaneously, variation in those traits cannot be explained by sampling location. In other words, while certain traits (e.g., sex steroids) may vary consistently across reference, near-field and far-field sites, the same pattern does not hold when all traits (n = 10) are considered together. The three sites that do not cluster together are on the Athabasca River downstream of Hinton, a location that showed the highest levels of dioxins and furans and sites on the Athabasca River downstream of Ft. McMurray and on the Wabasca River, river stretches that pass through tar sands deposits positioned close to the surface. This observation confirms other lines of evidence indicating that the reach of the Athabasca River below Hinton and the tar sands area deserve special attention, and further reinforces the need for research into the linkages between contaminants (i.e., dioxins and furans), biomarker response (i.e., MFO induction) and ecological response (i.e., changes in fecundity, growth and survival).

Figure 21: Principal Component Analysis on Burbot (1994 Collection). Prin 1 and Prin 2 represent the first and second principal component axex respectively.



While NRBS did not address in detail the availability of critical fish habitat, particularly in the mainstem sections of the rivers, it has determined that fish habitat availability in delta areas has been affected by changes in flow regime and flooding frequency. These changes have reduced the availability of flooded spawning habitat in the spring and have reduced access to certain lakes and tributaries in the delta area. Upstream of the deltas, many fish species spawn primarily along the smaller tributaries. Stable isotope analyses reveal they may rely on carbon sources generated in tributary basins. However, spawning and rearing and foraging habitat is found along most stretches of the mainstem rivers and is vulnerable to changes induced by anthropogenic inputs to these systems. Of particular importance is the need to ensure adequate under-ice dissolved oxygen levels to spawning and over-wintering habitats in the Wapiti-Smoky rivers and in the Athabasca River between Whitecourt and Grande Rapids as these areas are susceptible to further reductions in under-ice dissolved oxygen levels resulting from pulp-mill activities. As discussed in Section 2, lower dissolved oxygen levels have been shown to affect development rates in fish eggs and larvae and behaviour and survival in selected macroinvertebrates.

As with fish, the primary cumulative effects on benthic macroinvertebrates appear to occur in the areas immediately downstream from pulp-mill and municipal discharges. Measures of benthic macroinvertebrate community structure in the areas immediately above and below pulp mills indicated that while communities did not differ in terms of major taxa, there was a tendency for downstream communities to show higher diversity and density. This is most likely a consequence of nutrient enrichment, an observation supported by artificial stream experiments that demonstrated enhanced macroinvertebrate growth as a consequence of nutrient exposure and an absence of significant contaminant effects from pulp-mill effluents.

Results of ecotoxicological studies showed that in general, sediment-related toxicity was virtually non-existant for the classes of macroinvertebrates tested. An exception was observed in the Emerson Lake reach of the Athabasca river where oligochaete (aquatic worms) fecundity was reduced and macroinvertebrate contaminant body burdens exceeded CCME guidelines. This is also the reach identified by the sediment-transport model as a primary location for the deposition of flocculated material contained in the Weldwood pulp-mill effluent. In addition, chironomid (midge larvae) analyses revealed a possible increase in the frequency of morphological deformities immediately downstream from the Weldwood pulp-mill at Hinton (the only mill tested). These data provide further evidence indicating that the Athabasca river reach between Hinton and Whitecourt has suffered ecological impacts.

IMPLICATIONS FOR HUMAN USE

Given their position in the ecology of these basins, understanding the effects of ecological stressors on humans is an integral component of cumulative effects assessment. The extent of human-related cumulative effects is as much a function of public perception and cultural/spiritual values as scientific evidence. To explore more fully and quantify public perception, the NRBS, through the Traditional Knowledge and Other Uses Components undertook extensive surveys of community and stakeholders' views. The resulting databases identified concerns and provided insights in perceived changes in these systems. To be clear, NRBS did not conduct a human health study but through its linkages with the Alberta Northern River Basins Human Health Study, scientific data provided by NRBS are now actively incorporated into a companion initiative that has the specific mandate to assess human health. Consequently, our discussion of cumulative effects focuses on how aquatic resource use by people living within the basins has been altered by cumulative environmental stress. A discussion of how flow alteration has impacted use is provided in the previous section.

In general there is agreement between the scientific research and the general public perception of the state of these basins. Most agree that the upper reaches of the Peace and Athabasca systems while affected by anthropogenic activities on a local (reach) scale, as a whole remain relatively unchanged. In these areas both scientific and public concerns relate to localized impacts and the need to preserve and maintain the ecological integrity of these reaches. In contrast, the lower reaches of the Peace and Athabasca rivers and particularly the PAD and Slave River Delta are perceived to have been more severely affected, both because of alterations to flow regime and because of their position downstream from most point and non-point source discharges. Although public concerns varied across communities, concerns related to drinking water quality and fish health were common to most.

Box 32: Drinking Water Concerns

- **treatment efficiency at plants serving populations less than 500**
- **drinking water withdrawn from below pulp mills and oil sands (taste and odour)**
- **aesthetic and microbial issues dominate**
- **trihalomethane levels in drinking water resulting from chlorination**
- **non-conventional treatment methods (efficacy)**
- **training of treatment plant operators**
- **monitoring and response time to identified problems**

Cumulative impacts on drinking water quality relate to the general quality of raw drinking water including the concentration of anthropogenic and microbial contaminants and the efficacy of water treatment procedures. NRBS scientific evidence and an assessment of the Canadian Drinking Water Quality Guidelines indicate that contaminants in drinking water are not a public health issue at this time. The only exception to this concerns the formation of trihalomethanes, a by-product of chlorinating (disinfecting) drinking water containing organic substances, often, but not necessarily, associated with coloured waters (see Section 2). Public perception is that drinking water from the rivers below the pulp mills is tainted by pulp mill effluents. NRBS has confirmed this perception and found that tainting substances (e.g. phenolic compounds) can be detected for hundreds of kilometers below point sources. While such tainting poses an aesthetic problem requiring further investigation, we understand this is not currently a human health concern.

The NRBS also determined that microbial contamination of drinking water represents a greater threat to human health than does chemical contamination. Microbial contamination can result in digestive problems, intestinal discomfort and dermal diseases. Most of the basins residents are served by excellent quality water. Those that are not, tend to be in small communities of less than 500 and/or rely on non-conventional water supplies (Figure 22). These people have a moderate to high risk of encountering microbial contaminated water. The level of risk is highly dependent on the operational efficiency of small water treatment plants and on an individual's method of treating raw water. Other water quality issues relate to coal mining and the dispersion of coal dust in the upper Smoky River and to increased sediment loading and turbidity in the spring run-off period.

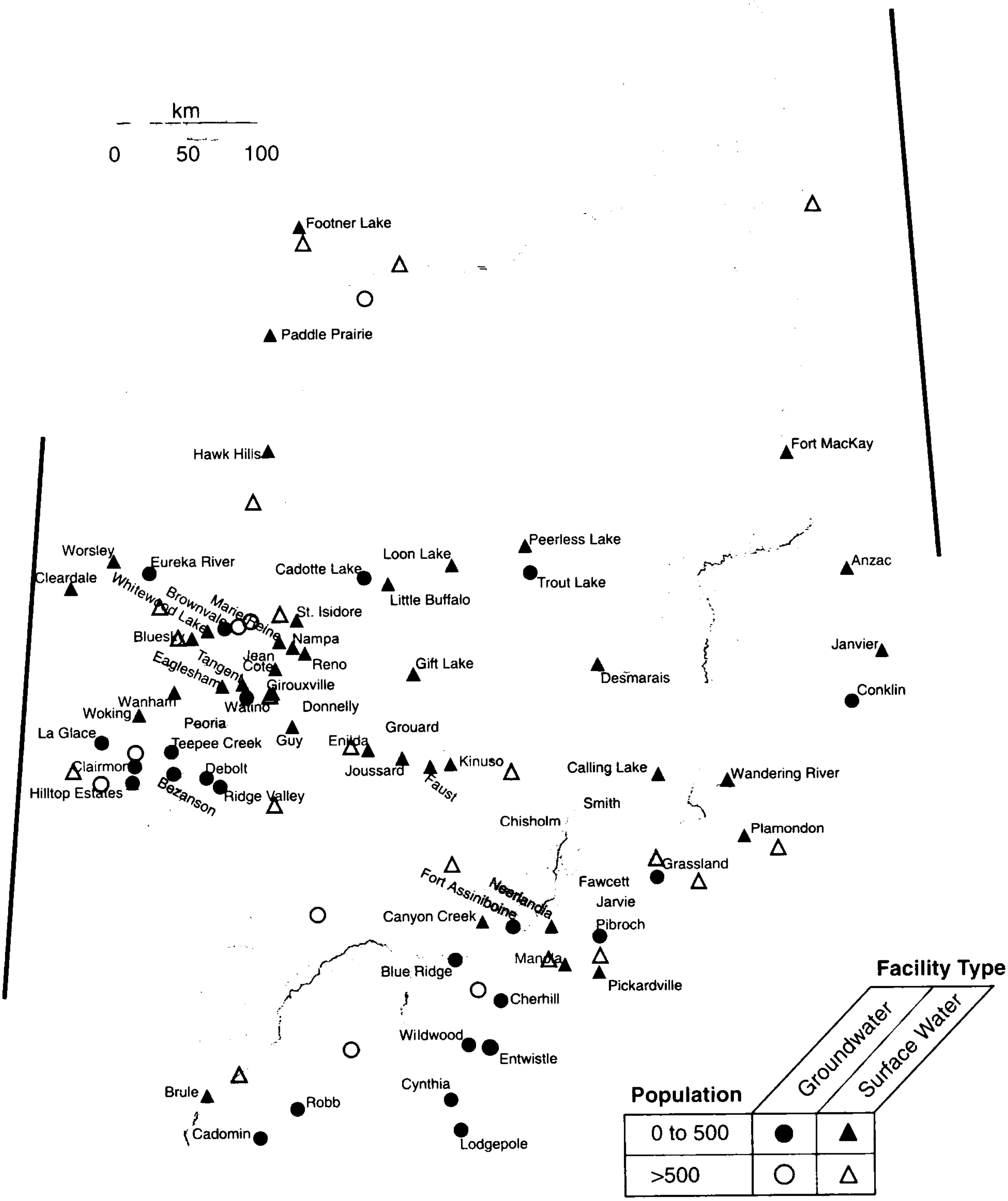
People who live at the downstream end of the Peace, Athabasca and Slave River systems have also repeatedly indicated they are the ultimate recipients of pollution originating from upstream developments. The evidence obtained by NRBS confirms that dioxins, furans, PCBs, phosphorous and other chemicals are transported downstream; however, the extent of their movement, their ultimate distribution and concentrations depend on the specific chemistry of the contaminant and several environmental factors. Analyses of sediments collected from Lake Athabasca and Great Slave Lake confirm the occurrence and long-range transport (both aerial and riverine) of chemicals and serve to document developmental changes occurring in the basins. More importantly, these chemicals contain signatures unique to upstream pulp-mills, confirming that such mills contribute to the cumulative contaminant loadings in distant areas of the basins.

Of particular interest to the aboriginal people of the basin is the quality and quantity of fish and wildlife they consume and how these might be affected by contaminant exposure and changes in land use patterns. To assess the potential for residents in the delta area of exposure to high levels of contaminants, NRBS examined the level of several contaminants in wild foods including fish, waterfowl, muskrats and mink. Fish from the Peace-Athabasca Delta collected by people living in the delta were tested and found to have non-detectable to barely detectable levels of 2,3,7,8-TCDD and TCDF, and levels of mercury in muscle below the commonly used Canadian guideline. An exception is found in the case of walleye which in several locations in the lower Athabasca displayed mercury levels that exceeded this Canadian health consumption guideline. The highest levels of mercury recorded in the basins were in bull trout collected from Williston lake. Contaminants in fish, waterfowl, muskrats and mink were similarly absent or barely detectable.

However, we stress that there is virtually no information in the scientific literature that allows us to identify potential long-term implications to human or ecological health caused by ongoing exposure to low levels of any of the contaminants studied. This is of particular concern among populations such as these that traditionally consume large quantities of fish and other wildlife on a regular basis, indicating a need to reassess the health consumption guidelines.

It was outside the scope of this study to investigate and quantify the combined effects of perceptions and scientific evidence of contamination on the health of people. From community to community, especially in the lower part of the Peace, Athabasca and Slave River Basins scientists and Board members were reminded that the entire diet of the Indian peoples has changed, in part, a direct result of the perception that fish and other wildlife were contaminated and unfit for consumption. The adjustments made to their diets must be assumed to have health implications. The NRBS databases include numerous references linking diet changes to human health. NRBS has provided a comprehensive record of perceptions of several generations of peoples including Elders that could serve as a foundation for future investigations in this area.

Figure 22: Drinking Water Sources in the Northern River Basins.



■ SUMMARY OF CUMULATIVE EFFECTS: BY RIVER REACH

As shown in the Key Findings and Cumulative Effects Assessment sections of this report, cumulative environmental effects manifest themselves at a variety of spatial, temporal, and organizational scales within the ecosystem. Although it is important not to lose sight of cumulative effects occurring at a basins-wide level and the inter-relatedness among river reaches, we now summarize our understanding of cumulative impacts on a reach-by-reach basis. This approach provides the opportunity to focus on characteristics which are unique to reaches and identify related management considerations. A summary of scientific findings is provided, as is a social perspective which was developed from input obtained at community gatherings, science fora, and through the household and traditional knowledge surveys. In addition to the individual the reach profiles, a basin-wide profile is included to highlight those factors that apply throughout the basins.

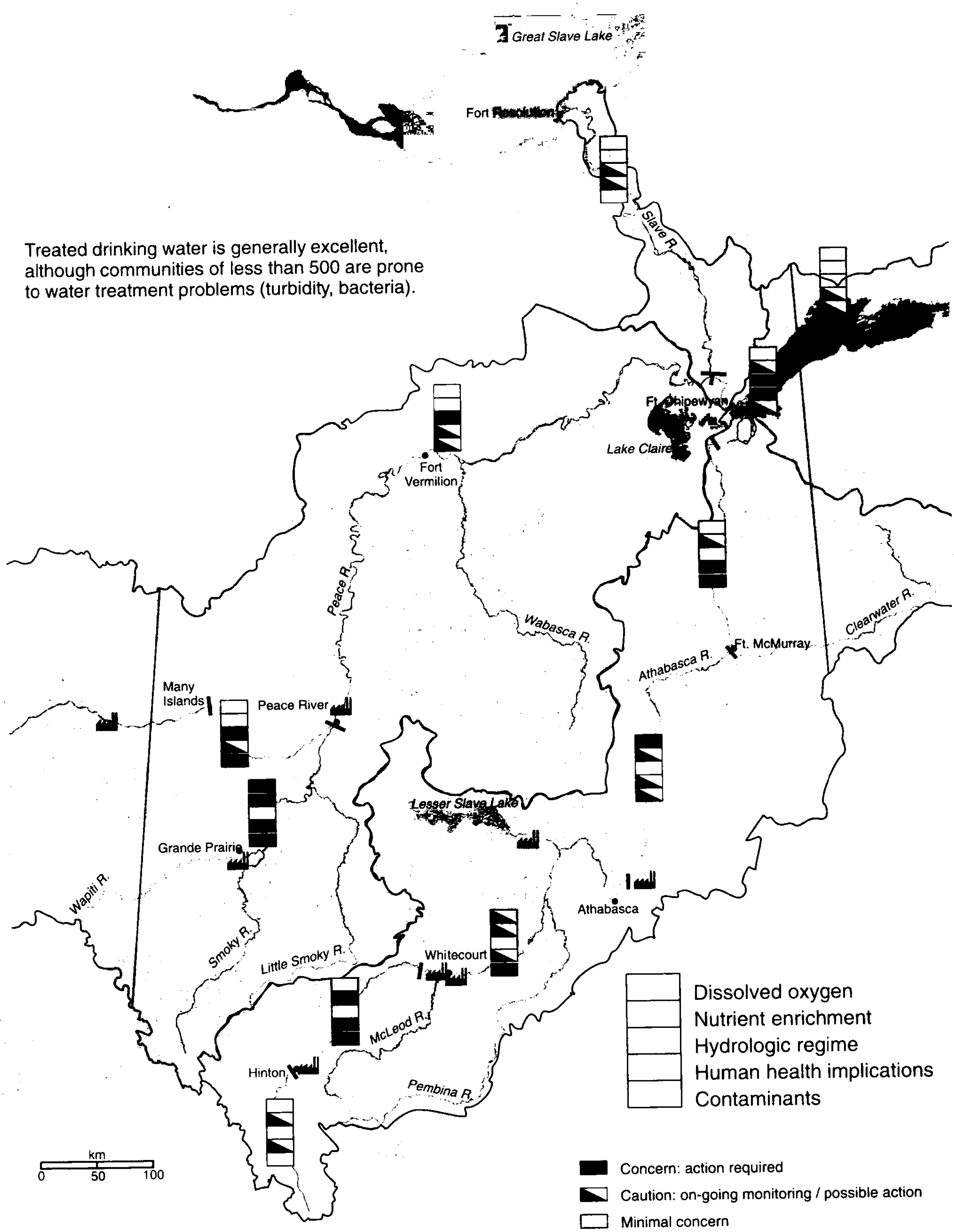
While this summary is inclusive of NRBS and companion investigations, we remind the reader that investigation of some facets of the ecosystem including: climate change, agricultural practices, forestry management, biodiversity and human health were beyond the scope of this study. While these issues were not investigated directly, they will almost certainly have implications for cumulative effects within the basins and should not be ignored in any future ecosystem management program.

As well, because of the higher level of industrial pressure, primarily existing pulp mills, the NRBS science program placed a greater emphasis on the Athabasca River than on the Peace and Slave rivers. The reader is therefore cautioned that not all issues were equally investigated in all reaches, reflecting perceived impact priorities at the outset of NRBS. Issues not investigated (e.g., nutrient enrichment studies on the Peace River), should not be interpreted to mean that these issues are not important, rather they reflect the research and funding priorities of the NRBS.

Figure 23 summarizes overall cumulative effects with the Northern River Basins on a reach-specific basis. This figure provides a mechanism for illustrating priority areas for environmental management and identifies issues of concern based on a weight of evidence approach. Within each reach a histogram, consisting of five stacked boxes, is provided. Each box represents one of the five major issues in the basins (i.e., dissolved oxygen, nutrient enrichment, hydrologic regime, human health implications and contaminants) and the shading of the box reflects the level of concern for that issue in that reach. A completely dark box indicates significant concern and a need for action. A partially shaded box indicates caution and a need for ongoing monitoring and/or further investigation. A clear box indicates that, based on current information, the issue is of minimal concern. In most cases ongoing routine monitoring should be adequate for those issues designated as being of minimal concern; however, further investigation may result in a change in designation for some of these issues. The reader is referred to the Recommendations Section of this report for further information concerning recommended response to those issues designated as being of concern and requiring action as well as those requiring ongoing monitoring and/or further investigation. More specific recommendations provided by the various Study Components are given in Appendix 2.

The purpose of Figure 23 is to provide a general overview of cumulative effects in these basins. A more detailed description of these effects is provided on a reach-by reach basis in the following section. The histograms presented in Figure 23 are provided again in this section along with the criteria and rationale used to determine the levels of cumulative effects concern.

Figure 23: Summary of Cumulative Environmental Effects.



BASIN-WIDE

Scientific Summary

The basin-wide fish surveys and other fish collections by NRBS have confirmed that dioxins and furans occur in the food web at low levels across the basins, relative to other areas in Canada. The highest detection frequencies for all 2,3,7,8-substituted dioxin/furan congeners were observed immediately downstream of bleach kraft mills. NRBS corroborates other investigations which have reported a recent decline in concentrations of dioxins and furans in fish, commensurate with improvements in pulp mill treatment technologies. Although there is evidence of PCB contamination in both the Athabasca and Peace river systems, PCDD/Fs, rather than PCBs or organochlorine pesticides, are the chemicals of concern for human exposure. Levels of TCDD and TCDF, the major contributors to toxicological concerns in these groups of compounds, are expected to decline further because of technology improvements. Low level contribution of several contaminants from the atmosphere have been demonstrated by NRBS. Fish health investigations have raised concerns about exposure of fish to contaminants, hormone disruptors and the proportion of sexually immature fish. The vulnerability of fish to anthropogenic contaminants remains uncertain because of the general deficiency of information on fish ecology within the basins. However, the level of knowledge for larger fish in the Slave River basin is good.

Natural sources and processes contribute to some of the perceived environmental problems e.g., mercury levels in fish, eutrophication, low dissolved oxygen, taste and odour of drinking water, hydrocarbons and turbidity. The primary human health concerns related to contaminants need to be assessed by health authorities, and include dioxins, furans and mercury in fish, and trihalomethanes and bacteria/pathogens in treated drinking water (especially in communities of less than 500). Dietary information (e.g. fish consumption) obtained as part of NRBS should be useful in reviewing health implications. Science findings to date do not establish thresholds related to ecosystem health or to pollution loadings. There is a lack of long term monitoring data related to contaminants in edible fish tissue.

Enrichment of river reaches below pulp mill and municipal sources is observable and quantifiable. It is recommended that nutrient regulations should be developed which are ecosystem based, not technology based.

Hydrologic regimes influence the state of aquatic ecosystems. The ecology of the Peace-Slave river-delta systems are particularly vulnerable on account of the Bennett Dam. The quality of the Athabasca River ecosystem, although not influenced significantly by river impoundments, is highly influenced by natural variability of flows coupled with the use of the river for handling treated effluents. Climate variability is potentially a factor in explaining some of the water issues in the deltas but more research is required to expand on the NRBS findings.

The ecological knowledge of traditional peoples is highly relevant and valuable to understanding the behaviour and distribution of wildlife, ecosystem functions and ecosystem responses over space and time.

Current monitoring in the basins is not designed to address cumulative effects assessment needs. There remain inconsistencies across agencies with regard to scientific design, collection-analysis-data handling/storage and reporting protocols that would benefit from coordination, integration and standardization.

Societal Perspective

Overall, the public recognizes the high quality of water within the northern basins and their uniqueness relative to other areas of Canada and the world. For this reason, the public favour tight controls to protect this asset over the long term. They are however concerned about the contaminants from industries and they frequently perceive fish and water to be unsafe to consume. Fish are a valued resource of the basins. As indicators of ecosystem integrity, society has indicated the need to protect fish health, population, distribution, migration and spawning behaviour and critical habitat. The public surveys of NRBS clearly reflect a need for public involvement in the decision making affecting the sustainability of the basins' resources as well as a role in the monitoring of ecosystem health. There appears to be a general lack of public trust for industries to self-regulate and conduct their own monitoring. Management philosophies of no further degradation and zero discharge frequently surfaced in community discussions.

Key Management Considerations Applicable to all Basins

- Adoption and application of risk assessment approaches to pollution prevention and ecosystem protection
- Reach-specific aquatic ecosystem guidelines to guide pollution prevention including regulatory control of nutrients
- Effects of persistent low and bioaccumulative dioxins, furans and mercury in fish throughout the basins
- Quantification of natural versus man-made sources of contaminants
- Non-point source pollution: land use, landfills, and atmospheric deposition of remotely derived contaminants
- Effectiveness of drinking water treatment systems in small communities; trihalomethanes in most supplies
- Biology and life cycle of fish species and critical habitats
- Public consultation, involvement and education, information management, and multi-agency coordinated monitoring

ATHABASCA RIVER: Athabasca Falls to Hinton

Scientific Summary

Dissolved Oxygen	Naturally high
Nutrients	Enrichment is evident immediately below the town of Jasper
Hydrologic Regime	Natural flow conditions; effect of deforestation outside the park is unknown
Health Implications	Human health guidelines for fish consumption may be exceeded
Contaminants	Dioxins, furans and mercury in fish

The Athabasca River between Athabasca Falls and Hinton reflects a unique river/tributary system (e.g., Snaring, Snake-Indian, Rocky rivers) which is vitally important to the survival of the remnant pygmy whitefish population and the spawning movement of mountain whitefish, bull trout, and lake whitefish. Because of large populations of mountain whitefish that spawn in these areas major habitat disruptions could have significant impacts on these species. NRBS has reported that lake whitefish likely spawn on the mainstem in the area upstream of Jasper Lake. Fish containing contaminants associated with downstream developments are known to seasonally frequent the waters of Jasper National Park. Sources of pollution in this reach are mainly municipal. Nutrient enrichment below the townsite of Jasper is readily evident in the river by the increased abundance of algae, the main impact of which appears to be on the aesthetic/recreational value of the river. The potential effects of contaminants from landfill sites have not been investigated nor have the effects of deforestation.

Societal Perspective

Public views expressed at community gatherings, science fora, past public hearings, and views expressed by the Study Board members would suggest that this reach is generally viewed as being pristine and deserving of a high level of protection. The presence of a National Park in the headwaters of the river is seen as providing a high level of protection by virtue of its non-degradation policies. Concerns were expressed about the air emissions from the Weldwood of Canada Ltd. pulp mill and respiratory diseases as well as the impact Jasper effluent is having on the Athabasca River.

Key Management Considerations Unique to Reach

- Fish spawning habitat and protection of fish stocks aggregating near mouths of tributaries
- Threatened populations of pygmy whitefish and bull trout
- Ecological effects of Jasper townsite effluents and of active and abandoned landfill sites
- Land clearing downstream of Jasper Park and its interactions with the aquatic ecosystem including flow regimes

ATHABASCA RIVER: Hinton to Whitecourt

Scientific Summary

Dissolved Oxygen	Naturally high although a sag occurs immediately below Hinton in certain low flow years
Nutrients	Non-limiting: Enrichment evident immediately below Hinton
Hydrologic Regime	Natural regime; influence of deforestration is unknown
Health Implications	Consumption of fish (mercury, dioxins/furans); drinking water taste and odour
Contaminants	Contaminant levels in sediment/biota; fish abnormalities, depressed sex steroids, sexual immaturity

The quality of water entering this reach is generally excellent (natural) but deteriorates upon receiving effluent from the City of Hinton and the Weldwood of Canada Ltd. pulp mill. With the addition of the Hinton combined effluent (HCE) there is evidence immediately downstream of nutrient enrichment in the benthic community, but no evidence in this community of acute toxicological effects; certain contaminants e.g., dioxins, furans, PCBs and mercury, are bioaccumulated in the aquatic food chain. Depressed steriods in fish have been observed as has, what appears to be, abnormally high ratio of sexually immature to mature fish relative to reference locations.

The highest levels of contaminants in sediments of the Athabasca River exist in this reach, specifically below the pulp mill to below Emerson Lakes. The HCE was found (1992/93) to have the highest levels of TCDD/F of any effluents sampled on the Athabasca River. All mean levels of TCDD (and their toxic equivalents) in fish muscle or liver were below the Health Canada limit for commercial fish sale. A few individual fish tissues, mainly burbot liver, downstream of Hinton, exceeded the 20 pg.g-l guideline.

Tainting compounds (chlorophenolics) are introduced by the effluent, and affect the palatability of water. In 1992/3, odour causing compounds from Hinton were detected 1200 km downstream indicating the large spatial influence of the effluent. In the 1994 survey, Hinton-related odours, although present, were not distinguishable from other influences such as from Alberta Newsprint and Millar Western pulp mills at Whitecourt.

Biomarkers, bioindicators and gross pathology indicate sub-lethal influence of contaminants in this reach. The frequency of deformity is above background exist in the chironomid community below Hinton.

Relative to elsewhere in Canada, this reach is considered to be lightly impacted by contaminants but the implications of long-term exposure to sub-lethal concentrations is still unknown.

Although dissolved oxygen is not an issue in the reach, the cumulative effect of the HCE and sources in the next river reach combine to become an issue further downstream. As with all mills, there is a concern that mill effluents can, under extreme hydrologic conditions of low flows and high summer temperatures or winter ice cover, deplete oxygen to levels where the instream and/or streambed dissolved oxygen levels may threaten various life stages of fish and other biota.

Societal Perspective

Public input at community gatherings, science fora, from past hearings, and from household surveys suggest that this reach is generally viewed as being impacted by the HCE. Public opinion seems to favour tighter effluent regulation and monitoring and public views have included philosophies of zero discharge and "capping" of pollution loads. To many, no level of dioxins and furans is acceptable in effluents or the environment and the quality of the system is worth protecting from further degradation. Particular concern has been expressed about high levels of phosphorus from the HCE and the need for reduction to protect river water quality. The McLeod River has been identified as a water quality concern due to sewage effluent releases. Other concerns include: scum on surface water, garbage dumping along the river, pesticides, forestry (clear cutting) impacts, point source controls, impacts on song birds, use of chlorine, handling of toxic wastes, contamination of wildlife, and safety of drinking water

Key Management Considerations Unique to Reach

- Land clearing (forestry and agriculture) and aquatic ecosystem interaction
- Nutrient enrichment from Hinton to Whitecourt
- Contaminants (organochlorinnes) and others in fish and macroinvertebrates
- Ecological implications of low flows under ice, coupled with effluent loadings
- Health of aquatic life
- Fish use of critical habitat in tributaries (e.g., McLeod River)
- Influence of HCE effluent on river sediment processes

ATHABASCA RIVER: Whitecourt to Athabasca

Scientific Summary

Dissolved Oxygen	Oxygen sag below Whitecourt in some years
Nutrients	Non-limiting to confluence with Lesser Slave; trophic enrichment below Whitecourt
Hydrologic Regime	Natural regime; effect of deforestration is unknown
Health Implications	Human health guidelines for consumption of fish may be exceeded; drinking water taste and odour
Contaminants	Levels in fish and sediment; depressed sex steriods; incidence of fish abnormalities

The Athabasca River has naturally occurring low flows and low oxygen levels under ice conditions. The loading of organic wastes to the river are known to further reduce oxygen levels. Oxygen sags have been recorded under ice conditions immediately below Millar Western at Whitecourt. Since 1989, the minimum winter dissolved oxygen levels appear to have not fallen below 6.8 mg/L. A concern is the progressive longitudinal downstream decline in dissolved oxygen in the river until it is enhanced by the entry of the Lesser Slave River. The miminum mid water column level indicates that the oxygen level at the sediment-water interface could be as low as 4 mg/L. In order to ensure the survival of fish eggs and other biota, this level should not fall below 3 mg/L . The Pembina River displays naturally low oxygen levels during the winter and summer. Ground water is important to the base flow of the Pembina River.

The benthic community downstream of the town of Whitecourt is reflective of nutrient enrichment. The pulp mill practice of adding phosphate to encourage biological breakdown of organic wastes prior to release into the river should be reviewed and controlled

Coal development on the upper Pembina River was not investigated; fish collected from the lower Pembina River show unusually high metallothionein induction indicating possible exposure to metals in this system. Optimal mountain whitefish spawning habitat exists in this reach. Fish health is suspect in this reach based on a high incidence of abnormalities below Whitecourt pointing to the need for in-depth investigations of the causes. Levels of dioxins, furans, PCBs, chlorinated resins acids and chlorophenols in fish and/or sediments are lower than in the reach immediately upstream but tend to be highest below Whitecourt. None of the contaminants investigated were detected at levels thought to cause acute toxicology in aquatic life. Taste and odour compounds in the river improve longitudinally throughout.

Societal Perspective

Statements of concern from the public relate to issues arising during the AlPac hearings including: dissolved oxygen requirements of fish; fish quality and health; nutrient enrichment; dioxins and furans; drinking water quality; land use impacts; etc. Members of the public have identified the Pembina River as having nutrient, turbidity and dissolved oxygen problems. Other concerns include: deforestration effects on water quality, drainage of muskegs and wetlands, long term monitoring, edibility of fish, quality of fish, mink and other wildlife, abundance of fish, spills, sewage discharges, and effluent treatment.

Key Management Considerations Unique to the Reach

- Ecological effects (e.g., nutrient enrichment) caused by discharges from municipalities and pulp mills
- Management of dissolved oxygen levels (Whitecourt to Grande Rapids)
- Organochlorine compounds: dioxins, furans, chlorinated phenolics, resin acids and PCBs
- Health of aquatic life (e.g., abnormalities, depressed sex steroids, etc.) and use of the mainstem system by fall spawners downstream of Whitecourt
- Deforestration and its influence on hydrologic regimes and fish habitat

ATHABASCA RIVER: Athabasca to Fort McMurray

Scientific Summary

Dissolved Oxygen	Low winter dissolved oxygen; longitudinal decline in DO
Nutrients	Localized nutrient enrichment
Hydrologic Regime	Natural regime; effect of deforestration is unknown
Health Implications	Human health consumption guidelines for some fish exceeded; drinking water taste and odour
Contaminants	Naturally occurring hydrocarbons; mercury in fish; dioxins in municipal effluents

This reach includes the AlPac pulp mill near the town of Athabasca. Dissolved oxygen levels sag below the town of Athabasca and conditions in this reach likely reflect the cumulative organic loading from upstream sources. Based on NRBS research it is recommended that the provincial water quality objective for dissolved oxygen be increased to provide a greater safety margin for the protection of aquatic life.

The influence of oil sands deposits begin to show in this reach with the natural occurrence of PAHs and other organic compounds. Overall, concentration of organochlorine contaminants in sediments and biota decline throughout this reach relative to upstream sites.

Mercury was detected in all fish however the levels were highest in the larger-older fish, particularly walleye, a predator known to accumulate this contaminant. These results corroborate those which lead to the existing fish consumption advisories. The highest level observed was in walleye collected from above Grande Rapids.

Taste and odour compounds are evident in this reach originating from upstream pulp mills and possibly enhanced by municipal wastes. The synergistic effects of these and oil sands hydrocarbons remain unknown.

Critical spawning habitat for fish exists in the vicinity of Mountain and Cascade rapids upstream of Fort McMurray. Upwards of 1,000,000 lake whitefish (fall spawners) and large numbers of long nose suckers (spring spawners) that originate from Lake Athabasca spawn in this area. Walleye are also believed to spawn in this reach. Re-aeration of the river by Grande Rapids significantly improves the instream dissolved oxygen levels thus providing optimal conditions for whitefish egg development.

Societal Perspective

Statements of concern from the public relate to issues arising during the AlPac hearings including: dissolved oxygen requirements of fish; fish quality and health; nutrient enrichment; dioxins and furans; drinking water quality; and land use impacts.

Key Management Considerations Unique to the Reach

- Ecological effects of discharges from municipalities and pulp mills
- Nutrients enrichment below Athabasca
- Management of dissolved oxygen levels
- Organochlorine compounds: Dioxins, furans, chlorinated phenolics, resin acids and PCBs
- Health of aquatic life
- Natural and anthropogenic loading of hydrocarbons
- Taste and odour producing compounds (fish and drinking water)
- Guidelines for human consumption of fish

ATHABASCA RIVER: Fort McMurray to Peace-Athabasca Delta

Scientific Summary

Dissolved Oxygen	Natural
Nutrients	Localized enrichment below Ft. McMurray
Hydrologic Regime	Natural regime; effect of deforestation is unknown
Health Implications	Human health consumption guidelines for some fish exceeded; taste and odour in drinking water
Contaminants	Highest MFO induction; naturally occurring organics

This reach includes the massive oil sand complexes and the municipal effluent from Fort McMurray. Natural hydrocarbon seeps are evident along the Athabasca River and contribute PAHs and other hydrocarbons to the river. The effect of these hydrocarbons on the ecosystem have not been extensively investigated but NRBS has obtained presumptive evidence that suggests that naturally occurring substances may be responsible for the MFO inductions in fish. The Clearwater and Steepbank rivers also provided evidence of MFO induction. Further investigations into the causes of induction and its implications are required. Of the CTMP and STP effluents, the Fort McMurray effluent is the largest source of PCDD/Fs, based on concentration and discharge, to the entire river during a one-time sampling in April 1993.

These same oil sand sources with their associated metals may also be linked to higher metallothionein in the lower Athabasca River and this requires investigation as well. Recent evidence submitted by Suncor indicates that the cause of mercury contamination of the Athabasca River benthic community has been remediated. Preliminary benthic invertebrate data, also provided by Suncor, suggest that the problem has been cleaned up. NRBS did not investigate mercury levels in benthos in this reach. Mercury levels are high in large walleye in this reach of the Athabasca River. Human consumption advisories are in effect. Nutrient enrichment is apparent in the benthic community immediately below Fort McMurray reflecting the addition of the municipal effluent. Unlike the two reaches immediately upstream, dissolved oxygen is not an issue in this reach. The Clearwater River influences the flow and quality of the Athabasca River. NRBS research has confirmed that the Clearwater River and the municipal discharge from Fort McMurray contribute to increased productivity in the Athabasca River.

Taste and odour compounds are evident in this reach originating from upstream pulp mills. The synergistic effects of these and oil sands hydrocarbons remain unknown.

Societal Perspective

At public gatherings, science fora and through surveys, statements of public concerns included: the lack of involvement of traditional knowledge in decision making and local people in monitoring; pulp mills are contaminating and fouling our fish and drinking water; oil sand developments are affecting wildlife; fish populations have declined; river looks dirtier and there are more weeds now; applicability of consumption guidelines for fish containing high levels of mercury; little or no warning provided to downstream interests when spills occur; effects of contaminants on human health and way-of-life.

Other concerns expressed include: safety of tailing ponds and leachates, presence of carcinogens and linkages to human health, fish health and quality, drinking water quality, turbidity, taste and odour, hydrocarbon seeps, uncertainty in cumulative impacts and reliability of industry data. The Clearwater River is perceived as having become polluted in recent years and contain high levels of nutrients. Non-point source pollution was raised as regards the Clearwater River. Spill notification times and responses are a concern to citizens.

Key Management Considerations Unique to Reach

- Pollution prevention in light of downstream interests and cumulative effects
- Naturally occurring hydrocarbons and metals
- Nutrient management
- Health of aquatic life
- Long term management of oil sands tailing ponds, oil sands operational emissions and expanding operations
- Spill response: Timely response in reporting of municipal and industrial spills to downstream interests
- Wetland drainage and deforestation effects
- Tainted fish and drinking water

ATHABASCA RIVER: Peace-Athabasca Delta

Scientific Summary

Dissolved Oxygen		Natural
Nutrients		Some evidence of enrichment in shallow open water
Hydrologic Regime		Significantly impacts: drying of delta lakes; habitat loss; water levels
Health Implications		Fish consumption guidelines relevant to locals (mercury); way-of-life
Contaminants		Contamination from remote sources in fish and sediments

Science has demonstrated significant ecological changes in this area during the last two decades. Drying of the delta is related to the Bennett Dam and it is hypothesized that this may be exacerbated by climate variability. Ecological changes in the delta have resulted in impacts on fisheries habitat, fish movement and spawning behaviour, changes in waterfowl migration routes, decline in populations of ungulates, muskrats and other wildlife, and changes to way-of-life of people living in the delta.

The PAD supports abundant fish populations of a number of species (walleye, northern pike, lake whitefish and goldeye), and a commercial fisheries operation. A subsistence fishery exists in the delta. Critical spawning areas are: Mamawi, Claire and Richardson lakes. Spawning does occur throughout the delta.

Contaminants such as dioxins, furans and mercury exist in burbot liver and the muscle and liver of other fish species. Levels need to be assessed relative to the unique dietary intake of Aboriginal people. Radionuclide research confirms the fish collected at the delta and west end of Lake Athabasca have not been contaminated by mining operations in the basin.

Biological, sediment and water transport processes move contaminants from the headwaters of the basins to the delta. When the sediment contaminants reach the delta they become dispersed through particle size partitioning processes and are deposited throughout the delta, Lake Athabasca and/or transported into the Slave River system. Deep core investigations have confirmed this and the "dilution" effect of these processes. NRBS has confirmed that pulp mill contaminants have reached the perched basins. Weak PCDD/F signatures were evident in muskrat and canvasback ducks collected from perched lakes and Flour Bay. Health Canada reviewed the NRBS mammal and waterfowl contaminant data and concluded that consumption of these muskrats and canvasback ducks would not pose a hazard to humans.

Societal Perspective

At public gatherings, science fora and through surveys, statements of public concerns included: pulp mills are contaminating and fouling our fish, increasing abnormalities in fish, and affecting wildlife, vegetation and drinking water; oil sand developments are affecting wildlife; uranium mining; fish populations have declined; spawning beds have dried up and migration patterns affected through infilling of channels; fish nets are now covered with weeds; applicability of consumption guidelines for fish containing high levels of mercury; little or no warning provided to downstream interests when spills occur; and, effects of contaminants on human health and way-of-life. Major concerns were expressed related to the affects of the Bennett Dam including the loss of a way-of-life. Several Elders noted that their concerns and views seem to be often ignored; and, they recommend that traditional knowledge be incorporated into decision making related to resource management and approval of developments.

Key Management Considerations Unique to Reach

- Options for enhancing ice dams and delta flooding
- Delta ecosystem response to flow regulation
- Way-of-life impacted...cultural...spiritual...economic....trapping/hunting
- Declining wildlife and fish populations
- Fish quality and health; non-conventional drinking water treatment
- Public information, timely response and reporting of spills

ATHABASCA RIVER: Lake Athabasca

Scientific Summary

Dissolved Oxygen	Natural
Nutrients	Cores reflect evolution of basin;TK provides annecdotal evidence of increases in algae
Hydrologic Regime	No issues identified
Health Implications	None identified; vigilance required at west end of lake as regards consumption guidelines
Contaminants	Pulp mill signature in sediments; declining radionuclides; mercury levels in some fish

Lake Athabasca traps some of the sediments which move through the Athabasca River system. Sediments also deposit directly in the delta and/or move into the Slave River system and Great Slave Lake. Investigations have confirmed that pulp mill contaminants have reached the lake over very long time periods. Concentrations are close to the analytical detection limits, organochlorine contaminants in fish are near reference levels. Atmospherically derived contaminants are apparent in the cores as are PAHs originating with forest fires and hydrocarbon development. Some fish from the lake have high concentrations of mercury. A survey of subsistence fish in 1994/95 indicated that mercury in burbot, walle ye and pike are below the commercial guideline of 0.5 mg/kg (parts per million). Given the subsistence use of fish from the lake, the Alberta consumption advisories should be reviewed for relevancy to the traditional peoples.

Radionuclide concentrations in fish are well within the guidelines provided by Health Canada. There is evidence of radionuclides moving out into Lake Athabasca at the east end of the lake from the Gunnar mine site although this has diminished in recent years due to lower mining activity and controls. Ongoing and increased mining in response to international pressures, is a significant concern of the people who live along the shores of the lake and downstream in the NWT.

Fish health assessments were not undertaken on fish from the lake however, local people and commercial fisherman report fish abnormalities (external and internal) which should be investigated further.

Societal Perspective

People from the delta area have expressed fears that the lake is vulnerable to contaminants from uranium mining, pulp mill developments, oil sands and other pollution sources. Commercial fisherman have noted an increased incidence of poor quality fish (livers) however this has not been confirmed. Water quality is generally seen as vulnerable to industrial development and poorest at the mouth of the Athabasca River. There have been observations that fish nets are now becoming covered by algae and a perspective is, that this is man-induced pollution from upstream developments. Other concerns include: incomplete environmental impact assessments, atmospheric contaminants, contaminants in fish and most of the concerns noted for the delta.

Key Management Considerations Unique to Reach

- Remedial works in the delta and their effect on fish movement and habitat use
- Mining of uranium in the headwaters and the management of abandoned uranium mines
- Fisheries management: stock assessment
- Atmospheric deposition of contaminants
- Eutrophication of the west end of Lake Athabasca
- Relevancy of fish consumption guidelines to traditional peoples

PEACE RIVER: Many Islands to confluence with Smoky River

Scientific Summary

Dissolved Oxygen	No NRBS research was undertaken; natural conditions likely exist
Nutrients	No NRBS research was undertaken into nutrient enrichment
Hydrologic Regime	Radical changes: regime, ice, extremes, timing, sediment load, open winter areas, ...
Health Implications	Human health consumption guidelines for fish (mercury, PCBs)
Contaminants	Mercury, PCBs, resin acids, PAHs, dioxins and furans in sediment/burbot higher than reference

An altered flow regime is an obvious consequence of the Bennett Dam. Winter flows tend to be higher than normal, summer flows and the spring peaks lower on average. Changes in channel geomorphology, aquatic vegetation and riparian habitat are evident throughout this reach and could take decades or centuries to "stabilize." The effect of open water winter conditions, higher winter water temperatures and geomorphological changes on fish, habitat use and on other biota, have not been quantified. Snow pack and spring runoff in tributaries have been lower in recent years.

This section of the Peace River is of generally good water quality although there is some evidence of industrial contamination as determined by the presence of certain contaminants in sediments and fish. Levels of PCBs, resin acids, and PAHs are higher than reference locations in sediments above the confluence with Smoky River and in this area. PCB levels in the sediments exceed the interim Canadian sediment quality guidelines for the protection of aquatic life. The concentration of PCBs in burbot liver are an order of magnitude higher than found in burbot from the Wabasca River, a tributary to the Peace River but still well below PCB guidelines for the commercial sale of fish. The extent to which observed PCB levels in fish are a function of their concentration in the food web as opposed to point source release is unclear; however, the PCB data should be reviewed from the point of view of traditional life styles.

Levels of PCDD/Fs in sediments were low but detectable. The only sampling done for PCDD/Fs in fish was in 1994 when we tested burbot livers. All results were at or below the analytical detection limit. There are no data in this reach which could be used for assessing temporal trends in dioxins and furans

Mercury levels in fish of this reach are generally lower than elsewhere in the basins with the occasional larger fish having levels which exceed the commercial health guidelines of Health Canada. There is no fish consumption advisory in effect for this part of the Peace River and our data (for mercury, dioxins, furans and toxaphene) would seem to corraborate that none is required.

The large river volume probably assimilates existing sources of nutrient and organic wastes effectively. NRBS did not investigate the effect of B.C. pulp mills or municipalities on Peace River water quality. Dissolved oxygen levels are not an issue.

Unique fish and riparian habitats exist within the Many Islands area downstream to the Montagneu river although they are unstable and undergoing change with evolving shorelines and shifting and new sand bars as evident in the Many Islands area.

Societal Perspective

The Peace River is considered a valuable and precious resource. Flow regulation has been seen as self-serving to B.C. with little consideration of the downstream ecosystem and human interests. Concerns have been expressed about the possibility of contaminants from B.C. pulp mills and municipalities and mercury contamination of Peace River fish.

Key Management Considerations Unique to Reach

- Hydrologic regime and geomorphological responses
- Contaminant sources (PCBs, PAHs, resin acids and dioxins and furans) and levels in sediment and/or fish
- Transboundary river; pollution from B.C. and high mercury in fish of Williston Lake
- Ecologically sensitive regulation of flows from the Bennett Dam
- Human consumption advisories
- Periodic monitoring of contaminants in fish

PEACE RIVER: Confluence of Smoky River to Riviere Des Rochers

Scientific Summary

Dissolved Oxygen	Natural
Nutrients	Information is lacking although localized enrichment is evident
Hydrologic Regime	Radical changes: regime, ice, extremes, timing, sediment load, channel/riparian changes, ...
Health Implications	Fish consumption guidelines (mercury and PCDD/F)
Contaminants	Depressed sex steroids; proportion of sexually immature fish, pulp mill contaminants, PCBs

The most dominant stressor affecting the entire length of the Peace River is flow regulation by the Bennett Dam. Although hydrologic effects are attenuated downstream, there is concern related to reduced flooding of the Peace-Athabasca Delta. There is preliminary evidence that climate variability may be an important factor in explaining reduced tributary runoff in the upper basin and drying of delta lakes

The large water volume and high sediment load in the Peace River dilutes the contaminants discharged from pulp mills and municipalities. There is evidence of trace contaminants (PAHs and chloro-phenolics) in sediments with tetrachlorodibenzo-p-dioxin (TCDD) levels below detection. Increases in chlorinated resin acids were not seen below Daishowa although total resin acids are as high in this reach as on the Athabasca River at Emerson Lakes. PCB levels doubled in fish from the Peace River near Notikewin, and near Ft. Vermilion, between 1992 and 1994. Tetra-chlorodibenzodioxins and furans (TCDD/F) have decreased in burbot livers since 1992. Nutrient enrichment was not investigated by NRBS in the reach. Dissolved oxygen is not an issue. Depressed sex steroid levels (based on basin-wide analysis of near field sampling stations) occur in burbot and longnose sucker below pulp mills relative to reference samples and coupled with a low ratio of mature to immature fish is worthy of management follow-up. The levels of TCDD/Fs in fish have decreased by 50-80% since 1992, probably as a result of technology improvements. The effects of agriculture on the Peace River or its tributaries has not been investigated. Examining the potential for non-point source pollution, NRBS scientists have noted that agriculture and forestry operations may be important considerations in the long term management of the system. The oil sands which intersect the Peace River have not been found to cause any unusual water quality or ecosystem health effects. However, elevated levels of MFO were found in burbot liver collected in the Wabasca River. This reach is critical winter habitat for goldeye which spend the spring and summer in the lower Peace River within Wood Buffalo National Park. Goldeye are the dominant fish species in this reach with an estimated population of one million.

High level of free retinoids in burbot from the lower portion of this river reach suggests physiological stress but the cause is unknown.

Societal Perspective

The public fears river degradation by pulp mills, forestry, agriculture, mining, oil and gas, and municipal wastes. Frequent observations were made about past spills related to PCBs and other substances on the Smoky and Wapiti systems which may impact the Peace River. Observations of fiber, foam, odours, and tainted drinking water have been associated with pulp mills. Increased sediment and dirty ice, likely caused by increased winter flows, leaves an impression of degraded water quality. Changes in wildlife and fish populations are perceived to be linked to development on the river. Apparently uncontrolled agricultural activity, especially the clearing of land right down to the water's edge is a growing concern. Land clearing for forestry is increasing in the tributary watersheds (Notikewin, Cadotte, Buffalo, Wolverine, Ponton, Wabasca and Mikkwa) with concerns expressed about water quality and vulnerability of fish habitat.

Key Management Considerations Unique to Reach

- flood management and safety of property and humans
- ecological changes in the river channel
- ice formation, quality and timing
- agricultural land use; interaction with aquatic ecosystems
- effects of deforestation
- health and quality of fish and fish habitat
- information on nutrient enrichment is lacking
- options for enhancing ice dam formation and delta flooding
- depression of sex steroids and increased incidence of immature fish

WAPITI-SMOKY RIVERS

Scientific Summary

Dissolved Oxygen	■	High rate of decline in short river length
Nutrients	■	Non-limiting except in lower Smoky where N limited; enrichment below pulp mill/Grande Prairie
Hydrologic Regime	□	Recent decrease runoff due to climate variability
Health Implications	■	Human consumption of fish
Contaminants	■	PCDD/Fs, PCBs, fish deformities, depressed sex steroids, proportion of sexually immature fish

Based on the weight of evidence approach, the Smoky-Wapiti river system is currently the most heavily stressed in the northern river basins. Issues of concern include high levels of nutrient addition from the city of Grande Prairie and the Weyerhauser pulp mill, sharp declines in under-ice dissolved oxygen, and high PCB concentrations in sediment and fish. The extent to which observed PCB levels in fish are a function of their concentration in the food web as opposed to point source release is unclear. Whatever the factors responsible for these PCB levels, the issue clearly requires further investigation. Concerns relate to the rapid decrease in the river system's capacity to assimilate further organic wastes without implications to fish (dissolved oxygen) and long term eutrophication on this system. Twenty-three percent of annual TP loading in the Wapiti River is from Grande Prairie and Weyerhaeuser and is in excess of 40% during low flow periods. The proportion of bio-available phosphorus in these effluents is higher than in the receiving water. Recent decreases in basin runoff related to decreased snow pack would further exacerbate the effect of nutrient/contaminant additions to the rivers.

Contaminants related to dioxins, furans, PCBs and chlorophenolics are present in sediment, water and/or fish.

Unexplained doubling of PCB levels in fish occurred between 1992 and 1994 on the Wapiti River.

TCDD/Fs in biota appear to have declined by a factor of 10 since 1992 but are still relatively high relative to other locations in the basins. Depressed sex steroids coupled with an apparent anomolously high ratio of sexually immature fish (burbot and long-nosed suckers), and a higher than normal incidence of fish deformities below the mill give cause for concern and the need for further research. Although pulp mill effluents may have affected the reproductive ecology of individual fish, there is no evidence yet that populations have been affected.

These small river systems provide critical spawning habitat for several fish species and therefore are particularly vulnerable to pulp mill and municipal wastes.

NRBS has determined that variability in precipitation and winter snow pack has played a significant role in influencing observed levels of spring runoff in these tributaries to the Peace River. This has important implications for several areas of water management including flood forecasting and control, water licensing and apportionment, instream flow needs, pollution control and water quality.

Societal Perspective

Public statements about the state of the resource in this system include perceived impacts from coal mining (dust), power generation (transformers: PCBs), red snow, spills, deformed fish, air quality associated with oil and gas field flaring, aesthetics (such as foam, wood chips, and odours) and fish and water tainting.

Key Management Considerations Unique to Reach

- Highest levels (on lower Wapiti) of dioxins, furans, PCBs and chlorophenols in sediments, fish and/or water of the Peace drainage
- Relative to river discharge the Wapiti-Smoky systems are most heavily impacted in the basins (dissolved oxygen, nutrient enrichment)
- Fish health, reproductive ecology and exposure to pulp mill effluents
- Pollution loading relative to naturally occurring low flows
- Forestry management and land clearing relative to water quality

SLAVE RIVER: Riviere Des Rochers to (including) Slave Delta

Scientific Summary

Dissolved Oxygen	Not investigated but natural regime expected to exist
Nutrients	Likely natural but not investigated; algae apparent on submerged rocks at Rapids of the Drowned
Hydrologic Regime	Modified: higher winter flows and sediment loads, reduced peak flows, possible impacts on delta
Health Implications	Fish consumption guidelines linked to dietary intake; non-conventional treatment of drinking water
Contaminants	Atmospheric sources; methallothionein, pulp mill signatures

Flow alterations in the Slave River may have implications to fish movement, distributions and the state of the delta. NRBS did not conduct in-depth investigations of the flow regulations effects on Slave River Delta ecology. Impacts of the flow regulation are therefore not adequately described except as related to understanding the hydrologic regime of the river itself. Research is needed to assess the state of the delta and its vulnerability to upstream flow regulations. Increased suspended sediment has been observed during winter with the higher than normal flows.

The Rapids of the Drowned to Cunningham Landing is critical spawning habitat for inconnu and lake whitefish as is the lower-middle reach between Pointe Ennuyeuse and Grand Detour where inconnu spawn. The Slave River delta is known to be a spawning and rearing habitat for burbot and northern pike.

Although contaminants (e.g. PCDD/F) have only been detected in fish (e.g. burbot) and lake sediments at or near analytical detection limits, this indicates upstream sources are beginning to show their presence many hundreds of kilometers downstream. Atmospheric sources of contaminants are implicated. Further research is needed to explain the cause and the significance of these findings.

Fish health apparently remains exceptional throughout this reach. A "recommendation" by the NWT Government, similar in nature to the Alberta consumption advisories, exist for fish taken from the Slave River because of toxaphene. Due to analytical difficulties, NRBS data could not corraborate the toxaphene issue for fish from the Slave River.

We heard from the people that wide use is made of drinking water using non-conventional treatment. Particular concern relates to the practice of using untreated water in back country locations and the possible consequences.

Societal Perspective

Local people have indicated concerns related to: long term sustainability of the white pelican colony; waste from Fort Smith, enhanced algal growth at the Rapids of the Drowned, increased turbidity in the winter, drinking water quality, buried landfill leachates, water level fluctuations, declining wildlife populations, and fish quality.

Key Management Considerations Unique to Reach

- Habitat protection; Fisheries management fish biology
- Ecological effects of flow regulation on the Slave Delta
- Contaminant (metals, toxaphene) in fish
- Human consumption guidelines relative to fish muscle and livers
- Transboundary river

■ RECOMMENDATIONS

These recommendations are a result of an interpretative, integrated synthesis of results from the eight study components. The analysis also considered advice received from public gatherings and science for a held during the study. These recommendations are science-based and not reflective of societal values. It is the challenge of the Study Board with its multi-stakeholder representation to incorporate societal values in the final NRBS recommendations.

Each of the Component synthesis and project reports contain a number of issue- and discipline-specific scientific recommendations, too many to list here. We recommend that management authorities review and consider these recommendations as the issues and concerns warrant. A summary of all NRBS science reports by issue of concern is provided in Ouellette (1996).

The recommendations which follow are divided into four primary issue areas:

I. **Environmental Contamination**
II. **Aquatic Ecosystem Health**
III. **Environmental Monitoring and Awareness**
IV. **Cumulative Effects**

Within each of these areas, recommendations are presented in order of priority.

I. Environmental Contamination

Given the prevailing concerns about the presence, concentration and distribution of contaminants in the aquatic ecosystems of the Peace, Athabasca and Slave River systems, the following monitoring and research recommendations should be considered immediately by governments:

1. We recommend that a basin-wide monitoring program be undertaken at least once every three years to assess fish health and levels of contaminants in fish tissue.

NRBS research has identified that although the health of fish is generally believed to be good across the basins there are indications that some fish may be showing early signs of stress and possibly exposure to contaminants. For instance, there is a high incidence of abnormalities reported in fish below Whitecourt, and higher than normal incidence of abnormalities in fish below other pulp mills. As well, our findings indicate depressions in sex steroids in fish from these same locations. Together, there is a body of evidence which suggests that there maybe sub-lethal toxicological concerns. There is no active fish contaminant monitoring program in the basins. Given the concerns related to human consumption of fish containing mercury, dioxins, furans, PCBs and toxaphene (various fish consumption advisories exist now in the basins), and given that fish contamination is changing over time and space due to improvements in technologies and due to biological and ecological processes, periodic assessments would provide governments, public and other stakeholders with current information. It is our view that a three year monitoring cycle reflects a reasonable time frame over which one could expect fish and other organisms to respond to changing conditions within the basins.

2. We recommend that the federal and provincial governments and industry consider further optimization of the Environmental Effects Monitoring (EEM) protocols for pulp mills based upon the NRBS findings.

NRBS undertook investigations to assess the state of aquatic ecosystems, and in particular, the health of fish and the benthic communities upstream and downstream of pulp mills. The most in-depth work was conducted on the Athabasca River.Considerable effort went into the selection of appropriate fish species, sampling design and selection of assessment protocols. We anticipate that the fish information concerning contaminants, fish movement and distribution, fish health (biomarkers) and indicator development, and sampling design could be used to optimize the Environmental Effects Monitoring (EEM) protocols. Consideration should be given to coordinating the industry collections (timing, species, number of samples, etc.) of all the mills so that data can be comparable and integrated on a larger basin scale.

3. We recommend that all levels of government actively support and encourage ongoing research investigating ecosystem structure and function within these basins.

An explicit objective of the NRBS was to acquire a baseline data set pertaining to the basic ecology of the Peace, Athabasca, and Slave river basins. The importance of understanding the structure and function of the ecosystem cannot be over emphasized. It is this understanding which determines our view of the system and provides a context within which all management priorities and objectives are developed. Gaps in this understanding could result in a failure to identify key issues or in the misdirection of time and effort. Unfortunately, there are considerable gaps in our current knowledge of the ecology of the Peace, Athabasca, and Slave river basins. These knowledge gaps are reflective of the difficulties associated with working in these systems and of a more general lack of information on the ecology of large rivers, particularly large northern rivers.

Additional research on ecological structure and function is required to determine more precisely the distribution and fate of contaminants in the environment and to further parameterize analytical models developed to predict the consequences of discharging contaminants to the environment. Governments should participate directly in such research, particularly when the research question falls within their mandate. In addition, governments should actively encourage, and perhaps subsidize, ecological research conducted in these basins by other groups such as universities, colleges, community groups and international agencies.

4. We recommend that the governments of Canada, Alberta, and Northwest Territories and the key Industries investigate the feasibility and implementation of an integrated environmental information system.

There is a continuing problem, not unique to these basins, of access to environmental data and information. Virtually every industry, certainly the senior governments, all have computerized systems for handling their own data. For purposes of facilitating the sharing of information, protocols could be developed which would outline the basic standards for handling, storing and reporting of environmental data. Furthermore, protocols could be developed which would link the many databases together so as to permit the transfer of data between them, or at the very least, could direct the user to where the data could be obtained. The five private laboratories and the several provincial and federal laboratories used by NRBS all had different analytical method codes, methods of reporting detection limits, quality assurance methods, and reporting protocols. Considerable human intervention was needed to ready the laboratory data for NRBS use. We believe that a concerted effort by the partners could be successful at reconciling these sorts of problems and the product ultimately developed could be marketable nationally and internationally. This multiplicity of approaches and techniques amongst agencies can be reduced but not eliminated because differing methods are often justifiable. Opportunities exist to make advances now through such organizations as the Canadian Association of Environmental Laboratories, using the INTERNET, and through existing informatics initiatives of governments. Bibliographic inventories of studies and reports undertaken in the basins, land and water use, monitoring data, etc. could be incorporated.

II. Aquatic Ecosystem Health

5. We recommend further research be undertaken to address the observation of endocrine disruption and increased numbers of sexually immature fish in reaches immediately below pulp mills.

Preliminary NRBS data concerning endocrine function and sexual maturity of at least two fish species (burbot and longnose suckers) suggest that pulp mill effluents may adversely affect the reproductive ecology of individual fish; however, there is as yet no evidence for an effect at a population level. Using a weight-of-evidence approach, we recommend using the precautionary principle as the basis to initiate more detailed studies examining the linkages between reproductive ecology and exposure to pulp-mill effluent before further developments, singularly or in combination, cause additional ecological stress on the fish populations.

6. We recommend investigations be undertaken to determine the linkages between exposure to environmental stresses and sub-lethal effects on fish and other aquatic biota, including physical abnormalities and biomarker responses.

NRBS studies reveal basin-wide variation in the frequency of physical abnormalities and in the extent of biomarker response. In some cases the measured response appears to be associated with specific point-source discharges (e.g., increased incidence of fish abnormalities below pulp mills); however, in other cases the measured response is not as obviously associated with a particular environmental stress, this is particularly true in some of the tributaries not intensively studied by the NRBS (e.g., elevated levels of metallothionein response in fish collected from the Pembina River and MFO induction in fish from the Wabasca River). The consequences of long-term exposure to contaminants takes on added significance in light of NRBS data indicating the presence, usually at low levels,of environmentally persistent contaminants (e.g., dioxins, furans and PCBs) throughout the basins.

7. We recommend investigations be undertaken to identify the sources of PCBs to the upper portions of the Peace River Basin, including the Smoky and Wapiti river systems, in the upper Athabasca River between Jasper and Athabasca and the extent to which PCBs are concentrated in the food web.

PCBs are known to bio-concentrate and in some cases higher measured levels of PCBs in fish tissue (e.g., burbot) may be a consequence of changes in the fish foraging behaviour (e.g., large burbot feeding on other fish will concentrate PCBs to a greater extent than those feeding on macroinvertebrates) rather than a consequence of exposure to a PCBs spill. The role of food web interactions in observed tissue concentrations of PCBs could be investigated using stable isotope analysis.

NRBS has identified that PCBs are one of the major contaminants in the tissue of biota from these basins. Importantly PCBs are not produced by pulp mill activities and are not uniformly distributed throughout the basins. In particular, PCBs concentrations have doubled in several locations in the Peace River Basin between 1992 and 1994, although the explanation for this increase is unknown.

8. We recommend the development of ecologically rather than technologically-based endpoints for the regulation of nutrient discharges from industries and municipalities.

Current levels of nutrient discharge from both industry and municipalities have been demonstrated to change patterns of nutrient limitation and hence primary and secondary productivity. At present issues associated with these changes are large aesthetic, but continued and or additional loadings have the potential to dramatically impact the trophic structure in these basins. Current guidelines focus exclusively on technology-based endpoints and do not incorporate ecological responses. Technologically-based effluents guidelines and regulation should be viewed as a means to preserve adequate ecological structure and function, and not as an end in themselves. Implicit in this approach is the recognition that regulatory levels may vary from reach to reach as a function of river size, cumulative effects and unique ecology of each reach.

9. We recommend further research into the dissolved oxygen requirements of the most sensitive life-history stages of fish species and their invertebrate prey. We further recommend the development of ecosystem/reach specific dissolved oxygen guidelines.

Much of the available information on dissolved oxygen is not representative of the aquatic species and conditions existing in these northern rivers.

NRBS review of under-ice river dissolved oxygen levels reveal an enhanced diminishment of dissolved oxygen in the Wapiti-Smoky rivers, and the Athabasca River between Hinton and Grande Rapids. These river reaches receive major inputs of municipal and pulp mill effluent. In a river channel fish and other riverine biota focus much of their life processes, close to the river bed or bank. Current dissolved oxygen monitoring practices record dissolved oxygen levels away from the steambed. Consequently, the dissolved oxygen data does not accurately reflect conditions existing within habitats utilized by fish and other biota. Available scientific knowledge indicates that an average three mg/L differential exists between dissolved oxygen levels within the water column and those existing in the streambed. The availability of sufficient dissolved oxygen influences the aquatic community composition within a river reach. Fish and other biota exposed to diminished dissolved oxygen will respond by altering life processes. NRBS work into the embryonic development of three fall-winter spawning fish species: mountain whitefish, bull trout, burbot, and the feeding behaviour of an invertebrate species provided insightful information. The information indicated a need for further research and the establishment of reach specific dissolved oxygen guidelines. More specific information is needed to manage effluent for the protection of sensitive life stages in biota likely to be subjected to diminished dissolved oxygen levels. Research must be done to find out the acceptable limits of northern river aquatic biota to lowered dissolved oxygen levels, and the relationship between water column and substrate-water/substrate interface dissolved oxygen levels.

10. We recommend that research be undertaken by Environment Canada and partners to develop an understanding of the inter-relationship between climate variability and hydrologic regimes of the mainstem rivers and major tributaries in the basins.

The NRBS has determined that variability in precipitation and reduced winter snow pack have reduced the magnitude of recent (up to 1995) spring run-off in the Peace River drainage and the probability of ice-jam formation in the delta area. Reductions in the spring runoff volumes in recent years are therefore not just a result of the Bennett Dam.The implications of climate change on the regulated flow regime of the Peace River and on the ecology of the delta must be understood, especially if solutions for the long term are to be sought for alleviating the ecological problems in the Peace-Athabasca Delta. Eventually, scenarios of climate variability could be factored into water management strategies and the operational plans for Bennett Dam.

11. We recommend that current human health advisories for the consumption of fish, including the "recommendation" issued by the Government of the Northwest Territories, be reviewed, revised and/or developed, based upon human dietary and fish contaminant information reported by NRBS.Further, we recommend starting an ongoing contaminant monitoring effort for fish consumed as food by domestic and sport fisherman.

Similar to previous investigations, NRBS has identified contaminants in the fish flesh and organs (liver) that are the subject of current provincial human health consumption advisory (e.g., mercury, dioxin-furan) or territorial recommendation (e.g., toxaphene).NRBS sampled fish from the mainstem rivers of Peace, Athabasca and Slave rivers and major tributaries (e.g., Wapiti-Smoky rivers). Many of these sampled fish species are eaten for domestic and sport purposes. Currently, aside from the monitoring associated with the export of commercial fish products (Freshwater Fish Marketing Corporation), a program does not exist for the regular collection and analysis of fish obtained for domestic and/or sport purposes. The current guideline utilized by Health Canada in preparing human health assessments has provision to incorporate the unique dietary information of the human population consuming the contaminated fish product. Often this dietary information on the human population consuming the contaminated fish product are scant. There are there are instances where an advisory or recommendation can be in force within one jurisdiction and not an adjoining jurisdiction when but for a line on a map the same fish population is being considered, e.g., dioxin-furan advisory on the upper Athabasca River downstream of Jasper National Park but not in the Park, toxaphene recommendation for burbot liver in the NWT portion of the Slave River but not in Alberta. The public perception of the risk is at best confusing. The current human health consumption advisory or recommendation should be reviewed in light of the NRBS findings. As well, the traditional users who rely or used to rely on fish for a significant portion of their dietary protein source, require special consideration in preparation of the advisories and/or recommendation that takes note of their consumption use patterns. A need also exists for a semi-regular monitoring program that acknowledges the likely variation in contaminant levels as effluent standards are modified.

12. We recommend the extent and causes of fish tainting be quantified and action taken as appropriate to remediate the problems.

Although human health is not believed to be threatened by current levels of fish tainting, NRBS scientists learned that a widely held public perception is that fish are contaminated. This perception is based on fish odour and appearance;fish possessing oil and/or pulp mill odours are immediately perceived to be "contaminated" and unfit for human consumption. The occurrences of these observations is highest in the lower end of the basins but also occur in the Smoky and Wapiti systems, and some evidence exists (traditional knowledge) that suggests that the quality of fish livers has deteriorated. As long as these issues persist in the basin, the public will associate taste and odour with polluted fish and drinking water. In-depth assessment of tainting substances (synergistic effects of multiple effluent types) and alternatives for their control may be required to meet the public need to know. Insufficient data exist to address the issue of fish tainting and the particular substances responsible for tainting of drinking water supplies.The primary sources of tainting substances to the Athabasca River exist in the reaches between Hinton and Fort McMurray where dilution ratios are lowest and where there is a succession of industrial and municipal waste sources.

13. We recommend that provincial and federal authorities undertake, in accordance with their responsibilities, to ensure the ongoing training and certification of drinking water treatment plant operators, education of the public about their choices concerning drinking water sources and treatment, and timely reporting and corrective action for water quality problems.

The vast majority of people within the basins receive excellent quality drinking water. The problems which have been most frequently observed are usually in communities of populations less than 500. Typical problems have included: high bacteria, turbidity, odours, and trihalomethane compounds. High levels of coliform bacteria indicate the potential risk associated with viruses and waterborne diseases. Although some of the facilities may be aging and therefore not capable of high performance, concern was expressed by some community members over the experience and dedication of treatment plant operators. Given the importance of quality water to the health of people, treatment plant operators should be recognized as critical assets to the community and afforded the best level of training and certification. Furthermore, monitoring protocols must be standardized and subject to quality assurance, and monitoring data regularly reported with timely corrective action taken, as needed.

NRBS public surveys have confirmed that tainting substances (derived from pulp mill discharges and municipal disinfection with chlorine) are still an issue with respect to drinking water. Basin communities should be provided with documentation about the quality of their drinking water, explanations of why odours exist (natural occurrence included), and advice as to alternatives and choices people can make about their drinking water.

III. Environmental Management and Monitoring

14. We recommend the adoption of an integrated basin management and the assessment of cumulative effects of developments. Such an approach requires an integrated environmental monitoring framework to ensure that ongoing scientific validity of results, and rationalization and optimization of monitoring and research conducted within the basins. It is further recommended that an Integrated Environmental Monitoring Committee (IEMC) be immediately established to coordinate basins' monitoring and research within this framework.

Governments, industries, some municipalities and to a lesser extent other organizations conduct various types of monitoring within the basins. Individual agencies collect monitoring data for their own purposes, however, the total benefit realized would be greater if monitoring within the basins was coordinated so as to avoid duplication and provide the maximum return in information for each dollar invested. Such an approach would also allow for the consideration of a broader range of issues (e.g., basin-wide effects, cumulative effects) than would be considered by any one agency or industry. Appropriate priority needs and scientifically acceptable protocols should be identified and applied across agencies. Quality assurance and quality control practices as well as procedural standardization should be incorporated into all aspects of monitoring activities. A process is required by which this database can be maintained, updated and made publicly available. A scientifically rigorous integrated environmental management program requires expert advice on its design, implementation, data interpretation, and scientific recommendations. Similar to the Science Advisory Committee of the NRBS, this committee would serve as an independent and objective reviewer of the integrated environmental management program.

The Synthesis and Modelling Component has presented a practical procedure for the development and application of ecosystem indicators and has recommended indicators for adoption by governments, industry and the public.

Conformance with this monitoring and research template should be a condition of all monitoring and research undertaken in the basin. Government authorities may wish to consider the requirement of monitoring and research permits in order for agencies to conduct their work in the basins similar to what is done in the Northwest Territories. This would bea means of optimizing the monitoring and research in the interests of the basins needs.

15. We recommend that existing information on northern river fish movement, behaviour, and habitat use, must be compiled and interpreted. On completion, this work should be assessed for itssupport of cumulative effects assessment, deficiencies in knowledge identified and corrective action implemented.

The composition and extent of fish species within the basins is generally known. A wide gap in knowledge continues to exist on seasonal distribution/abundance, habitat utilization and general biology of fish species, particularly for the non-domestic/sport/commercial varieties. NRBS, industry and government investigations since the start of the Study have further augmented the available knowledge but there remains a lack of interpretation on this existing body of knowledge. Consequently, the likelihood of redundant information being gathered at the expense of needed information remains high. NRBS investigations have identified significant freeze-up and morphological changes to the Peace River downstream of the Bennett Dam. The implications of these changes to the fish community reliant on the mainstem Peace River are unknown, particularly in the river reach downstream of Peace River and the lower portion of the Peace River within Wood Buffalo National Park. Without better understanding of fish movements and populations there is much difficulty in interpreting the significance of contaminant levels on the fish health effects documented by NRBS and others. It is also difficult to design effective monitoring programs to assess changes in fish health. This compromises the use of fish as reliable indicators of ecosystem health even though they remain the most obvious animal for the public to do their own evaluation of risks to human health.

IV. Cumulative Effects

16. We recommend additional research and/or remediation in those areas of the basin identified as deserving of special attention by applying the weight of evidence approach to the assessment of cumulative effects.

Cumulative environmental effects manifest themselves at a variety of spatial, temporal, and organizational scales within the ecosystem. Although it is important not to lose sight of cumulative effects occurring at a basins-wide level and the inter-relatedness among river reaches, it is equally important to employ a weight of evidence approach to identify those portions of the ecosystem particularly deserving of attention. This approach provides the opportunity to focus on characteristics which are unique to reaches and identify related management considerations.

What follows is a brief description of what we consider to be the five areas in the basins requiring priority consideration by managers at the federal, provincial and territorial levels.

16a. ***Protection of the Wapiti-Smoky river systems***

Based on the weight of evidence approach, the Smoky-Wapiti River system is currently the most heavily stressed in the Northern River Basins. Issues of concern include high levels of nutrient addition from the city of Grande Prairie and the Weyerhauser pulp mill, sharp declines in under-ice dissolved oxygen,and high PCBs loadings in fish. Dioxin and furan concentrations in biota have declined since 1992, but remain among the highest observed in the basins. Reduction in winter snow pack and subsequent declines in discharge levels will serve to further concentrate contaminants and nutrients in the system. Prevention of further deterioration should be a priority of both provincial and federal management authorities as should be the remediation of an already stressed aquatic ecosystem. These small and relatively shallow systems provide critical fish spawning habitat and are therefore particularly vulnerable to pulp mill and municipal wastes.

16b. ***Remedial action plan for the Peace-Athabasca Delta***

The Peace-Athabasca Delta is internationally recognized as one of the most important and largest freshwater deltas in the world and has been designated as a Ramsar site under the international Ramsar Convention as well as a World Heritage Site. The NRBS has recognized that the Peace-Athabasca-Delta has been significantly impacted by flow regulation and climatic variability. Most significantly, a reduction in the frequency and extent of ice-jam flooding has resulted in the drying of perched basins and delta lakes. This in turn has had profound ecological consequences for the geomorphology of the delta and for the aquatic biota, terrestrial wildlife, and riparian vegetation in this region. Moreover, the ability of aboriginal peoples to pursue a traditional lifestyle has been significantly compromised.

We believe that sufficient information now exists based on the previous studies in the delta, studies by Wood Buffalo National Park, research by NRBS, and the forthcoming results of the

Peace-Athabasca Delta Technical Studies to develop and implement a remedial action plan. We further believe that options for remediation could include modifying the operation of the Bennett Dam so as to be more ecologically sensitive to the needs of the downstream ecosystem. Adaptive management strategies, whereby the best option (based on collective knowledge) can be implemented, and then modified based on the results, should be considered. To begin with, it will be necessary to have the stakeholders agree upon the ecosystem attributes (goals and indicators) which should guide the action plan.

16c. *Intensify monitoring activity in the reach of the Athabasca River from Hinton to below Whitecourt*

Recent improvements in process technology at the Hinton and Whitecourt pulp mills have reduced levels of persistent organochlorine contaminants entering the environment. This improvement is reflected by declines in measured levels of certain contaminants (e.g., dioxins and furans) in sediment and biota. However, NRBS has identified contaminant-related concerns in the Emerson Lakes area below Hinton and has recorded a high incidence of fish abnormalities below Whitecourt. In addition, nutrient discharges from the Weldwood mill have resulted in "nuisance" growth of algae for up to 30 km downstream of Hinton. Improvements in pulp mill technology may serve to reduce these impacts, but given current conditions this reach, we recommend that monitoring be particularly vigilant.

16d. *Research into the ecological consequences of exposure to hydrocarbon-related contaminants in the oil sands area*

In the 1994 basin-wide fish survey, the only locations to produce significant MFO induction in burbot were located in the oil sands area (below Ft. McMurray and the Wabasca River). Moreover research using semi-permeable membrane devices supported this observation in the Athabasca mainstem as well as in the Steepbank and Clearwater rivers. These observations point to the importance of environmental stress caused by exposure to natural sources of hydrocarbons in the oil sands area and to the need to distinguish and characterize the consequences of exposure to these natural sources and to effluent from oil sands refineries.

16e. *Protection of the Slave River Delta ecosystem*

NRBS studies consistently found that fish in the Slave River Delta were the largest and in the best condition. However, these same populations also exhibited elevated biomarker responses (e.g., metallothionein). Although NRBS has obtained evidence that pulp mill contaminants are deposited in the delta and Great Slave Lake, observed levels are currently low and the actual exposure of these fish to contaminants, either from Great Slave Lake or from upstream sources remains unknown. Similarly, although there is little evidence to suggest that flow regulation on the Peace River is currently impacting the Delta there are suggestions that such impacts will become more apparent over time. The current state of the Slave River Delta thus provides an opportunity for conservation rather than remediation. An appropriate conservation strategy is particularly important in light of the fact that the Delta is downstream of all development in the basins.

17. We recommend that future management of these basins explicitly recognize and consider land use activities (forestry, agriculture, urban development, mining, etc.)occurring in the adjacent terrestrial ecosystem.

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

REFERENCES

Cash, K.J., M.S.J. Ouellette, F.J. Wrona and G. Wagner. 1996. Quantitative Analysis of Benthic Macroinvertebrate and Fish Community Structure. Northern River Basins Study Project Report No. 123.

Donald, D.B., F. Wrona, W.F. Warwick, W. Aitken, F.G. Hunter, and J. Syrgiannis. 1996. Indicators of ecosystem integrity: Peace-Athabasca Delta. Northern River Basins Study Project Report No. 107.

Gibbons, W., K. Munkittrick, and W. Taylor. 1996. Suitability of Small Fish Species for Monitoring the Effects of Pulp Mill Effluent on Fish Populations, Athabasca River. Northern River Basins Study Project Report No. 100.

MacCauley, E. 1996. Modelling of the Peace, Athabasca and Slave Rivers.

Mill, T.A., P. Sparrow-Clarke and R.S. Brown. 1996. Fish distribution, movement and critical habitat in the Peace, Athabasca and Slave rivers. Northern River Basins Study Project Report.

NRBS Synthesis Report No. 1. 1996. General hydrology and effects on flow regulation on the Peace, Athabasca and Slave rivers. Northern River Basins Study, Edmonton.

NRBS Synthesis Report No. 2. 1996. Effects and toxicity of contaminants on aquatic organisms in the Northern River Basins. Northern River Basins Study, Edmonton.

NRBS Synthesis Report No. 3. 1996. Distribution of contaminants in the water, sediment and biota of the Peace, Athabasca and Slave Rivers: present levels and predicted future trends. Northern River Basins Study, Edmonton.

NRBS Synthesis Report No. 4. 1996. Nutrient enrichment in the Peace, Athabasca and Slave rivers: assessment of present conditions and future trends. Northern River Basins Study, Edmonton.

NRBS Synthesis Report No. 5. 1996. Dissolved oxygen, fish and nutrient relationships in the Athabasca River. Northern River Basins Study, Edmonton.

NRBS Synthesis Report No. 7. 1996. Characterization of aquatic uses within the Peace, Athabasca and Slave river basins. Northern River Basins Study, Edmonton.

NRBS Synthesis Report No. 8. 1996. Environmental overview of the northern river basins. Northern River Basins Study, Edmonton.

NRBS Synthesis Report No. 9. 1996. Assessment of drinking water quality in the Northern River Basins Study Area - synthesis report. Northern River Basins Study, Edmonton.

NRBS Synthesis Report No. 10. 1996. Assessment of ecosystem health and cumulative effects in the Peace, Athabasca and Slave rivers. Northern River Basins Study, Edmonton.

NRBS Synthesis Report No. 12. 1996. A report of wisdom synthesized from the traditional knowledge component studies. Northern River Basins Study, Edmonton.

Pastershank, G.M. and D.C.G Muir. 1996. Environmental Contaminants in Fish: Polychlorinated Biphenyks, Organohlorine Pesticides, and Chlorinated Phenols, Peace and Athabasca Rivers, 1992 to 1994. Northern River Basins Study Project Report No. 101.

Plafkin, J.L., M.T. Barbour, K.D. Porter, S.K. Gross, and R.M. Hughes. 1989. Rapid bioassessment protocols for use in streams and rivers. Benthic macroinvertebrates and fish. EPA/444/4-89-001. Office of Water Regulation and Standards, US Environmental Protection Agency, Washington, DC.

Prowse, TD., B. Aitken, M. N. Demuth and M. Peterson. 1996. Strategies for restoring spring flooding to a drying northern delta. Regulated Rivers: Research & Management, in press.

■ APPENDIX 1 : CANADIAN ENVIRONMENTAL QUALITY GUIDELINES USED IN THE ASSESSMENT OF CUMULATIVE EFFECTS

Parameter	Water ($mg \cdot L^{-1}$)			Sediment ($mg \cdot kg^{-1}$)	Biota ($\mu g \cdot kg^{-1}$)	
	Drinking Water (a)	Recreation (b)	Freshwater Life (c)	Freshwater Life (d,f,g)	Freshwater Life	Wildlife
Chlorinated Phenols						
Monochlorophenols	NA	NA	0.007	NA	NA	NA
Dichlorophenols	NA	NA	0.0002	NA	NA	NA
2,4-Dichlorophenol	0.9 (0.0003) (j)	NA	NA	NA	NA	NA
Trichlorophenols	NA	NA	0.018	NA	NA	NA
2,4,6-Trichlorophenol	0.005 (0.002) (j)	NA	NA	NA	NA	NA
Tetrachlorophenols	NA	NA	0.001	NA	NA	NA
2,3,4,6-Tetrachlorophenol	0.1 (0.001) (j)	NA	NA	NA	NA	NA
Pentachlorophenol	0.06 (0.03) (j)	NA	0.0005	NA	NA	NA
Chloroguaiacols	NA	NA	NA	NA	NA	NA
Chlorocatechols	NA	NA	NA	NA	NA	NA
Chloroveratroles	NA	NA	NA	NA	NA	NA
Chlorosyringaldehydes	NA	NA	NA	NA	NA	NA
Chlorosyringols	NA	NA	NA	NA	NA	NA
Trichlorotrimethoxybenzene	NA	NA	NA	NA	NA	NA
Chlorovanillins	NA	NA	NA	NA	NA	NA
Chloroanisoles	NA	NA	NA	NA	NA	NA
Radioactivity						
^{137}Cesium	50 $Bq \cdot L^{-1}$	NA	NA	NA	NA	NA
Dioxins and Furans						
PCDD/PCDF	NA (h)	NA	0.02 pg $TEQ \cdot L^{-1}$ (g)	under development	0.0182 TEQ (g)	0.0011 TEQ (g)
Metals						
Arsenic	0.025 (f)	NA	0.05 (h)	5.9 (17.0) (k)	NA	NA
Cadmium (total)	0.005	NA	0.0002-0.0018	0.6 (3.53) (k)	NA	NA
Chromium (total)	0.05	NA	0.002-0.02	37.3 (90.0) (k)	NA	NA
Copper (total)	(1.0) (j)	NA	0.002-0.006 (l)	35.7 (197) (k)	NA	NA
Mercury	0.001	NA	0.0001	0.17 (0.486) (k)	NA	NA
Methyl Mercury	NA	NA	NA	NA	NA	NA
Lead	0.01	NA	0.001-0.007 (l)	35.0 (91.3) (k)	NA	NA
Vanadium	NA	NA	NA	NA	NA	NA
Zinc	(5.0) (j)	NA	0.03	123 (315) (k)	NA	NA
Organochlorines						
Aldrin + Dieldrin	0.0007	NA	NA	NA	NA	NA
Dieldrin	NA	NA	0.000004	0.00285 (0.00667) (k)	NA	NA
bamma-BHC (Lindane)	0.004	NA	NA	NA	NA	NA
Chlordane	0.007 (h)	NA	0.000006	0.0045 (0.0089) (k)	NA	NA
p,p'-DDE + *o,p'*-DDE	NA	NA	NA	NA	NA	6.3 (g)
p,p'-DDD	NA	NA	NA	0.00142 (0.00851) (k)	NA	NA
p,p'-DDD + *o,p'*-DDD	NA	NA	NA	NA	NA	6.3 (g)
p,p'- DDE	NA	NA	NA	0.00354 (0.00675) (k)	NA	NA
p,p'-DDT + *o,p'*-DDT	NA	NA	NA	NA	NA	6.3 (g)
DDT	0.03 (total isomers)	NA	0.000001	0.00698 (4.45) (k) (total isomers)	NA NA	NA under development
Endosulfan	NA	NA	0.00002	NA	NA	NA
Endosulfan sulphate	NA	NA	NA	NA	NA	NA
Endrin	NA (i)	NA	0.0000023	0.00267 (0.0624) (k)	NA	NA
Hexachlorobenzene	NA	NA	0.0000065 (h)	NA	NA	NA
Heptachlor + Heptachlor epoxide	0.003	NA	0.00001	NA	NA	NA
Heptachlor epoxide	NA	NA	NA	0.0006 (0.00274) (k)	NA	NA
Methoxychlor	0.9	NA	NA	NA	NA	NA
Mirex	NA (i)	NA	NA	NA	NA	NA
trans-Nonachlor	NA	NA	NA	NA	NA	NA
Oxychlordane	NA	NA	NA	NA	NA	NA
Toxaphene	NA (i)	NA	0.000008	under development	NA	under development
Polycyclic Aromatic Hydrocarbons						
Naphthalene	NA	NA	0.001(f,g)	NA	NA	NA
Alkylated naphthalenes	NA	NA	NA	NA	NA	NA
Acenaphthylene	NA	NA	NA	NA	NA	NA
Acenaphthene	NA	NA	0.006 (f,g)	NA	NA	NA
Fluorene	NA	NA	NA	NA	NA	NA
Phenanthrene	NA	NA	0.0005 (f,g)	0.0419 (0.515) (k)	NA	NA
Anthracene	NA	NA	0.00001 (f,g)	NA	NA	NA
Alkalated phenanthrenes + Alkalated anthracenes						
Fluoranthene	NA	NA	0.00004 (f,g)	0.111 (2.355) (k)	NA	NA
Pyrene	NA	NA	0.00002 (f,g)	0.053 (0.875) (k)	NA	NA
Alkalated fluoranthrenes						

+ Alkalated pyrenes						
Benzo(a)anthracene	NA	NA	0.00002 (f,g)	0.0317 (0.385) (k)	NA	NA
Chrysene	NA	NA	NA	0.0571 (0.862) (k)	NA	NA
Benzo(b)fluoranthene	NA	NA	NA	NA	NA	NA
Benzo(k)fluoranthene	NA	NA	NA	NA	NA	NA
Benzo(b/k)fluroanthene	NA	NA	NA	NA	NA	NA
Benzo(a)pyrene	0.00001	NA	0.00001 (f,g)	0.0319 (0.782) (k)	NA	NA
Benzo(e)pyrene	NA	NA	NA	NA	NA	NA
Indeno(1,2,3-c,d)pyrene	NA	NA	NA	NA	NA	NA
Dibenzo(a,h)anthracene	NA	NA	NA	NA	NA	NA
Perylene	NA	NA	NA	NA	NA	NA
Benzo(g,h,i)perylene	NA	NA	NA	NA	NA	NA
Retene	NA	NA	NA	NA	NA	NA
Dibenzothiophene	NA	NA	NA	NA	NA	NA
Total PAHs	NA (i)	NA	NA	NA	NA	NA
PCBs						
Total	NA (h)	NA	0.000001	0.0341 (0.277) (k)	NA	7.6 (e,g)
Aroclor 1242	NA	NA	NA	NA	NA	56 (e,g)
Aroclor 1248	NA	NA	NA	NA	NA	7.6 (e,g)
Aroclor 1254	NA	NA	NA	under development	NA	7.6 (e,g)
Aroclor 1260	NA	NA	NA	NA	NA	8.0 (e,g)
Resin Acids						
Pimaric Acid	NA	NA	NA	NA	NA	NA
Sandaracopimaric acid	NA	NA	NA	NA	NA	NA
Isopimaric acid	NA	NA	NA	NA	NA	NA
Palustric acid	NA	NA	NA	NA	NA	NA
Dehydroisopimaric acid	NA	NA	NA	NA	NA	NA
Abietic Acid	NA	NA	NA	NA	NA	NA
Neoabietic Acid	NA	NA	NA	NA	NA	NA
Chlorodehydroabietic Acids	NA	NA	NA	NA	NA	NA
Total Resin Acids	NA (i)	NA	NA	NA	NA	NA
Water Chemistry						
pH	(6.5-8.5) (j)	5.0-9.0	6.5-9.0	NAP	NAP	NAP
Conductivity	NA	NA	NA	NAP	NAP	NAP
Turbidity	1 NTU(<5 NTU) (j)	50 NTU	NA	NAP	NAP	NAP
Total Dissolved Solids	NA	NA	NA	NAP	NAP	NAP
Total Hardness	NA (i)	NA	NA	NAP	NAP	NAP
Total Alkalinity	NA	NA	NA	NAP	NAP	NAP
Total Kjeldahl Nitrogen	NA	NA	NA	NAP	NAP	NAP
Nitrate	45.0 (m)	NA	NA	NAP	NAP	NAP
Nitrite	3.2 (n)	NA	0.06	NAP	NAP	NAP
Fluoride (total)	1.5 (h)	NA	NA (h)	NAP	NAP	NAP
Chloride (total)	(≤250) (j)	NA	NA	NAP	NAP	NAP
Sulphate	(≤500) (j)	NA	NA	NAP	NAP	NAP
Bicarbonate	NA	NA	NA	NAP	NAP	NAP
Carbonate	NA	NA	NA	NAP	NAP	NAP
Ammonia (total)	NA (i)	NA	0.08-2.5 (h)	NAP	NAP	NAP
Dissolved Orthophosphate	NA	NA	NA	NAP	NAP	NAP
Dissolved Phosphate	NA	NA	NA	NAP	NAP	NAP
Total Phosphate	NA	NA	NA	NAP	NAP	NAP
Total Organic Carbon	NA (i)	NA	NA	NAP	NAP	NAP
Dissolved Organic Carbon	NA	NA	NA	NAP	NAP	NAP
Calcium	NA (i)	NA	NA	NAP	NAP	NAP
Magnesium	NA (i)	NA	NA	NAP	NAP	NAP
Sodium	(≤200) (j)	NA	NA	NAP	NAP	NAP
Potassium	NA	NA	NA	NAP	NAP	NAP
Iron (total)	(≤0.3) (j)	NA	0.3	NAP	NAP	NAP
Manganese	(≤0.05) (j)	NA	NA	NAP	NAP	NAP
Colour	(≤15 TCU) (j)	NA	NA	NAP	NAP	NAP
Total Suspended Solids	NA	NA	10 (o)	NAP	NAP	NAP

(a) Health and Welfare Canada. 1993. Guidelines for Canadian Drinking Water Quality. 5th ed. Prepared by the Federal-Provincial Subcommittee on Drinking Water of the Federal-Provincial Advisory Committee on Environmental and Occupational Health, Ottawa, Ontario.
(b) Health and Welfare Canada. 1992. Guidelines for Canadian Recreational Water Quality. Prepared by the Federal-Provincial Working Group on Recreational Water Quality of the Federal-Provincial Advisory Committee on Environmental and Occupational Health, Ottawa, Ontario.
(c) Canadian Council of Resource and Environment Ministers (CCREM) 1987. Canadian Water Quality Guidelines. CCREM Task Group on Water Quality Guidelines, Ottawa, Ontario.
(d) Environment Canada. 1995 (draft). Interim Sediment Quality Guidelines. Guidelines Division, Evaluation and Interpretation Branch, Ecosystem Conservation Directorate, Ottawa, Ontario.
(e) MacDonald Environmental Sciences. 1996 (draft). Canadian Tissue Residue Guidelines for Polychlorinated Biphenyls. Submitted to Guidelines Division, Evaluation and Interpretation Branch, Environment Canada, Ottawa Ontario.
(f) Interim Guideline.
(g) Draft.
(h) Guideline under review for addition to, or possible changes to, the current value.
(i) No numerical guideline required [See Health and Welfare Canada (1993) (a) for explanations].
(j) Value in parenthesis is an aesthetic objective
(k) Value in parenthesis is the probable effects level (PEL). The PEL is the chemical concentration above which adverse biological effects are expected to occur frequently; these assessment values provide guidance in addition to sediment quality guidelines for evaluating the toxicological significance of sediment-associated chemicals [for further implementation guidance regarding these values see Environment Canada (1995) (d)].
(l) Guideline changes with hardness.
(m) Equivalent to 10.0 mg•L^{-1} nitrate as nitrogen.
(n) Equivalent to 1.0 mg•L^{-1} nitrite as nitrogen.
(o) Guideline is 10 mg•L^{-1} when background concentration is ≤100 mg•L^{-1}, when background concentration is >100 mg•L^{-1},suspended solids should not exceed 10% of the background concentration.

NA = Not Available NAP = Not Applicable NTU = Nephelometric turbidity units TCU = True colour units

APPENDIX 2

This appendix contains the recommendations from each of the synthesis reports prepared by the eight component leaders. The recommendations for Synthesis Report #11 are contained on pages 64 to 71 of this report. Also included are the recommendations of a technical report dealing with fish distribution, movement and gross external pathology. At the time of assembling this appendix, the recommendation for contaminant effects, and distribution were in draft form. Consequently they may differ somewhat from the final synthesis documents on contaminants.

Synthesis Report No. 1

Impacts of Flow Regulation on the Aquatic Ecosystem of the Peace and Slave Rivers

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RECOMMENDATIONS

Primary Recommendations

1. "Naturalized" Flow Modelling

Evaluating the effects of regulation on the overall flow regime is hampered by the of the pre-regulation period data set. One method to extend the "un-regulated" period is to model flow conditions since regulation without the effect of the dam. Such a model has been under development by Alberta Environmental Protection in conjunction with British Columbia Hydro. It was originally hoped to incorporate the results of this model into some of the NRBS studies but the model is still being calibrated and results remain in draft form. It is recommended, therefore, that a priority be placed by Alberta Environmental Protection and B.C. Hydro on finalizing this work, and a re-evaluation made of the type of flow statistics presented in this report. Integral to this study should be an assessment of the significance of hydro-climatic variations in affecting the post-regulation flow characteristics.

2. Hydro-Climatic Studies of Tributary Flow

Given the importance of tributary flow in producing downstream peaks on the Peace and Slave River systems, a hydro-climatic study needs to be conducted of inter-annual variations in tributary flow. Special attention should be placed on spring snowmelt events that are known to enhance sediment contributions and be a driving force in producing break-up floods. A companion study should also be undertaken of the apparent climatic signal in the snowpack record. Temporal anomalies needs to be evaluated relative to atmospheric circulation and synoptic climatic variations. The network of snow survey stations must also be improved/expanded to permit more accurate snowmelt modelling of critical tributary basins. No data, for example, is currently collected within the Wabasca catchment, a tributary known to be important to break-up conditions near the Peace-Athabasca Delta.

3. Linking of Hydraulic Models

The current one-dimension hydraulic model of the Peace-Athabasca Delta needs to be coupled with the new hydraulic flood-routing model of the Peace and Slave Rivers. The focus of the Peace-Athabasca Delta model should be expanded beyond water levels within the Peace-Athabasca Delta to include explicitly full-season modelling of discharge to the Slave River, including the dynamic freshet period. Obtaining reliable modelled discharge from the Peace-Athabasca Delta is the only way by which flow can be modelled accurately through to Great Slave Lake and by which pre-regulation and "naturalized" flows can be calculated for the Slave River. The one-dimensional flow model of the Peace-Athabasca Delta should also be integrated with ice-jam models currently being developed in the PADTS for the reach of the Peace River that controls spring flooding of the Peace-Athabasca Delta

4. Ice Break-up Modelling

The importance of ice-jam floods on the Peace River (negative impacts to settlements and positive to riparian ecosystems) presents an excellent reason for developing and testing a river-ice break-up model. The Peace River hydraulic flood routing program, developed for the NRBS, offers the ideal building block for the development of such a break-up model. Testing and validation of the model will require more extensive monitoring of break-up conditions in the lower portions of the Peace River. This could be accomplished by extending downstream the current ice observation program conducted near the town of Peace River.

5. Ice Jam Enhancement

Although break-up modelling and forecasting is still in a state of early development, it is recommended that the current regulation scheme be modified to increase the chances of creating a break-up jam near the Peace-Athabasca Delta. Relying solely on the reservoir to produce a major break-up near the Peace-Athabasca Delta would require an enormous release of water from the Williston reservoir. Notably, this could also lead to unpredictable ice-related backwater flooding at other upstream and downstream locations. Some success could be achieved, however, if minor adjustments are made to the regulation strategy in years where tributary inflow is forecast to be large. In some years, the only modification might be a delay in the retarding of spring flows. Current ice jam modelling by the PADTS should provide an idea of the size of combined flow needed to initiate flooding of the Peace-Athabasca Delta. Furthermore, PADTS water-balance modelling will provide guidance on how frequently such intervention might be required. A single agency is needed to co-ordinate these scientific activities.

6. Changes to Morphology and Riparian Habitat

Evaluation of morphologic/vegetative changes to the Peace River involved comparison of two sets of aerial photography: just prior to regulation in the mid-1960's and a recent set obtained by the NRBS in 1993. Additional sets of photography covering other decades before and after regulation were also assembled but insufficient time precluded their analysis. It is recommended that this additional photography be analyzed to provide a better long-term record of morphological and vegetative change, one that permits validation of predicted rates of change likely to result from flow regulation.

Although morphologic studies of the Peace River included four representative reaches, the lack of aerial photography precluded an analysis of the lowest reaches, characterized by broad floodplains and numerous large islands. This zone represents a significant and productive riparian habitat consisting of a multitude of wetlands interspersed among old-growth boreal forest. Furthermore, it has been observed that the large number of split and side-channels located in this area (downstream of Peace Point) may contain backwater areas bedded with silt and clay sediment -the fine fractions known to be associated with industrial pollutants. It is therefore recommended that this reach be selected for long-term monitoring and that monumented cross-sections specifically include backwater areas that can be assessed for changes in bed sediment quality. Monumenting of sites should be conducted in collaboration with Parks Canada who have already established some permanent study plots to monitor vegetation succession within the floodplain.

7. Riparian Habitat Assessment

Some of the most significant ecological impacts produced by altered flow and water level regimes are experienced along the flow margins. To evaluate the nature and spatial extent of habitat impacts within this zone, it is recommended that further quantification (following from experienced gained from the test trials of multi-spectral imaging) be made of habitat availability, over the full range of flow conditions. This will provide the basis for establishing requisite seasonal sets of regulated flow conditions, specifically in terms of timing, duration and magnitude.

There is also a need to more fully understand how vegetation changes on the river mainstem and particularly in the two deltas affect wildlife habitat and related species populations and diversity. It is recommended that wildlife habitat changes be assessed through such methods as Habitat Evaluation Procedures (HEP) and associated wildlife surveys. Because it is not practical to assess the habitat suitability for all affected wildlife species, representative species such as muskrat, moose and buffalo should be used. A recommendation should be made to the upcoming "Bison Research and Containment Program" for the Peace-Athabasca Delta to include a science component that focuses on developing linked hydrologic, vegetation-succession and wildlife-habitat models.

8. Peace-Athabasca Delta Lake Stabilization Effects

Further investigations of the aquatic impact of stabilized water levels should be conducted for some of the large delta lakes, especially regarding changes in the nature and availability of waterfowl habitat. A special focus should be placed on fall and winter water levels that do not experience the natural seasonal drawdown as a result of both forms of regulation (weirs and upstream reservoir).

9. Slave River Delta

To obtain a better understanding of the temporal and spatial effects of flow regulation in the Slave River Delta, further studies related to the changing dynamics of the Delta are recommended possibly similar those of the PADTS. Integral elements of this ecological monitoring program should include assessments of: a) flood frequency, including open-water and ice-jam flooding, and the role of Great Slave Lake fluctuations; b) water-balance studies to determine the relative importance of flooding recharge; c) sediment regime changes including under-ice investigations; and d) vegetation succession, aided by remote-sensing assessments and the establishment of permanent transects through representative cover.

Secondary Recommendations

The following recommendations stem from the results of studies conducted in response to NRBS Question #10 but are considered secondary to completing a first-order assessment of flow-regulation impacts. Aspects of some, however, relate directly to the primary recommendations.

10. Water Temperature Model

A water temperature model should be applied to the Peace River so that the relative effects of variations in climatic conditions and regulated flow can be discerned. Ideally, the model should be integrated with the new hydraulic flood-routing model developed for the NRBS.

11. Ice-Hydraulic Study of Open-Water Zones

Detailed ice-hydraulic study should be conducted of flow conditions leading to reductions in open-water zones associated with rapids such as the Vermilion Chutes. Such an evaluation should include other turbulent reaches that historically remained open under lower pre-regulation flow conditions and be coupled with hydro-ecological studies of the importance of open-water zones to aquatic life, especially fisheries.

12. Freeze-Up Staging and Groundwater

Studies should be conducted of the long-term effect of freeze-up staging on regional groundwater levels and of its more local effect on riparian zone habitats, such as in the recharging of backwater snyes or in the succession of seral vegetation.

13. Frazil Ice and Habitat

Studies should be conducted on the role of frazil deposition in modifying/eliminating winter aquatic habitat.

14. Monumented Cross-Sections - Long Term Monitoring

The ultimate adjustment time of a large river is extremely long but no system has been studied systematically for more than a few decades. The Peace River data set provides an excellent opportunity to evaluate fully the long-term effects of flow regulation. As part of a long-term study, it is recommended that monumented cross-sections for monitoring changes in channel morphology and riparian vegetation be established within the representative reaches used in the current NRBS studies.

15. Sedimentation and Slave River Delta

More detailed studies of sedimentation processes in the outer delta are required. These are essential to separate the effects of flow regulation from natural processes, such as isostatic rebound and the role of wave action from Great Slave Lake on the Save River Delta. Such work first requires completion of the hydraulic flood-routing model of the Peace-Slave Rivers, preferably with a delta-channel network component similar to that developed for the Peace-Athabasca and Mackenzie deltas.

16. Hydrologic Vegetation model

An attempt is being made by the PADTS to improve the understanding of how changes in the hydrologic regime of the perched basin environments control changes in the vegetation regime. It is recommended that further efforts be expended on such model development and that the model be applied and validated for conditions on the Slave River Delta.

PEACE-ATHABASCA DELTA ACTION PLAN

The following was produced in response to a request from the NRBS for an experimental action plan for the Peace-Athabasca Delta. It presupposes, based on groundwork conducted by the PADTS, that flooding of the PAD is the key to restoring the ecosystem health of the perched-basin environments. Many of the proposed actions also stem from the results of PADTS discussions about potential methods and, in some cases, actions that have already been field tested in the PAD. Prior to describing these, it is useful to review the PAD hydrology so that the recommendations can be placed in context.

Background Review

As described in Sections 2.6.2; 3.2; and 3.8.2 of Synthesis Report # 1, the PAD is composed of two different hydrologic regimes. The first includes the large shallow lakes and the major deep channels which link them to Lake Athabasca and the Peace, Athabasca and Slave rivers. It is this flow system that has been affected by the construction of rockfill weirs. In general, the weirs have restored the summer mean-maximum water levels to near pre-regulation values but they have also reduced the seasonal amplitude in water levels. Although the decrease in amplitude should create an ecological impact on lake margins, research in this area has been meagre (see Section 4.8.1: Recommendation [8] of Synthesis Report #1).

The second major regime is that of the "perched basins" which are to varying degrees disconnected from the main flow system. It is these basins that have experienced the most extensive drying and are not affected directly by water levels produced by the rockfill weirs. Notably, however, this perched-basin regime can be further subdivided according to source and frequency of flooding. For example, since the time of the last major flood of 1974, the Athabasca River has inundated some of the perched basins in the southern portions of the PAD. Similarly, some of the low-lying southern basins have been flooded by high lake levels. Perched basins that have experienced the most extensive drying exist in the northern portions of the PAD and are dependent on macro-scale flooding of the Peace River for filling.

Proposed Experimental Actions

Given the above differences in hydrologic regime, it is useful to consider experimental actions that differ by scale and location.

1. Small-Scale Basin Specific

The basic experimental approach here is to capture water in single basins during high flow events with the use of simple control structures. The structure is constructed within the levee of the basins and operated to permit the entry of water during periods of high stage and prohibit its exit when flow in the main channels and lakes decline. Since this method relies on the main flow network, it can only be conducted in basins with suitable levee/elevation characteristics. The results of such an approach (e.g., on vegetation succession or small mammal populations) are limited to the experimental basin. Results could provide, however, invaluable data for developing the requisite models for predicting vegetative response to large-scale wetting of the PAD.

An alternative to the expensive construction of variable-height weirs is the use of pumps to recharge specific basins. Pumps offer the additional opportunity of flooding basins perched above the main flow network.

2. Meso-Scale Basins Adjacent to Large Lakes and Channels

Meso-scale flooding of the PAD requires the redirection of water flowing through the Delta onto the adjacent landscape. The best method to achieve this is to present an obstruction to the flow at a critical hydraulic node in the delta channel-lake system, thereby creating backwater which would inundate the surrounding perched-basin environment. The natural levels around such basins would retain the water after the backwater recedes.

The best hydraulic node for the construction of a flow obstruction within the PAD is near the Quatre Fourches Dog Camp. Notably, this was the site of one of the early rockfill weirs; a structure that was successful in significantly raising lake water levels during a large spring-runoff event in 1971, but also one that proved to be ecologically unsuitable because it impaired the migration of fish. As part of the PADTS (see section 3.8.2), an artificial ice dam was constructed overtop of the old weir. The objective was to use the temporary ice structure the passage of spring snowmelt runoff through the Delta, thereby creating backwater that would flood basins adjacent to the large delta lakes. Since construction of the early weirs, a significant percentage of the Athabasca flow has been diverted naturally into the Delta lakes through development of the Embarras River breakthrough to Mamawi Creek. This has increased the possibility of obstructing spring flow in the delta lakes. Success of using an artificial ice dam at this site is dependent on the vagaries of winter climate (specifically the magnitude, rate and timing of spring snowmelt) and the winter flow strategies of B.C. Hydro. For example, it appears that sudden winter decreases in upstream flow over the winter of 1994/95 hampered the ability of the artificial ice dam to elevate water levels to flood stage. If such an attempt is undertaken again, agreements should be made regarding winter flow operations.

An alternative to using an artificial ice dam would be to employ a gated structure. This, like the ice dam, would minimize problems associated with fish migration among the lakes and channels but problems may exist about the construction of such a permanent feature within a National Park.

It should be stressed again, however, that the above medium-scale approaches still only have the possibility of affecting perched basins close to the backwater effect that could be established near the Dog Camp hydraulic node. Such flooding will not affect the northern perched basins close to the Peace River -ones that are believed to have experienced the most drying since 1974.

3. Macro-Scale Flooding from the Peace River

Introducing macro-scale flooding of the PAD is possible only through disruption of flow on the large Peace or Slave rivers. Again, a permanent gated structure could be used but construction/engineering costs would be enormous. The possibility of constructing an artificial ice dam has also been considered by the PADTS. Recognizing the need for an environmental impact assessment of related effects, early community information meeting were also held by the PADTS.

Similar to the meso-scale approach, the success of an artificial ice dam depends very much on the vagaries of climate, especially as they affect the magnitude of spring runoff produced by tributaries downstream of the Bennett dam, such as the Smoky and Wabasca rivers. Given this, the most practical recommendation is "[5] Ice Jam Enhancement" outlined in Section 4.8.1. The success of an artificial ice jam could be enhanced further if there was a concurrent attempt near the PAD to increase the resistance of the Peace River ice cover to breakup. This could include increasing thickness using spray-ice techniques and/or the retardation of melt through the application of insulating materials.

Synthesis Report No. 2

Effects of Contaminants on Aquatic Organisms in the Peace, Athabasca and Slave River Basins

By: John H. Carey and Olga T. R. Cordiero

National Water Research Institute
Burlington, Ontario

CONCLUSIONS AND RECOMMENDATIONS

In summary, there was little evidence from the basin wide survey of physiological parameters in wild fish or from either of the more new approaches to specific monitoring of regional effects on biota in the basins. The Sediment toxicity studies supported this statement. There was some limited evidence that pulp mills may be causing depressed sexual hormones in fish. In light of the physiological responses observed in the lower Athabasca River area and in tributaries in this region, more attention needs to be devoted to understanding the long term effects of the tar sands and related petroleum pollution.

To further improve our understanding of the responses there are several scientific studies that could be conducted both in the field and laboratory:

1. Fish Response to Hydrocarbons

The long term response of fish in the lower Athabasca River to contaminants from the petroleum seeps, tar sands and other hydrocarbon related pollution needs to be investigated. In particular, the connection, if any, between the distribution of immature burbot in the downstream areas needs to be addressed.

2. Ecology of Burbot

More information needs to be obtained concerning the ecology of burbot to determine if the anomolous distributions observed in this study were caused by contaminants or are the result of some previously unknown aspect of burbot lifestyle.

3. Retinoid Studies

The apparent anomolous high concentrations of free retinols and depressed tocopherol in the lower Peace River needs to be further investigated. If the observation is replicated, it needs to be explained.

4. Life History of Small Fish

Not enough information is available on the growth rates, reproductive strategies, or life history of small fish to help plan monitoring programs based on forage fish to monitor impacts of industrial discharges in large rivers. Baseline data on life history characteristics of these species needs to be collected. Greater knowledge of the general biology would also improve the capture efficiency of small species. Due to higher levels of abundance associated with many forage species, the collection of adequate sample sizes would become very cost-effective.

5. Natural Variability and Small Fish

The NRBS studies demonstrated substantial variability in whole organism responses among reference populations of the small fish species studied, spoonhead sculpin and lake chub. More effort needs to be directed towards establishing the full range of variability associated with reference fish; both within a monitoring system and among a variety of similar aquatic systems. Interpretation of results of a small fish-based monitoring program will depend on a good understanding on the extent and causes of natural variability.

6. Mobility of Small Fish

More information is needed to further evaluate the mobility of smaller fish species. Although small species in this study were not as mobile as many of the large fish species, it is still necessary to increase our understanding of the degree and pattern of mobility, size of home range and habitat requirements associated with specific small species of interest.

7. Comparative Responses of Small and Large Fish

To further evaluate the suitability of small fish species, it would be of interest to compare responses between small and large fish species of the same monitoring system. If possible, it would be advantageous to monitor a system possessing habitat or man-made barriers that would restrict the movement of the larger fish species. The comparison would examine the consistency of responses between species and investigate the relative sensitivity of each species.

8. Endocrin Disruption

Laboratory evaluations of the potential of effluents to disrupt steroids and induce MFO activity need to be repeated. Preliminary work was done during the current project, but the steroid exposure protocol was still under development and has just been recently finalized. The exposures should be repeated using the final protocol. This information would be valuable to evaluate whether the effluents show the potential to induce physiological changes.

9.Standardized SPMD Protocol

Work on developing the SPMD concept further should be encouraged so that a standardized protocol for their use in a monitoring program can be achieved.

Synthesis Report No. 3

Distribution of Contaminants in the Water, Sediment and Biota of the Northern River Basins: Present Levels and Predicted Future Trends

By: John H. Carey , Olga T. R. Cordeiro , and Brian G. Brownlee

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RECOMMENDATIONS

Monitoring and Reporting

1. Refocused Contaminant Monitoring

Given the low levels of organochlorines in water, sediment and biota by the end of the study period, it is recommended that the design and purpose of existing water quality monitoring programs be reviewed based on the NRBS findings. There appears to be no need for intensive basin-wide monitoring for these contaminants. Periodic monitoring, on a two or three year cycle, for contaminants in relevant compartments only, for example PCBs and chlorinated dioxins/furans in fish and PAHs and resin acids in sediment, should be sufficient to detect changes in the basin.

2. Mercury Monitoring in Fish

Mercury levels in certain areas of the basin, for example the lower reaches of the Athabasca River, are high and likely exceed human health consumption guidelines. It is recommended that mercury levels continue to be monitored regularly, particularly in the lower Athabasca River and western Lake Athabasca.

3. Indicator Fish Species for Biological Monitoring

Burbot or, failing that, one of the sucker species are likely the most suitable large fish for use as an indicator species for biological monitoring. It is recommended that whitefish not be used for biological monitoring in this system.

4. Finger-Printing of Organic Effluents and Ambient Waters

It is recommended that a combination of the NRBS results from the broad spectrum analysis and selected target compound analysis be used to establish a baseline finger-print pattern of contaminants in effluents and ambient waters against which future changes can be assessed through the use of pattern recognition techniques.

5. Data Management System

It is recommended that a data management system be established to allow storage and access of all contaminant data collected by governments, industry etc.

6. Sample Archiving

In view of the unique character of the NRBS samples and their potential value to future generations, it is recommended that government agencies undertake to ensure that the NRBS samples are adequately stored so that they can be made available as a baseline reference for future studies.

Fish Consumption/Water Quality Guidelines

7. Permanency Technology Improment Fish Consumption Guidelines Review

In light of the dramatic decreases in chlorinated dioxin and furan concentrations in fish observed by the NRBS after bleaching changes by the pulp mills, it is recommended that these bleaching changes be permanent for the mills and that fish consumption advisories based on chlorinated dioxin/furan concentrations be reviewed.

8. Dietary Habits

It is recommended that better dietary intake information or subsistence fish consumers in the basin be collected. This information is needed to help establish fish consumption guidelines based on human health for these people.

Research

9. Sources of PCB and Metal Contaminates

It is recommended that the apparent local hot spots of PCB and metal contamination identified during the study be further documented and where the elevated levels are confirmed, that small site specific studies be conducted to identify the sources.

Synthesis Report No. 4

Nutrient Enrichment in the Peace, Athabasca and Slave Rivers: Assessment of Present Conditions and Future Trends

By: P.A. Chambers

**National Hydrology Research Institute
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SCIENTIFIC AND MANAGEMENT RECOMMENDATIONS

Monitoring, Data Handling and Reporting

1. Licencing for Nutrients

Regular monitoring and reporting of nutrients from sewage treatment plants should be license requirements, particularly the larger sewage treatment plants such as Grande Prairie and Fort McMurray. These larger sewage treatment plants have nutrient loads similar to that of pulp mills in the basins. Yet under the 1993 Alberta Environmental Protection and Enhancement Act, operators of continuously-discharging sewage treatments plants need only report exceedances (within 24 h) to Alberta Environmental Protection.

2. Compliance with Sampling and Analytical Procedures

Compliance with sampling and analytical procedures should be mandatory for all licensed dischargers. Demonstration of QA/QC for sampling and analytical procedures and adequate detection limits should be a license requirement and conducted at regular intervals. While all licenses stipulate that sample analysis must be done following the latest edition of Standard Methods for the Examination of Water and Waste Water (APHA 1995), some samples have been analysed incorrectly. In addition, some laboratories are not analysing to current detection limits (i.e., TP detection limits are reported as 0.05 mg/L).

3. Standardized Reporting of Water Data

Standard reporting requirements for water quality parameters should be established. For example, the units of reporting are not consistent (e.g., reporting of nitrite as nitrogen rather than nitrite) or misleading (e.g., nitrite reported as nitrogen but "as N" left off data sheet). Phosphate is reported when the analysis (digestion) would appear to be TP. TDP concentrations are greater than TP concentrations. Provision is needed for ensuring trained personnel to collate laboratory results and prepare data reports. Reporting proper water quality data should be a license requirement

4. Operator Training for Measuring Flows and Discharge

Provisions are needed to ensure training of certified operators to measure (and record) flows and discharge volumes and for enforcement of reporting requirements. At present, sewage treatment plant operators often supply missing, unreliable and/or ambiguous discharge data that then become incorporated in effluent databases (e.g., the Towns of Peace River, Barrhead and Wabasca have not reported reliable flow data). Reporting accurate discharge data should be a license requirement

5. Database System

A properly-maintained central database should be established for: (a) effluent monitoring data (discharge and water quality parameters for all industries and municipalities with licensed monitoring requirements), and (b) environmental data collected by industries. These databases should be linked with the provincial surface-water quality database.

6. Bioavailability of Industrial and Municipal Nutrients

The bioavailability of nutrients in industrial and municipal effluents should be characterized. At present, pulp mill licensing requirements include monitoring of NH_4, NO_3, NO_2, total Kjeldahl N, TDP and TP in weekly grab samples; there is not a monitoring requirement for nutrients by municipal dischargers. Analysis of SRP concentrations and/or algal bioassays for N and P availability in effluents would allow better assessment of instream impacts.

7. Artificial Streams for "Effects Monitoring"

Artificial streams and nutrient diffusing substrata developed for NRBS should be considered as a promising tool for environmental effects monitoring by the pulp and paper industry. Artificial streams allow investigation of cause and effect scenarios and development of ecological indicators for riverine biota under experimentally controlled dose-response regimes. They also facilitate the development, parameterization and testing of water quality models for predicting ecosystem-level responses to nutrient and contaminant addition. Nutrient diffusing substrata permit in situ assessment of the effect of effluents on river nutrient status. These approaches would assist in defining the effects of pulp mill effluent on benthic biota.

8. Fall Nutrient Monitoring

Limited data are collected on nutrient concentrations during fall, which is the time of maximum biological productivity. Environmental monitoring by industries should be undertaken in fall and, in the case of the Athabasca River, should be coordinated such that a comprehensive longitudinal survey of the river is obtained each fall.

Modelling

9. Coordinate Industry Monitoring

The scope of nutrient and biotic data collected to date is too limited for simulation modelling. The season of concern is fall and nutrient concentrations are not usually monitored at this time of year. The limitations in the nutrient, periphyton and benthic invertebrate data could likely be addressed if industries coordinated their environmental monitoring. However, there is still no information on rates of nutrient uptake and cycling for the Northern Rivers.

10. Simulation Modelling of Nutrient Dynamics

Given the limited database and the problems identified in attempting to model other less complex parameters in the Northern Rivers (Chambers and Mill 1996; McCauley 1996), simulation modelling of nutrient dynamics and associated biological responses is not recommended at this time. At present, predictions of changes in benthic communities can better be made from studies conducted in artificial streams or through empirical modelling.

Research

11. Effect of Nutrients on Biota

In situ experiments have identified nitrogen limitation of periphyton growth in the 230 km reach of the Athabasca River from downstream of Alberta Newsprint Co. to the Lesser Slave River and in the Smoky River downstream of the Wapiti River confluence. Controlled experiments are required to evaluate the effects of nitrogen addition on biota in these river reaches.

12. Non-Point Source Pollution

Data are almost entirely lacking on the contribution of non-point sources to nutrient loads in the Northern Rivers. While contributions can be estimated from the limited data for Alberta and other parts of the world, the large changes in landuse patterns that have taken place and continue to occur (e.g., agricultural land clearing, timber harvesting, oil and gas activities) warrant closer examination of the impacts of changing landuse on nutrient loading.

Water Quality and Effluent Guidelines

13. Ecosystem Based Permit Limits

Effluent permit limits should be assessed and should be based on environmental effects rather than on technology design standards. The 1 mg/L TP level for most municipal permits is a technology-based limit since tertiary sewage treatment plants can usually achieve P removal to less than 1 mg/L. Similarly, the 3 kg BOD_5/air-dried tonne for most pulp mill permits is a technology-based limit. All industries and municipalities should be licensed on the basis of environmental effects. In the case of no perceptible environmental effects, industries and municipalities should be regulated to a designated technology standard. It should be noted, however, that while phosphorus (and, in some locations, nitrogen) are important factors controlling periphyton abundance in the Athabasca and Wapiti-Smoky rivers, we still lack quantitative relationships between phosphorus concentrations and periphyton biomass for any given site. Thus, it is not possible to set effluent permit limits for phosphorus so as to control periphyton abundance at a specific level.

14. Nutrient Guidelines

Alberta Water Surface Quality Objectives (Alberta Environment 1977) are frequently exceeded for TP and occasionally exceeded for TN in the Athabasca, Wapiti, Smoky and Peace rivers. With the exception of the Wapiti River, many of these exceedances are attributable to high particulate loads associated with high flows. In the Wapiti River, many of the exceedances appear attributable to effluent discharge from Weyerhaeuser Canada Ltd. and, in the case of TP, to the Grande Prairie sewage treatment plant. Many regulatory agencies are moving away from numeric guidelines for nutrients but, instead, are evaluating or implementing qualitative or numeric guidelines based on aquatic plant abundance in the receiving water. At present, increased periphyton biomass is observed downstream of all mill and large sewage treatment plant (Fort McMurray and Grande Prairie) discharges. There is no evidence that this increased periphyton biomass has impaired spawning habitats, contributed to DO declines during winter or caused consistent long-term changes in benthic invertebrate taxonomic composition. However, if these reaches are deemed to be of recreational or aesthetic value, then a site-specific guideline for plant biomass may be desired. The British

Columbia Ministry of Environment has recommended a criterion based on periphyton biomass of < 50 mg/m^2 chlorophyll a to protect uses related to recreation and aesthetics in streams and < 100 mg/m^2 chlorophyll a to protect against undesirable changes in aquatic life. However, before adopting a guideline based on a quantitative nutrient response (i.e., a specific level of aquatic plant abundance), a quantitative relationship between periphyton biomass and its environmental controls must be established.

Synthesis Report No. 5

Dissolved Oxygen Conditions and Fish Requirements in the Athabasca, Peace and Slave Rivers: Assessment of Present Conditions and Future Trends

By: P.A. Chambers[1] and T. Mill[2]

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SCIENTIFIC AND MANAGEMENT RECOMMENDATIONS

Monitoring, Data Handling and Reporting

1. Licence Requirements - BOD_5

Regular monitoring and reporting of BOD_5 from sewage treatment plants should be license requirements. Some of these larger sewage treatment plants, such as Fort McMurray, have BOD_5 loads approaching that of pulp mills in the basins. Yet under the 1993 *Alberta Environmental Protection and Enhancement Act*, operators of continuously-discharging sewage treatments plants need only report exceedances (within 24 h) to Alberta Environmental Protection.

2. Compliance with Sampling and Analytical Procedures

Compliance with sampling and analytical procedures should be mandatory for all licensed dischargers. Demonstration of QA/QC for sampling and analytical procedures should be a license requirement and conducted at regular intervals. While all licenses stipulate that sample analysis must be conducted following the latest edition of Standard Methods for the Examination of Water and Waste Water (APHA1995), some samples have been analyzed incorrectly (e.g., some BOD_5 samples) and other methodologies (e.g., for BOD_u analysis) vary between laboratories.

3.Operator Training for Measuring Flow and Discharge

Provisions are needed to ensure training of certified operators to measure (and record) flows and discharge volumes and for enforcement of reporting requirements. At present, sewage treatment plant operators often supply missing, unreliable and/or ambiguous discharge data that then become incorporated in effluent databases (e.g., the Towns of Peace River, Barrhead and Wabasca have not reported reliable flow data). Reporting proper discharge data should be a license requirement.

4. Database System

A properly-maintained central database should be established for: (a) effluent monitoring data (discharge and water quality parameters for all industries and municipalities with licensed monitoring requirements), and (b) environmental data collected by industries. These databases should be linked with the provincial surface-water quality database.

5. Dissolved Oxygen and Mixing Zones

Concern has been raised about DO concentrations in mixing zones.DO concentrations in mixing zones have never been explicitly studied although the Alberta Environmental Protection winter water quality surveys usually sample from both banks in reaches of effluent mixing. At low flow conditions, effluents to the Athabasca and Wapiti River are usually fully mixed by approximately 10 km downstream of the outfall. Since there have been no reports of impairment to fish in the mixing zones, further field work on mixing zones with respect of DO conditions is not recommended at this time.

6. Fish and Fish Habitat Oxygen Monitoring and Modelling

DO monitoring and modelling must be more closely tied to the distribution of fish and fish habitat and fish DO requirements.

Dissolved Oxygen - Modelling Deficiencies

7. Defining Modelling Goals

Modelling goals need to be clearly defined. There appear to be two goals with respect to DO modelling in the Northern River basins: (1) short-term compliance assessments (i.e., predicting DO levels during the upcoming winter), and (2) long-term basin management (i.e., establishing license requirements with respect to changing industrial operations). Dynamic models (i.e., allowing for temporal and downstream variability in DO) may be better suited for addressing the short-term goal because early DO winter data could be used in predicting DO concentrations during late winter. Modelling for long-term basin management focuses on average or low-flow conditions and, hence, could be accomplished using a deterministic approach. For both approaches, a probabilistic model should be employed so as to allow assessment of the effect of variances in model input parameters on the confidence of the model predictions.

8. Validation of Model Coefficients

Implementation of a dynamic model such as WASP (Water Quality Analysis Simulation Program) will address questions regarding temporal variability in the decrease in DO in the Athabasca River with distance (i.e., the changing relationship between upstream and downstream DO concentrations as the winter progresses). However, basic issues such as validating the ice-cover Leopold-Maddock coefficients used in calculating reach velocities (see Section 8.2.2 of Synthesis Report 5) need to be resolved before more complex modelling is attempted. If WASP or any other DO simulation model is implemented, the model rates established and validated by Chambers et al. (1996) should be employed rather than calibration values.

9. 2-D Dissolved Oxygen Model for Mixing Zones

Concerns about DO concentrations in mixing zones could be addressed by moving to a model capable of 2-dimensional simulation (i.e., changes across the channel as well as longitudinally down the channel).However, there are currently only limited data on DO concentrations within mixing zones.

10. Modelling Cumulative Impact of DO

Modelling of temporal DO patterns in the Athabasca River and the cumulative impacts on populations of mountain whitefish, bull trout and burbot should be attempted.

11. Effluent Discharge Schedule during Winter

Modelling of effluent discharge timing and seasonal DO sagging in the Athabasca River should be conducted whenever industrial operations change or unusually low winter flows are forecast, and a schedule developed to minimize increases in chemical and biological oxygen demand during late winter.

12. Independant Review of Modelling

Modelling needs to be undertaken by one group and independently reviewed by another group with modelling expertise to validate the assumptions and subjectivity that comes into play when modelling complex systems with parameter-rich (sometimes data-poor) models.

Dissolved Oxygen - Data Deficiencies

13. Biological Oxygen Demand at Sewage Treatment Plants

Additional measures of STP BOD_5 decay rates and BOD_u:BOD_5 ratios are required to verify the values currently used in the modelling. Currently this information is limited to data from Grande Prairie STP on one date.

14. Sediment Oxygen Demand

Cross-channel variability in SOD should be examined and the relationship between sedimentation and SOD should be assessed, particularly below mill outfalls and tributary inflows.

15. Ice-Cover Leopold-Maddock Coefficients

Ice-cover Leopold-Maddock coefficients, which are used to establish reach velocities and to convert a real SOD to volumetric SOD rates, should be re-evaluated for discharges similar to the long-term average discharge at Hinton. Comparisons of time-of-travel by Thompson and Fitch (1989) and Andres et al. (1989) showed discrepancies particularly in the reach downstream of Hinton (Chambers et al. 1996). An additional under-ice time of travel study should be conducted to verify the results of Andres et al. (1989) and provide further data for re-assessing the ice-cover Leopold Maddock coefficients.

16. Temperature Correction for BOD Decay
Temperature correction coefficients for correcting laboratory measurements of BOD decay made at 20°C to the river temperature of 0°C in winter must be validated.

17. Photosynthetic Rates below Ice
Photosynthetic rates below ice and snow cover of differing thicknesses should be measured during years when this is deemed significant and the influence of this parameter on DO modelling should be evaluated.

18. Parameters for 2-D DO Modelling
With respect to two-dimensional modelling (i.e., changes in DO over time and with distance downstream), little or no temporal data exist on parameters such as SOD, the size of open-water leads, photosynthetic rates (both temporally and diel), and BOD_5 sedimentation.

19. Standardizing of Discharge Measurement
The use of "balanced", "estimated" or "measured" river and tributary flows should be standardized. What discharge should be used for tributaries that are not gauged? How is discharge calculated on the mainstem between gauged stations?

20. Data for Factors Affecting Dissolved Oxygen
Data are not available on groundwater inputs, diffuse loading, the size of open-water leads, nitrification (i.e., nitrogenous oxygen demand), and the applicability of SOD rates measured near shore to the entire channel.

21. Forecasting DO Upstream of Hinton
The concentration of DO upstream of Hinton is an important factor determining downstream concentrations in the Athabasca River. Between 1990 and 1993, DO concentrations in the Athabasca River upstream of Hinton ranged from 11.5 to 12.5 mg/L approximately 3-4 weeks after freeze-up. Concern about forecasting DO concentrations upstream of Hinton could be resolved by recognizing that modelling for: (1) long-term basin management must focus on average or worst-case scenarios (thereby eliminating the need to predict headwater DO concentrations for any particular year), and (2) short-term compliance assessments could be initiated in early winter using headwater DO concentrations measured in early winter (December or January) and average winter variance of headwater DO, or could incorporate a model relating headwater DO concentration to ice development.

Research

22. Dissolved Oxygen in Winter Substratum
In situ measurements of DO levels in the substratum during winter and their relationship to water-column DO concentrations are necessary to assess the DO status of fish and benthic invertebrate habitat and to predict substratum DO concentrations from the more routine measurements of water-column values.

23. Studies into Combined Effects of Effluents and Low Dissolved Oxygen
Studies of the combined effects of effluent and low DO levels should be expanded to include fish species and important benthic invertebrates and to assess how impacts may be modified by differences in developmental stage or in acclimation time to low DO levels. In fish, contaminant-DO interactions should be examined, specifically the relationship between various hormonal and enzyme induction indicators of stress and seasonally low DO.

24. Sedimentation Rates
Sedimentation rates should be measured below all mills to determine if settling rates are the same for different effluent types. Also, a determination of whether the sedimentation rates measured for all material (organic and inorganic) applies to only oxygen-consuming material is needed.

25. Cause of Elevated SOD below Pulp Mill
The cause of elevated SOD rates below pulp mill discharges needs to be established. These higher SOD rates may be due to organic carbon loading or enhanced periphyton growth due to nutrient loading from pulp mills.

26. *In situ* Bioassays and Lab Dose - Response Studies
In situ bioassays with eggs of mountain whitefish, bull trout and burbot should be conducted at key sites in the Athabasca River in conjunction with measurements of DO, BOD_5, contaminant occurrence and effects, and ice cover effects. In addition, laboratory studies are required to determine a dose-dependent relationship between individual embryonic development stages and DO concentration for each of the major fish species. This work should include incubation trials at 0 to 1°C to more closely simulate natural winter temperature regimes.

Water Quality and Effluent Guidelines

27. Ecosystem Based Effluent Permit Limits

Effluent permit limits should be assessed and based on ecosystem effects rather than technology design standards. The 3 kg BOD_5/air-dried-tonne limit for most pulp mills and the 25 mg/L BOD_5 limit for most municipal discharge permits is a technology-based limit.

28. Impacts of BOD Non-compliance

The Towns of Peace River, Fort Smith and Fort Chipewyan have continuous sewage discharges that often exceed the permit limit of 25 mg/L BOD_5.In the case of Peace River and Fort Smith, these high discharges may not have biological consequences due to the large volumes of water in the Peace and Slave rivers. In addition, 26 periodic municipal dischargers (i.e., discharge from wastewater stabilization lagoons) exceeded the 25 mg/L BOD_5 limit (based on 1990-1993 data). An assessment of the environmental impacts of these exceedances is recommended.

29. Regulatory Standard for Dissolved Oxygen

Regulatory standards for DO need to be reviewed to ensure that they are consistent with the minimal requirements known to be important for the native fishes of the Northern River basins. Laboratory studies on effects of lowered DO levels (3 mg/L) at low temperature (2-3°C) showed that mountain whitefish eggs took longer to hatch and bull trout alevins were less well developed than at higher DO concentrations. DO concentrations of 6 mg/L may also extend the time required to hatch by some burbot. The commonly-occurring mayfly in the Northern Rivers (*Baetis tricaudatus*) was also found to have decreased survival and reduced feeding rates at a DO concentration of 5 mg/L. Given the fact that mayflies and the early life stages of fish live at or in the surface layers of the riverbed and that DO concentrations can differ by 3 mg/L DO between the water column and the sediment-water interface (Chapman 1986), DO concentrations in the Athabasca River could already be at levels that could have chronic effects on these animals at localized sites. Based on the fact that many fall-spawning fish species in the Northern River basins are in the salmonid family, the more conservative *Canadian Water Quality Guideline* (CCREM 1987) of $ 6.5 mg/L DO for salmonids is recommended as a policy-based guideline to be used in setting effluent license conditions for periods of ice-cover.

Synthesis Report No. 7

Use of Aquatic Resources in the Northern River Basins: Synthesis Report

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RECOMMENDATIONS

The socio-economic component of the NRBS represents a departure from the conventional, technical approach to water management studies. In mapping out public perceptions on water issues, the study has yielded information that allows water and environmental managers to better differentiate between technical and perceived management issues. Perceived problems are real problems, regardless of whether or not there is a technical cause, and still need to be dealt with by resource managers. However, the management approaches used to address perceived problems are substantially different from the technical solutions often considered.

The socio-economic studies also provide a rare, quantified summary of public views and understanding of current issues that can only be attained through surveys. This study shows that there are often very large differences between public and stakeholder values and opinions. It demonstrates that what industry wants or what local government wants, is not always what the general public wants.

This study is also a landmark in that no comparable research on water use and management issues has been attempted to date in the NRBS area. The social, economic, environmental, legal, jurisdictional and institutional views of northerners from both sides of the NWT-Alberta border will be of considerable value to the legislators and regulators of the three jurisdictions involved. Some basin residents who responded to the survey also mentioned that this type of survey provides a valuable means of monitoring river health and public perceptions of river management, and recommended that it be repeated on a regular basis.

1. Assessment of Public Perception

In response to these suggestions it is recommended that assessments of public perceptions of river health should be undertaken at regular intervals as a way of monitoring change. These assessments should follow the survey approach used by the NRBS in order to allow direct comparison of results. This approach, which was based on a combination of telephone and mail surveys from a stratified random sample of basin residents, proved to be quite satisfactory and cost effective. The surveys and related analysis conducted for the Northern River Basins Study were undertaken at a modest expenditure (approximately $150,000).

2. Boundaries of Future Surveys

It is also recommended that the same regional boundaries (based on telephone prefix regions or nearest equivalent) be used in future surveys. The NRBS surveys showed few regional differences in public opinion at the present time. However, some regional differences in perceptions and issues may evolve in the future, and these should be monitored so that water management can be responsive to regional needs.

3. Ecosystem Approach

Finally, it is recommended that future river or resource management studies be undertaken using an ecosystem approach.This approach involves:

- defining the area to be studied in terms of river basin or other ecoregion boundaries;
- using an integrated approach to examine the interactions among land, water and other resources;
- supplementing technical, biophysical information with socio-economic information that include perceptions and values; and,
- considering transboundary effects.

Within this process, surveys of the general public and stakeholder groups can be used to provide decision-makers with quantitative, representative data on public perceptions and values. In addition, surveys offer a structured opportunity for public involvement. They can be used to solicit input from a broad range of interests, and present a less intimidating and more user-friendly method for personal involvement in resource management decisions.

Synthesis Report No. 9

Assessment of Drinking Water Quality in the Northern River Basins Study Area: Synthesis Report

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RECOMMENDATIONS

Public Health

1. Assessment of Public Health

Drinking water quality and public health are closely related. The assessment of public health should continue with special attention given to the correlation of public health with drinking water quality and drinking water supplies in the study area. This would require additional monitoring of health records in conjunction with water quality data if possible.

2. Education Health Program

The Drinking Water Component perceives that there is a need for some public health educational programs in the NRBS area, particularly in communities where there is a large objection to chlorination. ,

The educational programs would be beneficial to those that turn to other supplies of drinking water as a result of their distaste for chlorine, to know why chlorine is used, and the risks and benefits associated with chlorinated versus unchlorinated water. Educational programs would also be beneficial for individuals who are involved in living off the land expeditions or other wilderness activities, so that they are provided with information with which they can make the best decisions regarding drinking water, sanitation and hygiene during activities such as these. Since all of these have an effect on health, good decisions in these regards would have a positive impact on public health protection.

Aesthetics

3. Monitoring Aesthetic Quality

Since the aesthetic quality of water is the generally the basis of evaluation by which consumers judge the safety of their drinking water, it is important that the aesthetic quality of the water in the northern river basins continues to be monitored and assessed.

In this manner, a historical database with baseline information would be compiled. This type of historical data base would allow an assessment of changes in the aesthetic quality of water due to new industrial developments as well as changes in existing industrial developments.

4. Causes of Taste and Odour

Additional scientific studies are required to better characterize causes of taste and odour from industrial discharge, in particular pulp and paper wastewater discharges. This characterization may lead to the development of new methods to reduce the taste and odour associated with these discharges.

Drinking Water Supplies

5. Treatment facility Optimization

The main recommendation in terms of conventional drinking water facilities in the study area is that existing facilities in the study area need to optimize treatment performance so that the best quality drinking water possible is supplied to the consumer.

This is especially true for small facilities which were found to produce poorer water quality than larger facilities. This will involve action at several levels:

5.1 Existing Monitoring Practices

Existing monitoring practices should be improved so that they are more representative of the plants performance. It must be recognized that monitoring is not only required for compliance with water quality guidelines but also needed for process control for operation of the facility. It is recommended that when possible finished water turbidity and chlorine residual should be monitored continuously. This would not only help to ensure facilities meet set guidelines for these important parameters but also provide valuable information for the operation of the facilities.

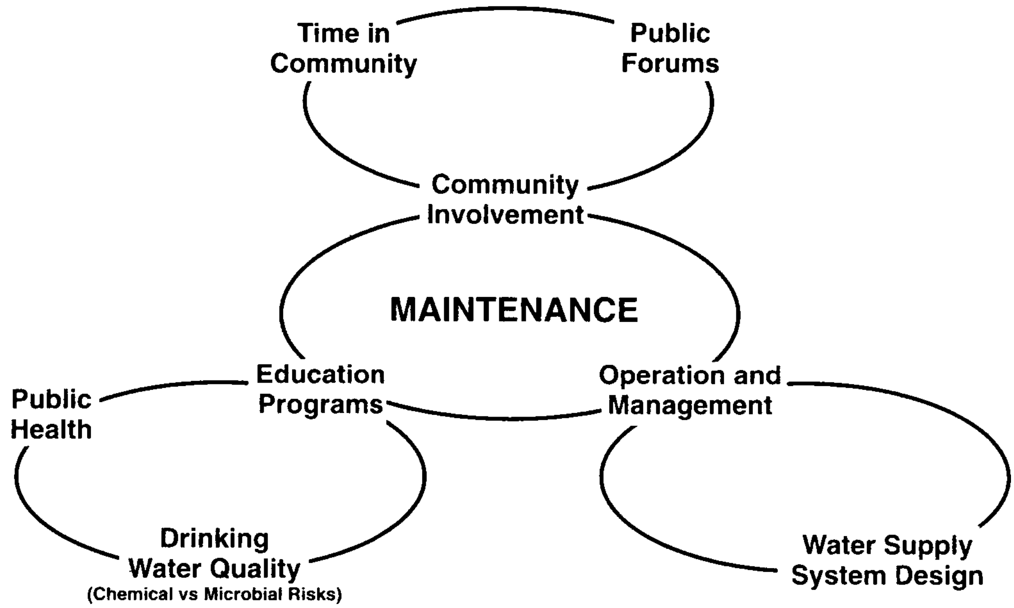
5.2 Remedial Actions

Based on monitoring results proper remedial actions should be practiced for parameters that do not meet recommended guidelines. Results from this study indicate that many of the facilities which produced poorer quality drinking water had done so for long periods.

5.3 Continuing Educational Programs

Based on site visits and similar results in other areas it was found that much of the difficulty that some facilities had in producing good quality drinking water can be related to operation and maintenance of the facilities. It is therefore recommended that continuing educational programs should be strengthened, especially for operations of small facilities.

Figure 24. Successful Drinking Water Supply System Implementation



5.4 Distribution Systems It must be recognized that the quality of drinking water which the consumer receives is not only dependent on the treatment system but also the distribution system. Although piped distribution systems are ideal, they are not financially or technically feasible for many of the remote areas typical in the Northern River Basin Study area. Where trucked delivery of water is supplied, the water should be delivered to water cisterns rather than water barrels which are still in use by some NRBS residents. This is primarily due to concerns related to post contamination that are associated with water barrels. Furthermore the state of the distribution system, piped or trucked, should be monitored to ensure proper maintenance and operation.

6. Community Investment

An effective water supply system should involve the community in all aspects of decision making. Although this is especially important during the design stages, it is also important for the maintenance of an existing water supply system. As illustrated in the following figure a simple approach can be used in communities in the NRBS area in the maintenance of a successful drinking water system.

There are three main components involved in the maintenance of a community water supply system. Community involvement is of paramount importance to the success of any project in the community. If an outside expert is to be involved in the project, then that person should spend time in the community getting to know the residents. During this time in the community, public forums can be held where questions, concerns and ideas can be discussed. The forums would also be a good time to educate residents regarding drinking water quality and general public health. Educational programs such as these comprise the second important component in this model. The third main component in the maintenance of an effective water supply program is the proper operation and maintenance of the system implemented. This is done through appropriate selection of community members to operate the designed system and through continued community involvement in future decisions. If a model such as this is followed in the design of a water supply system in the study area, a safe and sustainable supply of potable water is possible.

7. Non-conventional Supplies

Further scientific studies on non-conventional drinking water supplies in the study area and elsewhere are necessary. More drinking water quality data is needed, as well as the extent of consumption of non-conventional supplies.

8. Epidemiological Studies

As part of the scientific investigation into non-conventional drinking water, an epidemiological study could be carried out which would look at waterborne disease rates in selected areas and potential links with non-conventional drinking water consumption and/or quality. If a significant relationship was found, the results could then be used for educational programs and determining possible solutions.

Remote access to good quality drinking water is a challenge. When possible, the best source of drinking water for people living in remote areas away from conventional facilities is from a protected groundwater well. If groundwater is unavailable, then other supplies should be tapped and treated appropriately. If the safety of a given water supply is unknown or questionable, then the water should be boiled.

9. Protection of Drinking Water Sources

It is vitally important that all present and future drinking water sources are protected from physical, chemical and bacterial contaminants. In doing so, additional precautions are taken in the maintenance of safe drinking water supplies in the Northern River Basins.

Synthesis Report No. 10

Ecosystem Health and Integrated Monitoring in the Northern River Basins

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RECOMMENDATIONS

1. Integrated Ecosystem Monitoring Committee

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

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

2. Ecosystem Approach

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

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

3. Panel of Scientific Experts

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

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

4. Integrated and Harmonized Monitoring

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

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

5. Integrated Environmental Monitoring Database

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

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

6. Scientific Interpretation of Data

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

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

7. Community Involvement

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

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

8. Land-water Connectivity

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

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

9. Public Consultation

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

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

Synthesis Report No. 12

A Report of Wisdom Synthesized from the Traditional Knowledge Component Studies

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RECOMMENDATIONS

The Traditional Knowledge Component of the Northern River Basins Study recommends that:

1. Traditional Knowledge Research in all Communities

Traditional knowledge research of the Northern River Basin Study be extended to include all Aboriginal communities within the NRBS study area, especially those in the southern portions of the area; these locations were not included in the present study due to fiscal constraints.

2. Hunting / Trapping Economy

A comprehensive study be conducted to assess the economics of a traditional hunting/trapping economy within the Northern River Basin Study area.

There currently prevails a "doctrine of inevitability" which is a powerful idea held by prominent and influential people that supporting and sustaining the hunting/trapping economy is a futile exercise.

This doctrine is based on the myth that the human race has progressed by stages from hunting/gathering, to nomadic pastoralism, then to horticulture and agriculture, and finally to industrial society. This perspective is one with which we are so familiar that we take it as common sense. It is a basic cultural theme which biases the way in which, those who subscribe to this myth view the world. If one accepts this myth, it is clear that hunting and trapping cannot be taken seriously, because these activities are seen as an economic form that has historically been superseded. As such, those who partake in hunting and trapping are viewed as existing in an evolutionary backwater and they are thought, by those who subscribe to the myth, to have a need to move into a "more progressive," modern way of life.

There is a dearth of comprehensive research on the true economics of a hunting and trapping economy. The only fact that can be stated with confidence is that the people who devote labour at hunting and trapping do so to secure sustenance for economic reasons. It is, therefore, imperative that the fiscal realities of such an economy be carefully assessed and understood, and that sound methodology be developed in order that the true value (ie.economic, social, cultural, spiritual, health, ecological, etc.) can be identified. This research will enable the hunting and trapping economy to be weighed more realistically, and to be reviewed in context with other development initiatives that may negatively impact on this life-style.

3. Handbook for Traditional Knowledge Research

A "Handbook on Methodology for Traditional Knowledge Research" be developed for application on a local, national and international basis, and that the handbook be based on the experience gained by the Northern River Basin Study.

4. Effects of Land-Use Production

A comprehensive research and monitoring program be established, incorporating both traditional knowledge and conventional science, to assess the effects of land-use practices (eg.agricultural land clearing, logging, industrial development, municipal development, etc.) on the capacity of river basins to sustain ecologically desirable hydrologic regimes (surface and ground water) for future needs, and to recommend land-use management requirements to achieve this goal.

5. Water Quality Monitoring	A water quality monitoring program be initiated throughout the Northern River Basin Study area, integrating traditional knowledge and conventional scientific methodologies.
6. Co-management Agreements	Natural Resource Co-management Agreements (or cooperative management agreements) reflecting a partnership relationship between the Province of Alberta and the Aboriginal people inhabiting the Northern River Basin Study area be developed and implemented. Such agreements will integrate traditional knowledge and conventional science throughout the information-gathering processes, information interpretation, management, and decision-making processes on all matters relating to renewable natural resources within the region.
7. Economic Development Strategy	A comprehensive economic development strategy and implementation plan for the region encompassed by the Northern River Basin Study be developed, focusing on opportunities for local people using traditional knowledge as the key factor in pursuing economic development within the region.
8.Traditional Knowledge Transfer and Extension Program	A traditional knowledge transfer and extension program be developed and implemented to encourage the perpetuation of traditional knowledge from Aboriginal elders to the youth, as well as to other sectors of society.
9. Literature Search	An extensive literature search and information analysis be conducted to obtain the information that others have prepared, following analysis of specific aspects of archival and non-archival records relevant to this study.
10. Archive Studies	Additional archival studies be undertaken to expand the present database, to ensure comprehensive coverage of relevant environmental information within the study area.
11. Hudson Bay Company Weather Records	The Hudson Bay Company records of weather be studied and analyzed, then correlated with the data now included in the database(s) of Environment Canada; determine the extent to which decreased precipitation has been caused by developmental change factors.
12. Health-Related Issues	Health-related issues that have been alluded to throughout the community research component, but for which no detailed documentation exists, be the subject of extensive studies.
13. Compliance with Environmental Legislation	Industrial sites such as the now-closed mine at Pine Point be forced to adhere to environmental regulations, and to not contravene the ecological wisdom of those who live in close liaison with the land.
14. Climate Effects of Alternative Land Clearing Strategies	The climatological effect of land stripped of trees and used for agricultural purposes, compared with farm land left with 30 to 50 foot strips of trees along road allowances or in rows throughout the land mass of the larger farms, be specifically studied and analyzed.
15. Protocol for Incorporating Traditional Knowledge into Industrial Developments	A protocol be developed jointly and immediately by the Province of Alberta and the First Nations/Métis, to ensure that the knowledge and the respectfulness of the First Nations/Métis peoples toward the land is incorporated into each industrial process now in existence or contemplated for future development.
16. Incorporating Wisdom of the Ages into Industrial Practices	An elder of the First Nations/Métis community be appointed to a senior consultancy position with each major industry now operating or being planned, to ensure that the wisdom of the ages is incorporated into the day-to-day operational practices of the industries. Support by the First Nations/Métis community, of the elder and his/her appointment, is implicit and essential.

Synthesis Report No. 13a

Synthesis of Fish Distribution, Movements, Critical Habitat and Food Web for the Lower Slave River North of the 60th Parallel: A Food Chain Perspective

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RECOMMENDATIONS

1. Theoretical Models and the Lower Slave River

Further research on the lower Slave River should be undertaken with a unifying theoretical model in mind. Such an approach will do more to preserve all ecosystem components than studies specializing in one or two species or aspects of fish biology in the river.

The present theoretical models which have been developed based on river systems in the southern temperate and tropical regions may not be sufficient to describe the sub-Arctic Slave River. As stated before, the river continuum concept is most appropriate for headwater streams and small rivers, whereas the flood pulse concept is limited to large floodplain rivers and the RPM is relevant to large rivers with constricted channels and firm substrates in the photic zone. Where does the lower Slave River fit in? The original concern from NRBS was probably partly based on a river continuum model - that is what happens upstream profoundly affects function downstream. This is undoubtably true. However, the lower Slave River seems to fit better between the flood pulse and riverine productivity models because there is certainly of a flood pulse and yet much of the river is a restricted channel with productive tributaries. The recommendations that follow, therefore, keep in mind that much of the focus in the NRBS has been dealing with the linear nature of riverine systems and that research into lateral inputs and local productivity must be undertaken.

Effects on Fish Communities

2. Analysis of Current Vital Rates

Evaluating changes to the fish vital rates is limited by the lack of data prior to the construction of the Bennett Dam and other developments. Except for inconnu and burbot, most of the vital rates available are from 1978-79 collections. Analysis of the current vital rates of other species should be undertaken - especially goldeye, northern pike, walleye and lake whitefish

3. New Data on Vital Rates

Future evaluations of impacts on fish productivity will require good data on vital rates. Key species, such as inconnu, northern pike, burbot, walleye and goldeye should be assessed on a regular basis. The Department of Fisheries and Oceans should continue collection and analysis of inconnu from the lower Slave River. Collections and analysis of the other key species should be made at least once every five years to assess changes in productivity.

4. Juvenile Fish Life History

There is little information on the growth patterns of juveniles of the major species in the lower Slave River. Impacts from environmental degradation will probably affect juvenile stages first. Projects that focus on factors important to juvenile life history should be encouraged.

5. Forage Fish Vital Rates and Life History

There is almost no information on the vital rates of forage species such as emerald shiner, flathead chub, trout-perch. These species may be good indicators of changes that will ultimately affect the production of their predators, the harvested fish species.

Studies that quantify the life history trajectory (growth, age at maturity, fecundity, longevity, mortality) of forage species in the lower Slave River should be undertaken.

6. Life History Trajectory Models

There are no models that can be used to predict the response of the life history trajectory (hence how fishes are affected) to environmental degradation in the lower Slave River. Existing life history trajectory models relate to mortality factors such as fishing. Quantitative models of the potential consequences to vital rates of flow changes and/or contamination should be developed for the lower Slave River. Such models would allow more precise hypothesis testing and prediction of the effects of habitat change. This recommendation is key because it may help to priorize recommendations 2-5 and others.

Fish Species Diversity

7. Fish Species Diversity and Indicator of Ecosystem Health

Fish species diversity is a fundamental indicator of ecosystem health. Collections by gillnet and other means should be made at least once every 5 years over the entire season to determine if fish species diversity has changed.

A major problem with environmental degradation is the permanent loss of species. Lowering the diversity of ecosystems makes them less stable and able to withstand further environmental impacts. A total of 30 species have been reported in the Slave River and its delta. Twenty-seven of these species are confirmed from collection records. The other three are only reported in McCart (1986) but the references he provided do not confirm actual collections of these species. Within the confirmed group the most important family is the Salmonidae with 10 members. The Cyprinidae (5 species) is next followed by Percidae (2), Catostomidae (2), Cottidae (2), Percopsidae (1), Petromyzontidae (1), Esocidae (1), Hiodontidae (1), Gadidae (1), and Gasterosteidae (1). In the late 1970's 23 species were captured in the system compared to 18 in the mid-1980's and 19 in 1994/95. Different fish species are more or less vulnerable to capture depending on the gear used. When considering only one gear type common to all studies (gillnet) then there was no change in the number of species recorded (14) from the 1978-80 period to 1994-95. The NRBS funded study added two species to the lower Slave River list not collected before. Oncorhynchus nerka and O. tshawytsha. Overall, community composition differences were minor and are likely a result of chance in sampling. Therefore, there does not appear to be any affect of flow changes or contaminants on the fish species diversity in the lower Slave River.

8. Diversity Indices

A more formal analysis of the existing data using indices of diversity should be undertaken.

Fish Species Abundance

9. Mark-Recapture Studies

To validate the catch per unit effort method of estimating abundance and to get a benchmark estimate of the numerical abundance of each species it is recommended that mark-recapture studies be undertaken for each species.

While some species have been a relatively stable percentage of the community others have shown fluctuations in their relative abundance between 1978 and 1995. Lake whitefish, white sucker, northern pike, flatheadchub and walleye have remained relatively constant. Inconnu appears to have increased, probably due to reductions in fishing pressure. Burbot and longnose sucker appear to have decreased somewhat. Some of the differences may be due to sampling location - the late 1970s samples were taken more heavily from the Slave River Delta than the recent samples.

Invertebrate Diversity

10. Invertebrate Diversity Studies and Habitat Associations

Studies to determine the species diversity, habitat requirements and productivity of invertebrates in the lower Slave River should be undertaken.

In the flood-pulse and river continuum models all fish species in the Slave River would be considered predators. The basic medium of energy transfer is invertebrates. It is clear that maintenance of invertebrate populations is critical to the productivity of the fish populations. Effects of contaminants or flow changes may first affect the productivity of invertebrate populations.

Fish Distribution and Movement

The lower Slave River fish community is seasonally dynamic, constantly changing throughout the year. Fish movements vary according to species from extensive to limited. The lower Slave River is an important habitat used for spawning, feeding, rearing of juveniles and for over-wintering of fishes and serves as a migratory corridor for all of these activities. All major species appeared to show seasonal aggregations and all seasons were important for spawning or feeding of at least one of the major species.

11. Differences in Fish Habitat

Field and simulation studies to characterize the differences in fish habitat among the major areas of the lower Slave River drainage should be undertaken to determine what are the habitat characteristics that separate species in these areas. Particular attention should be made to develop a detailed scale of micro-habitat types and the preferences of fish to each.

Seasonal Variation in Community Structure

12. Fish Distribution under Ice

Little is known regarding the seasonal distribution of fish under ice. Field studies over the entire ice-on period should be undertaken to determine the fish community composition in different parts of the lower Slave River drainage and over- wintering habitat of each species. Sampling would necessarily be limited to the gill netting techniques used by local fishermen unless new methodologies are developed.

13. Relationship Between Contaminant Sources and Fish

Recognizing the seasonally dynamic nature of the Slave River fish community, geographic information system (GIS) analysis of relationship between probable point sources, fish distribution and contaminant concentrations in the fish over the seasonal cycle should be undertaken.

14. Species Composition

A study to determine the fish species composition in tributaries, backwaters and side channels throughout the season should be undertaken in the lower Slave River.

Studies to date (including the NRBS) have focussed on the main channel or the Delta of the Slave River. Much of the productivity, including fish production, must take place in still side channels, tributaries such as the Salt River, quiet backwaters and seasonally on the floodplain of the river. There is no information available on the fish distribution in these areas. Therefore, the importance of these areas to fish as habitat and the probability that fish might be exposed to contaminants while in these areas cannot be determined. The effects of hydrological changes on these areas must be considered, especially in the Delta, where the Bennett Dam effects may be or are ongoing.

15. Flood-Pulse Fish Distribution Relationships

A study of the distribution and activities of both juvenile and adult fish during the flood-pulse on the lower Slave River should be undertaken.

Probability of exposure to water quality changes due to distribution and movements

16. Winter Fish Ecology

There is nearly no data on winter movements of fishes (inconnu movements in Great Slave Lake during winter are known) in the Slave River and delta. While it is assumed that most species are relatively inactive at this time it is not confirmed and remains a gap in the knowledge base. A study of winter ecology, including floy tagging and radio-tracking experiments on the major species excepting inconnu and ciscos should be undertaken.

17. Radio-Telemetry Major Studies of Major Fish Species Movement

Other than inconnu and burbot there is only limited knowledge of the details of movement patterns of major species, such as northern pike, goldeye, lake whitefish, and walleye, in the lower Slave River. Radio-telemetry studies of these species' movement patterns throughout the year should be undertaken in order to determine their probability of exposure to contaminants and other effects of environmental degradation.

If the flow and water quality changes are transported from upstream then fishes undergoing critical phases of their life cycle near Rapids of the Drowned would be at greatest risk. Thus, lake whitefish and inconnu during spawning in the fall; pike, goldeye, flathead chub and walleye spawning in the spring near Fort Smith would most likely be exposed. However, if the change in water quality is strong enough to be transmitted from a great distance it is unlikely to attenuate at Rapids of the Drowned. Thus, species that rear or are resident in the Slave River Slave River Delta, or even Great Slave Lake since 85% of the water entering it comes from the Slave River,such as northern pike, lake whitefish, walleye, flathead chub, goldeye, burbot and longnose sucker would be most vulnerable.

18. Movement Patterns of Forage Fish

There is almost no knowledge of the movements of forage species such as trout-perch, emerald shiner, lake chub,and flathead chub. The movement patterns of these species may determine whether or not contaminants enter the fish food chain. Studies of movement patterns using floy tags and dye markers should be encouraged.

19. Juvenile Fish Movement

Juvenile movements in the river have not been investigated to date. Studies of the movements of juvenile fish should be undertaken.

20. Spring Flooding and Fish Movement in the Lower Slave River

If, when and how fishes migrate onto the floodplain of the lower Slave River has not been studied. Studies to determine the degree of flooding during the spring pulse and the movement patterns of fishes should be undertaken. This is a key recommendation given the present Bennett Dam and future hydrological impacts.

21. Fish Movement Simulation Model

A simulation model of the probable movement patterns of all species of fishes to feed, spawn, rear and over-winter should be constructed as a reference for habitat managers. The model could be checked against available data and modified as new data becomes available in the future. This is also key relative to assessing impacts from obstructions, such as dams.

Food Web

22. Ecology and Habitat of Invertebrates

The importance of invertebrates to the productivity of the fish community and as potential conduits of contaminants is obvious. Detailed studies of the ecology and habitat requirements of the invertebrate community, especially the chironomids and corixids, should be undertaken in the lower Slave River.

All fishes in the lower Slave River are carnivorous and would be classified as predators by general models of large rivers. Those lower in the food web, such as suckers, goldeye, lake whitefish, flathead chub and shiners concentrated on invertebrate prey. The top predators, such as inconnu, northern pike, walleye and burbot ate exclusively fish. Three species played key roles in the food web. Pike consumed all other major species of fish present except inconnu. Of the fish species occupying the lower part of the food web, goldeye and lake whitefish consumed the widest variety of invertebrates. Of the invertebrate fauna the most important by far were the chironomids, followed by the corixids.

In the Slave River delta the food web again revolved around pike, goldeye and lake whitefish. Corixids and chironomids were about equal in importance to invertebrate feeders and often composed 60 to 80% of the diet.

23. Bio-Energetic Food Web Model

To determine the organisms most at risk a bio-energetic model of the food web should be constructed.

Because all fish in the lower Slave River and Slave River delta are predatory they are all at risk of bio-accumulation of toxicants through the food chain. Clearly, the fish predator group, including inconnu, northern pike, walleye, and burbot are the most likely to concentrate contaminants to a high level.

Priorization of Recommendations

While all recommendations, above, should be carried out I believe it reasonable to emphasize some of the key ones in order to help researchers and habitat managers address the question of 'Where to proceed next?'. The key recommendations fall into three categories: critical gaps in the database, quantitative model development and long-term monitoring. There are serious knowledge gaps in the understanding of invertebrate ecology, winter ecology of the aquatic biota and the biological importance of side channels and the annual flood-pulse which are addressed in recommendations 14, 16, 20 and 22. Models to make predictions and quantitatively understand processes are completely lacking and therefore additional key recommendations are 6, 21 and 23. Finally, for the fish community there should be a monitoring effort that is ongoing, consistent and long-term in order to detect future changes, such as suggested in recommendation 7.

Technical Report No. 147

Fish Distribution, Movement and Gross External Pathology Information for the Northern Rivers in Alberta

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RECOMMENDATIONS

Several recommendations arise from the Food Chain Component studies for monitoring and further research.

1.Seasonal Life History Studies

Radio-telemetry studies of seasonal life history characteristics, habitat use and exposure to contaminant point sources should be conducted in the Athabasca River with bull trout, mountain whitefish and burbot to determine time and duration of exposure to contaminants.

2. Analysis of Fish Inventory Database

The fish inventory database needs to be subjected to detailed analyses to detect species, seasonal and basin specific trends in fish metrics (age, growth, maturity, etc.) that may exist at both the organism and population levels.

3. Gross Pathology

A detailed field analysis of gross pathology should be conducted on the fish species in the upper Athabasca River.

4. Fish Population Monitoring

A long-term, periodic monitoring program should be implemented to follow trends in fish population-level effects of ecosystem change. Fisheries monitoring should include systematic recording and periodic assessment of the occurrence of gross pathology using standardized techniques to assess whether long-term trends in the health of fish are indicated.

5. Food Webs

Further stable isotope work is needed for the tributary systems to refine our understanding of food production at the base of the fish portion of the food chain.

6. In situ Bioassay with Fish Eggs

In situ bioassay studies with eggs of bull trout, mountain whitefish and burbot should be performed at key sites in the Athabasca River. This would allow us to assess the influence of natural conditions and the effects of contaminants and dissolved oxygen variation.

7. Research / Monitoring of "Species of Concern"

Bull trout in the Athabasca and Peace Rivers and pygmy whitefish in the Athabasca River deserve additional species specific research and monitoring attention as fish species of concern.

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Synthesis Report

Synthesis
Report

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

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

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

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