State of the Aquatic Environment Peace-Athabasca Delta – 2002*

David B. Donald[1], William Aitken, Jim Syrgiannis,
Nancy E. Glozier, Fraser G. Hunter and Mark R. Gilchrist

[1]Environment Canada, Room 300, Park Plaza,
365 Albert Street, Regina, SK S4P 4K1
Ph: (306) 780-6723 Fax: (306) 780-7614 Email: David.Donald@ec.gc.ca

STUDY PERSPECTIVE

This "state of the environment" report provides a current assessment (2002) of ecological conditions in the Peace-Athabasca Delta. The report is a response to the Northern River Basins Study Question # 14. - What long-term monitoring programs and predictive models are required to provide an ongoing assessment of the state of the aquatic ecosystems? The state of the environment is evaluated against seven environmental goals assessed with appropriate indicators. The environmental goals for the Peace-Athabasca Delta are the maintenance of:

1) climate at Fort Chipewyan,
2) water quality,
3) water levels,
4) benthic invertebrate communities,
5) fish community composition,
6) goldeye abundance, and
7) walleye and goldeye commercial catch.

Environmental goals were identified for the Peace-Athabasca Delta to provide Parks Canada, and provincial and federal resources managers and pollution control officers within the Peace and Athabasca river basins, with information on the ecological integrity of aquatic ecosystems within the Peace-Athabasca Delta. Articulation of the environmental goals (ecological integrity) was influenced by the intent and purpose of the Canada National Parks Act. Eighty percent of the Delta is within Wood Buffalo National Park. About 10% of the Delta includes Chipewyan Indian

---

* This report may be cited as:

Donald, D.A., W. Aitken, J. Syrgiannis, N.E. Glozier, F.G. Hunter, and M.R. Gilchrist, 2004. State of the Aquatic Environment Peace-Athabasca Delta – 2002. In: Environment Canada, *Northern Rivers Ecosystem Initiative: Collective Findings* (CD-ROM). Compiled by F.M. Conly, Saskatoon, SK, 2004. (With Alberta Environment).

Reserve 201 with the remaining land under provincial (Alberta) jurisdiction. Indicators used to assess the status of the goals were determined from an assessment of threats to the Delta. These include industrial and municipal effluents, climate change, forestry, oilsands development, hydroelectric operations and development, atmospheric pollutants, and renewable resource use both within and beyond the Delta.

The data base available for the evaluation of these environmental indicators ranges from three decades (water quality) to much of the twentieth century (climate). The indicators were first assembled from a variety of environmental information in 1996 for the Northern River Basins Study (Report # 107, 'Indicators of Ecosystem Integrity: Peace Athabasca Delta', Donald *et.al*., 1996). The seven environmentally relevant indicators were selected due to a number of factors : 1) the existence of historic information (fish community, water quality), 2) continuous and long-term annual collection of data under other programs (climate, water levels, walleye commercial catch), 3) relevance to the public (water levels, climate, walleye, and goldeye), 4) low cost for determining status (clam shrimp, goldeye abundance), 5) linkages within the food web and, 6) because one of the indicators (clam shrimp) is a rare species in Canada. Three of the indicators are physical/chemical variables (meteorological, water quality, water level) and four are structural indicators (clam shrimp, fish community structure, goldeye, and walleye). In the future, other indicators, particularly those of a functional nature, should be added to this list as additional resources for monitoring are identified and when new information on ecological processes in the Delta become known.

Each year, Environment Canada, Parks Canada, Alberta Environmental Protection, and the Freshwater Fish Marketing Board collect agency specific information on meteorology, water quality, water levels, and the walleye and goldeye commercial catch. These annual records are evaluated in this report for long-term stability or trends. In addition, data were collected in 1994, 1999, and 2002 on the fish community, goldeye abundance, clam shrimp, and water quality of Mamawi Lake. All of these annual and specific monitoring and data acquisition programs which are compiled for this report should be maintained in the future. Finally, it is recommended that a full assessment of the ecological integrity of the aquatic environments of the Peace-Athabasca Delta should be completed at least once or twice per decade using the indicators identified in this report and other information.

Ecosystem Goal 1 - Climate and Atmospheric Contaminants

The climate of Fort Chipewyan and surrounding area follows recognized historical annual and longer-term climatic patterns and their variability.

Status: The Ecosystem Goals for climate are not being met in the areas of mean annual temperature and annual total precipitation. During the period 1917 to 2000, there has been a significant increase in mean annual air temperature. Annual precipitation patterns and annual total precipitation during the 1990s were different than previous decades. Recent decades have been wetter in summer while the other seasons have been drier.

Ecosystem Goal 2 - Water Quality

Water quality is maintained within historic limits to support indigenous flora and fauna, and consumptive uses of water by people. Surface water from lakes and rivers in the Delta is used for drinking water.

Status: The Ecosystem Goals for water quality are not being met for some parameters. From 1996 to 2001 there were exceedences of the dissolved sulphate and total dissolved solids objective for the Athabasca River. Most of the other water quality objectives for the Peace and Athabasca rivers were met.

Ecosystem Goal 3 - Water Level

Water levels are maintained in the Peace-Athabasca Delta to provide habitat for aquatic life and to support boat and barge transportation in the region.

Status: Water levels in Lake Claire, the Ecosystem Indicator, remain within the historic range recorded since the construction of the W.A.C. Bennett Dam. However, the annual water level fluctuations of 1.5 m to 2.0 m that were common in the 1960s and 1970s were reduced significantly during the early 1980s when summer precipitation in the headwaters of the Peace and Athabasca rivers was relatively light. High flows on the Peace River during the mid 1980s elevated Lake Claire levels. These higher levels generally declined until 1996 when a structural problem at the W.A.C. Bennett Dam forced the operators to lower Williston Lake. The resulting increased flows on the Peace River raised Lake Claire levels and they remained relatively high for almost two years. High runoff volumes also contributed to higher flows in the Peace River in 1996-97.

Ecosystem Goal 4 - Benthic Invertebrate Community

The abundance and diversity of aquatic benthic invertebrates is maintained in the Peace-Athabasca Delta. Benthic invertebrates are important foods of fish, and through the food chain, invertebrates can be an important source of contaminants in fish.

Status: The benthic invertebrate Ecosystem Indicator species, clam shrimp, was not present in Mamawi Lake in 2000 and 2002. The exact reason for the absence of this species is unknown, but it may be related to their life cycle requirements. This species was abundant in Mamawi Lake in 1994. In 1999 only two specimens were collected in 36 samples from 18 different locations. In 2000 or 2002, no clam shrimp were collected from a total of 60 samples.

Ecosystem Goal 5 - Fish Community Structure

The fish community of the Peace-Athabasca Delta is maintained. Fish have both social and economic value to the residents of the Peace-Athabasca Delta. They participate in a productive regional commercial, domestic, and sport fishery. Walleye, lake whitefish, pike, and goldeye are the preferred species in these fisheries.

Status: The Ecosystem Goal indicator for the fish community is catch from Mamawi and Claire lakes. This Goal is being met. The long-term relative abundance of fish species in the catch from Mamawi and Claire lakes has remained remarkably stable and constant over time. The catch from 1999 and 2002 was dominated by goldeye followed by northern pike, with lake whitefish and walleye equally abundant.

Ecosystem Goal 6 - Goldeye Abundance

The goldeye population of the Peace-Athabasca Delta is maintained at historic levels of abundance. Goldeye are an important part of the catch of the regional domestic fishery and the commercial fishery in western Lake Athabasca.

Status: The Ecosystem Goal for goldeye abundance is being met. The catch-per-unit-effort (CPUE) for goldeye in 1999 and 2002 was similar to the CPUE in 1973 (16.9) but greater than the CPUE in 1987, 1992, and 1994. Statistical analyses of mean CPUE indicate that there has been no significant change in the goldeye catch from 1973 to 2002. Since 1970 there have been five years with strong year-classes (1971, 1982, 1989, 1994, and 1996), and many years with poor or failed year classes (mid 1970's, 1985 and 1993). The number of years between strong year-classes ranges from 2 to 11 years.

Ecosystem Goal 7 - Walleye and Goldeye Fishery

Walleye and goldeye commercial catches in western Lake Athabasca are maintained. Walleye and goldeye are the most important fish species in the commercial fishery and are an important part of the domestic and sport fish catch as well. Walleye and goldeye are an economic and nutritional resource to the residents of the Fort Chipewyan area.

Status: The commercial catch limits identified for this Ecosystem Goal are being met (annual catches of 45,400 kg for walleye and less than 10,200 kg for goldeye). During the 1990s, 7 of 10 annual catches for walleye were between 45,400 kg and 79,950 kg. All annual catches of goldeye during the 1990s were less than or equal to 10,200 kg. In recent years, information on contaminant levels in fish has not been collected.

INTRODUCTION

The Northern Rivers Ecosystem Initiative addressed specific environmental questions and commitments made by Ministers in their response to the Northern River Basins Study (1996). The Northern River Basins Study (NRBS) was a 5-year program undertaken by governments in 1991 to obtain information on existing conditions in, and the effects of development on, the aquatic ecosystems of the Peace, Athabasca, and Slave river basins. Assessment of impacts of industrial developments on the Peace, Athabasca, and Slave rivers, and assessment of the cumulative impacts of current and future industrial developments on these basins were an important aspect of NRBS. The Northern River Basins Study Board developed 16 questions that determined the scope of that scientific program. Specifically, question 14 identified the need to implement long-term monitoring of key components of aquatic ecosystems:

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

This report was prepared for the Northern Rivers Ecosystem Initiative in response to the above question. Detailed information is provided herein on the state of the aquatic environment for the Peace-Athabasca Delta, as determined from monitoring and survey data collected during much of the twentieth century.

Definitions

In the context of the Peace-Athabasca Delta we define ecosystem, ecological integrity, and ecosystem indicator as follows:

"An ecosystem is an interacting dynamic and complex system of living and non-living components linked by the cycling of materials and the flow of energy."

"Ecological integrity is the maintenance of the structures and function of the Peace-Athabasca Delta ecosystem unimpaired by anthropogenic stresses with indigenous plant and animal species persisting at historic population levels and with sustained harvest (but not over-exploitation) of renewable resources by people." People are both indigenous to and an important ecological link in the Delta ecosystem.

"Ecosystem indicators are aspects or components of an ecosystem that are monitored (measured) to assess ecological integrity, and to determine if environmental goals are being met."

Peace-Athabasca Delta

The Peace-Athabasca Delta is one of the largest freshwater deltas in the world (Peace-Athabasca Delta Project 1973). The Athabasca River Delta is steadily expanding into Lake Athabasca (Figure 1); the Peace River Delta is much less active, only recharging perched basins and permanent connected lakes during high water and spring flood events. The Peace-Athabasca Delta has four major permanent lakes (Mamawi, Claire, Baril, and Richardson) all with a maximum depth of 3 metres or less. The near shore zone and bays of these lakes are characterized by thick growths of submergent and emergent vegetation. Freeze-up occurs in late October and ice cover lasts for a minimum of 6 months. Ice thickness is more than 1 m, and all delta lakes are devoid of oxygen and fish by late winter.

Eighty percent of the Peace-Athabasca Delta is within Wood Buffalo National Park. About 10% of the Delta is within the Chipewyan Indian Reserve 201 with the remaining land under provincial (Alberta) jurisdiction. The lower 250 km of the Peace River is also within the Park. The centre of the Athabasca, Embarras, Rivière des Rochers, and Slave rivers is the eastern boundary of Wood Buffalo National Park. The Peace-Athabasca Delta is an important regional source of fish, and supports a productive commercial, domestic, and sport fishery. An interesting biological characteristic of the Delta is the geographic segregation of the dominant fish species. In permanent channels and lakes east of Mamawi Lake, walleye are the dominant species, while goldeye are the dominant species in Mamawi and Claire lakes and their associated channels and lakes. The western portion of Lake Athabasca, including the actively expanding portion of the Athabasca Delta, supports a commercial fishery with an annual quota for walleye of 45,400 kg. Important spawning habitat for this walleye population includes Richardson Lake, and the bays and channels of the outer edge of the Athabasca River Delta. Mamawi and Claire lakes are critical spawning and feeding habitat for a population of goldeye that winters in the lower Peace River and migrates into the Delta in spring. The domestic gill-net fishery for walleye, lake whitefish, northern pike, and goldeye occurs throughout the Delta at traditional sites (Flett *et al.,* 1996). Sport fishing for walleye and northern pike occurs primarily in the Athabasca River Delta.

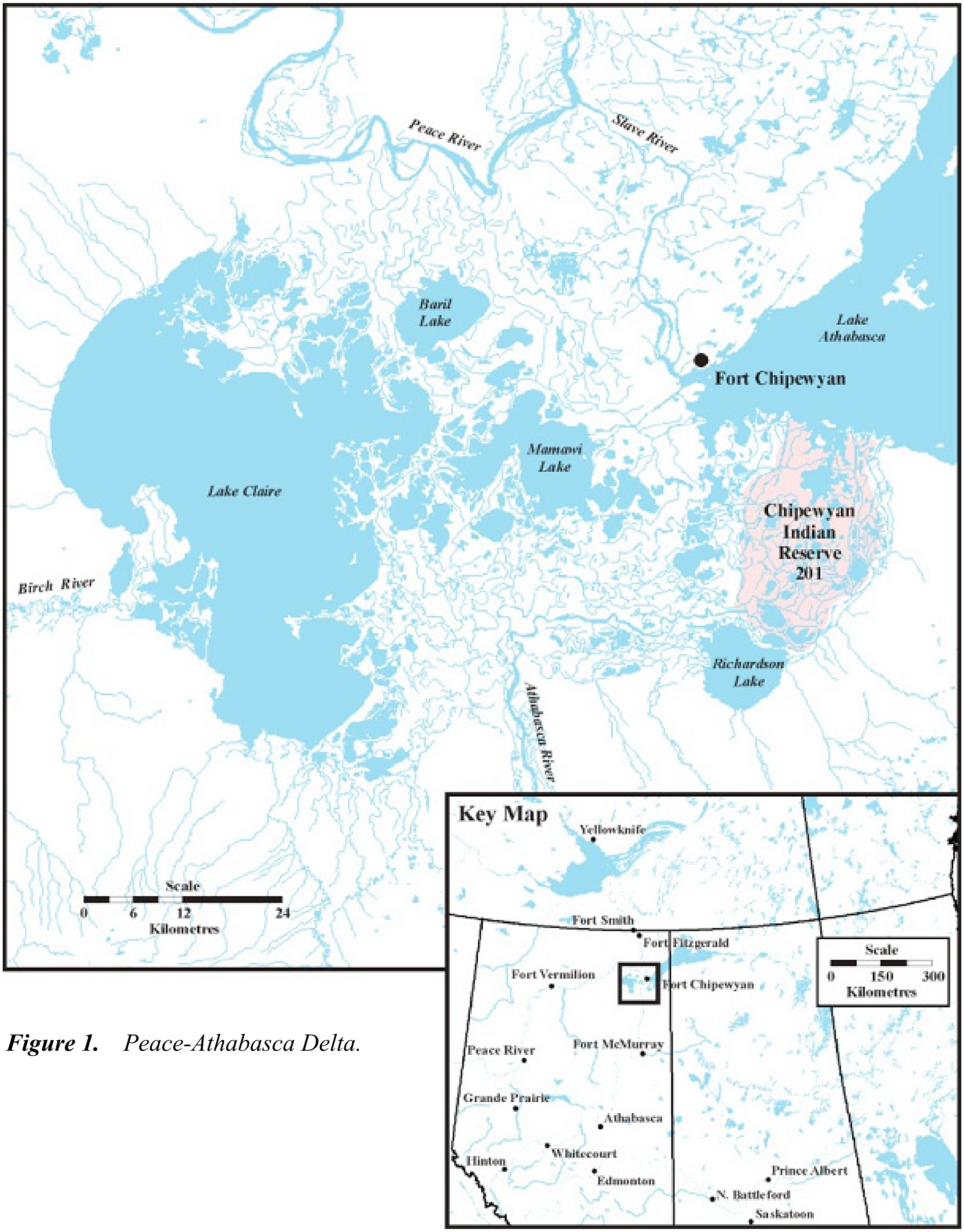


Figure 1. *Peace-Athabasca Delta.*

ECOLOGICAL INDICATORS

Ecosystem Objective

The overall Objective for the Peace-Athabasca Delta ecosystem is:

To maintain the ecological integrity of the Peace-Athabasca Delta for future generations.

The social/economic input to the development of this Objective was through review and approval of the Northern River Basins Study Board report, "Indicators of Ecosystem Integrity: Peace-Athabasca Delta". The Board had representation from the public, industry, First Nations, and municipal, provincial, and federal governments. In addition, social input and guidance is obtained through the intent and purpose of the National Parks Act which is, of course, a product of the elected representatives of the people.

Ecological Goals and Indicators

Identification, selection, and use of ecological goals and indicators is a social, economic, and scientific exercise that follows the general models outlined in Table 1. Ecosystem goals are established, indicators of that goal are identified, and procedures and methods to assess the indicator are outlined. Articulation of environmental goals can lead to responsible management and maintenance of natural resources and ecosystems through the process of identification of environmental indicators related to the goal, followed by assessment of trends and stability of the indicators.

Table 1. *Development and use of ecosystem indicators.*

ENVIRONMENTAL	RESPONSIBILITY	EXAMPLES
Goal	Social/economic	Maintain ecological integrity of moose habitat
Indicator	Social/scientific	Maintain moose population at 1/km
Measurement	Scientific/technical	Count moose (M), or Count moose pellets (p) M = a + b(p)
Remediation Adjustment	Senior-Management/ Technical	Increase or decrease harvest, Prescribed burn to increase habitat
Goal	Social/economic	Aquatic ecosystem integrity
Indicator	Social/scientific	Algal biomass
Measurement	Scientific/technical	Chlorophyll "*a*"
Remediation Adjustment	Senior-Management/ Technical	Waste water treatment

Ecological Indicator Selection

A suite of indicators is necessary to assess the effects of potential stresses to an ecosystem, and to assess the key functional linkages between abiotic and biotic components of the ecosystem. Several indicators are more likely to be sensitive to ecosystem dysfunction than a single indicator which may only be responding to limited and perhaps only local processes. The significant stresses to the Peace-Athabasca Delta in the future are likely to be: contaminants from municipal and industrial effluents within the Peace and Athabasca river basins, persistent contaminants originating from atmospheric deposition, overexploitation of natural renewable resources, and climate change.

Criteria for selecting indicators have been outlined by Johnson *et al*. (1993); Stribling (1994); Banff-Bow Valley Study (1995) and Cash *et al*. (1996). The selection of ecological indicators should consider, but not be restricted to, the following criteria:

1) relevance to the public,

2) cost of measurement,

3) linkages to other components of the ecosystem such as an important link within a known food web,

4) other or multiple purposes for collection of environmental data (such as meteorological information),

5) sensitivity to stresses such as contaminants, changes in hydrologic regime, exotic species introductions, climate change, or over-exploitation,

6) for biological indicators, life-cycles should be completed entirely within the ecosystem. For example, resident fish species would provide a better ecological indicator than a species of migratory bird that stages in the Peace-Athabasca Delta but breeds in the arctic and migrates to South America for the winter,

7) for biological indicators, life-cycles and trophic positions should be known,

8) for abiotic indicators, historic information should be available or be deemed important to understand.

Three physical/chemical and four structural indicators of ecosystem integrity are identified. Functional indicators were not proposed, although there are functional linkages between and among the indicators. The seven Indicators are:

Physical/Chemical Indicators

1) Climate and atmospheric contaminants,

2) Water quality,

3) Lake Claire water levels,

Structural Indicators

1) Clam shrimp abundance,

2) Fish community structure (Mamawi and Claire lakes),

3) Goldeye abundance, and

4) Walleye and goldeye commercial catch.

The "integrity" of the Delta ecosystem could be altered if any one of the seven environmental indicators were altered by anthropogenic stresses. Remedial action might then be undertaken by governments and the public to restore the ecological integrity of the Peace-Athabasca Delta. However, ecosystem science is not sufficiently advanced to predict with certainty how aquatic species of the Peace-Athabasca Delta will respond to the variety of potential disturbances and contaminants that might originate from within and beyond the basins. Therefore, the management of the Delta ecosystem should be dynamic and flexible, and not tied specifically to the set of indicators proposed herein. In the future, other and perhaps better indicators should be added to the above list. Finally, ecosystems and delta ecosystems in particular are evolving physically and biologically in time and space. Indicators need to be developed that record and account for the natural changes to the Delta. These indicators must be able to differentiate between anthropogenic stress and natural changes.

ECOSYSTEM ISSUES AND INDICATORS; PEACE-ATHABASCA DELTA

The information on ecosystem indicators presented in this report were obtained from historical data on the aquatic chemical and biological characteristics of the Peace-Athabasca Delta, the commercial fish catch from western Lake Athabasca, the climate of the region, and limnological and fisheries studies conducted from 1973 to 2002 in the Mamawi-Claire lakes system. More detailed surveys in 1994, 1999, and 2002 included assessments of water quality, the benthic invertebrates of Mamawi Lake, and an assessment of fish community composition and abundance of goldeye in both Mamawi Lake and Lake Claire combined.

Ecosystem Goal 1 - Climate and Atmospheric Contaminants

Goal

This Ecosystem Goal has two components. First, climate of Fort Chipewyan and surrounding area follows recognized historical annual and longer-term climatic patterns and their variability. Second, the Peace-Athabasca Delta and Fort Chipewyan are not affected by global or regional atmospheric pollutants.

Changes in climate and deposition of atmospheric pollutants can directly affect aquatic ecosystems, especially during spring to fall.

Indicators

Climatic indicators such as temperature and precipitation are measured. To maintain ecosystem integrity their annual variability should not be changed by regional or global input of human generated substances such as greenhouse gases (carbon dioxide, water vapour, methane, nitrous oxides, etc.). Additionally, aquatic ecosystems and the residences of Fort Chipewyan should not be affected by atmospheric contaminants such as industrial smoke, agricultural pesticides or depositions from oilsand mining and processing activities.

Any statistically significant change in climate trends at Fort Chipewyan would constitute a compromise of ecological integrity of the Peace-Athabasca Delta.

Indicator Measures

Temperature, precipitation, wind speed and direction are measured daily at Fort Chipewyan. Contaminant concentrations in the atmosphere are measured as opportunities and programs permit.

Status

The Climate Ecosystem Goal is not being met in the areas of mean annual temperature and annual total precipitation. During the period 1917 to 2000, there has been a significant increase in mean annual air temperature. Annual precipitation patterns and annual total precipitation during the 1990s were different from previous decades. Recent decades have seen wetter summers while the other seasons have been drier. If the current trend towards warmer temperatures and higher summer precipitation persist, the biological indicators should be monitored more intensively.

Background

A variety of weather parameters have been recorded at Fort Chipewyan beginning in 1883 (Tables 2 and 3). However, these observations are not continuous and they have been taken at two different locations in the Fort Chipewyan area. The record of continuous temperature and precipitation observations extends from 1963 to the present. Donald *et al.*, (1996) recommended that the weather observing program needs to be expanded to include 24-hour wind speed and direction, and duration of bright sunshine.

Global air pollutants are well mixed in the atmosphere and affect all areas of the earth. These pollutants, including greenhouse gases, are affecting the study area.

Table 2. *Mean Monthly Temperature at Fort Chipewyan, Alberta Station numbers 3072657 and 3072658.*

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1883											-15.8	-23.5
1884	-24.1	-24.2	-15.7	-4.7	6.4	12.3	16.0	13.5	7.5	-3.1	-10.4	-8.5
1885	-28.8	-21.6	-14.0	-1.7	5.6	14.7	15.8	14.3	8.2	-0.4	-4.3	-17.1
1886	-32.6	-26.4	-17.3	-2.9	3.9	16.2	16.6	13.4	4.6	1.3	-11.8	-21.0
1887	-30.4	-26.7	-18.8	-3.7	6.2						-12.2	-25.5
1888			-20.0	-8.6	3.9	8.6		12.3	10.9	3.1	-10.1	-14.0
1889	-17.2	-19.3	-8.4	0.8	6.6	12.9		16.0	6.1	1.8	-7.6	-22.8
1890	-26.9	-27.0	-16.8	-8.1	2.4	10.2	15.3	13.6	6.9	2.3	-8.2	-17.9
1891	-22.3	-27.0	-16.3	0.4	3.5		16.8					
1892												
1893		-22.2		-8.9			17.8	15.4	8.0	-0.8		-27.7
1894	-29.7	-21.1	-14.8	-4.6	6.8		17.4	16.6		1.7	-12.6	
1895	-26.2	-20.4				14.4		12.7	6.6	-0.3	-13.4	-19.3
1896	-29.1	-19.2	-15.7	-5.5	6.0	12.7	16.2	14.2			-15.1	-16.1
1897	-26.4	-22.1	-17.7	-1.8	6.5	13.4	15.8	15.7		-2.1	-14.3	-17.3
1898	-19.3	-23.3	-14.1	1.6	10.6		16.3	14.7		-3.5	-15.9	-17.1
1899	-25.1	-28.1	-21.2	-5.6							-5.3	-18.1
1900	-24.5	-26.1	-15.4	4.3	11.1	14.7	15.9	14.5		2.1	-12.6	-15.3
1901	-23.2	-19.3	-11.4	-1.0	8.4	12.1	15.8	15.3	8.6	3.6	-13.6	-16.9
1902	-20.0	-17.4	-15.7	-4.1	7.0	9.6	17.1	14.6	6.7	3.0	-13.8	-19.8
1903	-22.5	-17.8	-14.5	-4.5	4.0	13.5	17.0	15.4	6.2	0.4	-8.7	-17.3
1904	-24.4	-29.0	-16.1	2.7	6.8	12.8	15.4	13.6	5.5	2.8	-4.5	-19.6
1905	-22.9	-18.0	-9.6	0.8	10.3							
1906		-24.3	-14.2	1.7	6.5	15.1		11.7			-11.1	-25.5
1907	-31.4	-24.6	-17.6	-12.1	-2.5	8.9	11.2	10.1	3.0	0.1	-11.0	
1908		-20.5	-24.6	-7.8	6.5	13.2	16.3	14.3	9.7	2.4		-19.9
1909				-9.8		15.1	17.3	13.4	9.5	0.9		-17.8
1910		-22.7	-9.2	-0.5	5.3	14.2	17.0	12.6	7.2	2.2	-11.0	-18.8
1911	-34.0	-19.0	-11.8	-5.4	7.7	13.5	15.5	12.3	7.1		-11.5	-13.8
1912		-19.5		-1.8		15.5						
1913												
1914							16.6	15.2		4.2	-7.9	-22.3
1915	-20.7	-15.3		6.6	9.0	10.8	15.7	18.1	6.5	0.5	-10.3	-15.0
1916	-29.0		-16.5	0.5	6.9	13.7	16.0		9.4	0.8	-7.7	-23.6
1917	-29.1	-25.4	-12.7	-3.2	6.9	11.5	17.3	13.9	10.0	-0.8	-2.1	-29.5
1918	-26.3	-25.4	-15.9	-3.1	2.6	10.8	14.1	14.0	8.9	-0.1	-8.8	-15.8
1919	-17.8	-22.3	-19.6	2.1	5.9	12.5	14.6	16.5	11.0	-5.6	-14.2	-19.7
1920	-23.9	-12.6	-14.3	-5.9	6.5	11.3	18.4	15.6	8.8	1.8	-6.9	-19.6
1921	-22.1	-18.1	-19.2	0.0	7.5	15.4	16.6	13.1	8.2	3.2	-13.8	-16.0
1922	-20.6	-24.1	-16.2	-2.8	7.7	12.6	16.8	15.4	8.2	0.9	-7.8	-23.3
1923	-24.5	-22.0	-20.3	-5.3	3.8	15.1	15.9	12.5	10.0	4.7	-6.8	-21.3
1924	-26.4	-15.7	-9.6	-7.4	6.6	11.8	16.5	13.8	8.4	3.2	-11.0	-23.2
1925	-28.0	-26.3	-15.5	1.0	7.1	12.6	18.2		6.9	-2.8	-12.2	-16.0
1926	-19.2	-16.3	-10.9	-1.5	8.2		17.7	14.2	6.4	-0.9	-11.3	-18.2
1927	-21.0	-20.6	-9.9	-2.3	6.7	13.1	18.1		9.0	3.2	-17.1	-24.6
1928	-16.9	-12.8	-9.7	-7.8	7.1	14.5	18.2	12.8	9.4	2.2	-4.8	-12.0
1929	-27.6	-22.2	-14.8	-3.9	5.8	11.7	16.6	15.9	7.8	6.0	-8.0	-21.1
1930	-23.4	-16.9	-9.2	2.4	6.1	14.1	18.1	16.5	7.9	-0.4	-10.0	-11.1
1931	-18.3	-9.8	-15.8	-0.7		12.7	17.3	17.4	10.4	4.1	-7.9	-16.3
1932	-22.6	-23.6	-20.8	-0.1	9.2	14.0	18.9	18.5	8.5	-1.2	-15.7	-20.8
1933	-28.6	-27.0	-14.3	-3.8	8.7	13.6	16.4	16.3	8.1	-1.6	-13.6	-32.0
1934	-22.8	-16.3	-15.6	-0.3	8.3	13.1	15.3	12.7	5.1	0.7	-9.6	-20.0
1935	-29.1	-12.1	-17.7	-6.1	9.1	13.5	17.9	13.6	8.3	-0.9	-15.1	-16.4

***Table 2*. (cont'd)** *Mean Monthly Temperature at Fort Chipewyan, Alberta Station numbers 3072657 and 3072658.*

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1936	-30.3	-32.0	-12.8	-6.2	8.6	13.1	19.3	16.2	7.4	-1.4	-5.1	-19.9
1937	-27.5	-22.1	-11.0	2.4	10.4	15.2	18.7					
1938		-23.3	-10.9	-3.3	7.7	15.1	17.6	13.5	13.4	4.1	-9.6	-15.2
1939	-21.2	-30.0	-16.8	-1.3	8.1	12.6	17.1	16.2	7.1	-2.3	-6.1	-10.9
1940	-19.7	-18.3	-11.3	0.7	8.1		13.4	13.8	11.9			
		No Data for 1941 - 1961										
1962										3.3	-9.0	-18.3
1963	-27.6	-20.6	-14.7	-0.7	6.7	15.6	18.6	17.1	10.3	6.4	-11.5	-18.2
1964	-21.1	-14.2	-20.9	-2.7	7.8	14.9	18.4	15.2	7.7	3.7	-9.0	-23.3
1965	-26.0	-27.5	-13.9	0.4	7.9	13.2	17.5	15.0	4.4	2.9	-12.3	-16.6
1966	-31.3	-19.2	-10.9	-5.0	8.4	14.1	16.3	15.4	10.8	0.2	-17.9	-16.8
1967	-23.2	-22.0	-18.8	-4.7	5.8	12.6	16.6	16.4	12.1	2.1	-7.5	-17.3
1968	-26.4	-18.0	-8.4	-1.6	6.8	12.7	13.8	12.7	7.7	1.9	-8.8	-23.4
1969	-32.2	-17.5	-12.7	1.7	6.0	10.6	15.9	15.5	7.7	-1.2	-10.6	-11.9
1970	-24.9	-20.7	-14.0	0.0	7.7	15.8	16.5	15.0	7.5	0.8	-12.7	-23.1
1971	-28.6	-18.6	-13.3	0.9	10.6	15.2	15.8	16.4	8.5	2.5	-11.2	-24.9
1972	-29.2	-26.2	-11.4	-4.7	9.6	15.3	15.1	15.8	3.4	-1.7	-10.5	-23.5
1973	-19.8	-21.1	-8.1	0.2	12.7	14.9	17.3	15.0	9.0	2.2	-15.0	-22.2
1974	-29.4	-20.6	-18.4	-0.8	7.1	14.1	16.0	12.9	5.3	0.1	-6.2	-13.1
1975	-27.0	-20.9	-14.8	-0.2	8.1	14.7	18.1	13.8	9.7	1.3	-13.1	-20.8
1976	-22.8	-22.0	-15.1	4.6	10.2	14.2	16.8	16.3	10.2	-0.3	-8.6	-23.0
1977	-23.0	-10.5	-9.3	1.9	10.4	14.0	14.6	10.8	9.6	2.9	-11.0	-24.9
1978	-23.0	-16.3	-12.7	-1.4	7.3	13.2	14.2	13.1	8.5	2.8	-12.0	-22.6
1979	-23.1	-30.7	-14.8	-4.9	5.9	13.5	18.2	13.2	9.4			-13.9
1980	-23.0	-16.2	-12.5	6.6	9.7	16.2	17.2	15.0	7.3	3.9	-7.4	
1981		-16.3	-7.9	-3.8	9.9	13.5	17.2	18.7	10.1	-0.7	-5.5	-19.5
1982	-34.5	-22.4	-16.0	-3.2	7.1	13.4	16.7	12.2	9.4	2.6	-16.3	-20.5
1983	-21.6	-20.6	-11.7	-0.5	3.7	13.4	17.3	16.5	7.2	1.9	-5.4	-24.7
1984	-22.9	-13.1	-10.3	3.8	7.8	14.1	17.7	17.4	6.9	-0.3	-14.7	-26.3
1985	-19.0	-25.6	-9.0	0.2	9.4	13.8	15.0	13.2	6.6	-0.9	-18.2	-17.5
1986	-18.5	-19.3	-10.1	-1.5	9.7	12.8	15.7	14.6	8.7	1.6	-16.1	-12.5
1987	-14.3	-12.7	-12.4	2.4	9.8	15.0	16.7	12.4	11.4	2.0	-6.5	-13.1
1988	-23.4	-21.3	-9.4	-1.4	6.0	15.3	16.3	15.7	9.2	1.2	-11.6	-18.5
1989	-22.3	-18.0	-18.4	-2.7	7.9	14.3	18.1	16.8	8.2	1.4	-16.4	-22.3
1990	-23.0	-23.6	-8.5	-1.0	8.4	14.9	17.2	14.9	9.2	-1.8	-17.4	-25.3
1991	-22.7	-16.2	-13.2	1.4	10.7	15.0	17.2	18.5	8.4	-4.1	-13.0	-19.0
1992	-18.5	-18.4	-8.5	-0.3	8.0	13.6	15.8	14.1	5.8	1.2	-5.3	-21.4
1993	-19.1	-16.7	-4.0	2.9	7.2	13.2	15.6	14.0	7.3	2.4	8.0	-15.7
1994	-26.1	-27.4	-6.8	-1.9	8.6	14.8	18.3	15.4	9.8	3.4	-10.7	-15.6
1995	-16.5	-20.0	-13.4	-3.1	7.7	15.2	14.4	13.0	9.5	1.8	-14.6	-19.0
1996	-27.8	-18.1	-18.0	-1.7	6.4	14.4	17.8	15.3	9.4	-0.5	-13.8	-21.1
1997	-23.9	-15.2	-15.1	-2.7	6.1	14.6	18.4	15.3	10.2	-0.9	-6.6	-11.8
1998	-24.5	-10.6	-10.7	4.7	10.5	15.2	18.3	16.2	8.3	3.6	-7.3	-17.8
1999	-23.8	-12.9	-6.0	2.4	8.1	14.0	15.4	15.7	9.6	1.7	-7.5	-16.0
2000	-22.2	-14.7	-8.2	-1.1	6.4	12.4	18.3	14.2	7.4	0.8	-8.4	-24.1
2001	-12.5	-20.4	-11.1	-0.7	8.6	14.5	18.5	16.2	11.6	0.5	-6.2	-18.5
2002	-22.4	-16.0	-18.5	-7.6	2.7	14.7	16.7	13.8	8.6	-3.8	-10.2	-12.7
Monthly Mean	-24.2	-20.4	-13.8	-1.8	7.3	13.6	16.7	14.7	8.3	1.0	-10.4	-19.2

Table 3. *Mean Monthly Precipitation from 1883 - 2002, Fort Chipewyan, Alberta Station Numbers 3072657 and 3072658.*

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual Precip.
1883											22.6	21.8	
1884	31.2		10.9	10.7	10.7	47.5	54.4	28.4	14.2	32	9.7	4.6	
1885	14.2	27.9	34.5	5.6	12.4		37.6	6.9	56.1		16.5	33.8	
1886	15.5	59.2	21.6	29.2	8.6	44.5	59.7	19.1	66.5	11.4	35.1	22.1	370.4
1887	11.9	7.1	40.1	5.6							10.9	30.7	
1888			16.5	23.6	10.9	71.9	68.8	45	39.6	27.2	30.5	19.8	
1889	26.2	6.4	10.4	9.9	6.9	26.4	241.8	9.9			11.7		
1890	7.6	7.6			0.5	39.1	25.4	95	55.1	27.2	15.5	6.9	
1891	12.2	1.8	4.1	16.5	28.4								
1894		17.8	13.5	37.6		12.4	17.8	11.4	35.1	17.3	21.8	3.8	
1895	9.7	4.3						30.2	65.3	4.6	22.1	39.4	
1896	11.9	11.9	23.4	35.6	28.7								
1897	20.3					68.8	32.5	30.2	16.8	31.5	35.1	38.1	
1898	25.4	7.6	20.8	5.1	14.5	62.7	31	89.4	55.6		17.8	6.4	
1899	16	14	28.2	26.7	47						5.6		
1900	42.4	5.1	10.2	13.7	5.6	7.1	116.8	45.7	17.8	13	19.1	17.8	296.5
1901	14.7	16		17.8	49.3	20.6	5.3	29.2	6.9		53.3	16.8	
1902	15.5	5.3	18.5	2.5	43.4	29.5	41.4	112.5	17	12.4	30	27.9	328
1903	35.6	20.3	8.4	33	52.8	25.7	27.2	34.3	67.6	13	25.1	19.8	343
1904	26.7	8.4	14	27.2	6.6	84.1	63.8	9.9	46.2	9.9	20.3	35.6	317.1
1905	39.4	5.1	5.1	30.5	13.5						35.6	81.3	
1906	22.9	33			47.8		9.9	26.9	74.4	24.9	27.9	29.2	
1907	18.5	59.7	26.7		16.5	25.9	26.7	77.2	21.3		15.2	15.2	
1909	20.3		26.4		48.3	35.8	34.8	38.6	10.9	12.7	27.9	14	
1910	7.6	3.8	14.5		30.2	75.4	86.6		49	15	7.6	7.6	
1911					7.1	47.5	43.4	65.3	9.9				
1912				26.9	19.1	58.7	14.7	3.8					
1914							86.1	46		6.4	17	6.6	
1915					7.1	13.5	10.4	28.4	20.8	17.5	48.5	17.5	
1916	6.4		15.2	2	19.8	13.7	131.1	43.7	35.8	10.2	16.8	20.3	
1917	42.7	6.4	18.5	15.2	9.4	11.9	52.3	39.1	9.1	41.1	57.9	68.6	303.6
1918	33.3	44.2	30.5	21.1	23.1	23.4	21.8	93.2	11.4	60.7	56.1	30.5	418.8
1919	16.5	11.4	10.2	15	44.5	58.9	66.8	38.6		5.8	21.6		
1920	15.2	11.4	8.9	7.6	0	22.9	7.1	36.1	63.8	10.2	12.7	7.6	195.9
1921	10.2	16.5	17.8		41.7	29	49	52.6	8.6	12.4	28.7	15.2	
1922	19.1		44.5	27.2	46.2	24.6	75.4	31.8	25.1	57.2	49.3	15.2	
1923	19.1	3.3	7.6	5.1	26.2	0.5	23.9	24.1	14.5	5.1	2.5	12.7	131.9
1924	15.2	50.8	14	16.5	2.5	37.1	48	46.5	23.4	10.2	15.2	5.1	279.4
1925		15.2	27.9	27.2	11.7	11.4	25.9	16.3	44.2	12.4	16.5	17.8	208.7
1926	6.4	15.2			24.9	8.6	88.4	23.9	22.4	36.8	17.8	41.9	
1927	12.7	5.1	21.6	38.4	25.9	45.2	14.7	19.3	34.3	40.4	10.9	5.3	268.5
1928	11.7	8.9	26.9	32.3	0.3	32.3	26.7	24.1	16.5	5.8	8.9		
1929					11.2	48.3	57.4	45	79.8	13			
1930		30.5	0			35.8	36.3	79	47.5	20.6	26.2	38.1	
1931		6.4	11.4	14.7		7.4	69.9			8.4		22.9	
1932	20.3	20.3			37.3	64.3	3.3	52.6	19.1	9.7	40.6	12.7	
1933	6.4	40.6	21.6	21.6	16.5	18.8	34	18.8	92.7	24.1	63.5	10.2	358.6
1934	15.2	11.4	24.6	33.3	5.1	18.8	48.3	65.3	21.1	17.8	48.3	7.6	309.2
1935	6.4	33	19.1	12.4	31.2	37.6	86.6	42.9	22.1	57.4	16.5	27.9	365.2
1936	5.8		16.8		11.7	40.6	148.8	19.3	91.4	21.1	17		
1937	8.9	22.9	2.5	11.4	22.6	24.4	18.5	21.8	6.4	5.6	11.4	26.7	156.4
1938	10.2	10.2	12.2	7.4	13.5	25.9	32.5	26.9		30	7.6	17.8	
1939	29.2	5.1	14	11.7	62.7	7.6	33.8	31.8	40.4			22.4	
1940							15	28.2	32.8				

Table 3. (cont'd) *Mean Monthly Precipitation from 1883 - 2002, Fort Chipewyan, Alberta Station Numbers 3072657 and 3072658.*

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual Precip.
1962										29.5	11.4	16.8	
1963	31.5	9.4	20.8	15.5	14.5	27.2	136.7	48.8	61.2	14.2	43.4	13.7	423.2
1964	17	26.7	10.2	26.4	48.8	59.7	40.9	45.7	69.9	36.8	15.7	15.7	397.8
1965	13.5	39.9	9.9	6.9	11.4	71.9	37.1	62.7	40.9	35.6	21.1	25.4	350.9
1966	31.2	9.1	23.6	53.8	25.9	33.3	63.5	52.6	41.7	74.2	26.9	23.1	435.8
1967	29.2	23.6	35.3	14	10.2	19.1	70.4	93.5	68.8	34.3	32.5	14.2	430.9
1968	27.2	13	17.8	2.5	64	67.3	35.8	18.5	71.1	22.6	32.5	11.9	372.3
1969	11.7	6.9	12.7	35.6	30.2	24.4	22.4	56.1	31.8	3.6	19.1	6.1	254.5
1970	16	13.7	29.2	33.5	63	16.8	51.6	71.6	35.3	40.9	19.8	16.5	391.4
1971	23.4	26.7	11.7	9.7	26.9	44.5	94.5	41.9	80	17.5	34.3	16	411.1
1972	21.3	18.3	22.4	57.7	18.3	45.2	85.1	19.3	58.4	24.9	13	31	383.9
1973	18.8	6.4	10.2	12.7	25.7	38.4	111	69.3	48.5	48.5	28.4	24.6	417.9
1974	32.8	30	24.4	15.2	45.7	68.3	73.9	60.5	30	14	13.2	35.6	408
1975	21.6	7.4	6.1	15.7	36.8	66.8	24.4	79.2	22.1	53.1	41.1	18.5	374.3
1976	33.3	17.8	22.1	7.6	23.6	64.8	84.6	31	27.2	58.7	30	24.1	400.7
1977	17.6	8.7	10.8	4.3	9.6	84.9	97.7	54.2	10.8	12.6	21.7	25.5	332.9
1978	11.3	1	27.4	33.8	19.2	56.3	41.1	61.9	97.7	40.4	16.1	28.2	406.2
1979	8	16.6	31.6	28	9.4	17.6	86	26.8	52.4	28	10.2	21	314.6
1980	23.2	11.8	14	0.6	23.1	10	23.8	57.2	24.4	2	22.3	22.6	212.4
1981	20.4	22.4	14.8	35.1	9.2	42.8	77.8	20.8	18.8	36.5	11.9	22.6	310.5
1982	11.2	14.7	15	13.1	31	13.6	44.2	26.1	53.9	40.7	28.2	41	291.7
1983	18	14.3	8.6	20.2	24.2	23.6	74.3	43.1	32.9	19.4	8.7	15.4	287.3
1984	27.2	19.1	7.8	18.6	36.2	70.8	57.9	35.8	43.8	92.6	22.8	19.3	432.6
1985	8.9	11.6	14.9	25.3	21.7	15.6	39.2	54.8	23	49.1	30.8	25.4	294.9
1986	28	8.6	23	23	31.2	125.1	53.9	60.7	29.7	18	18.2	19.8	419.4
1987	26.2	13.4	33.3	8.7	39.6	47.8	77.8	74.6	19.8	42.8	14.5	25.5	398.5
1988	23.1	18.7	19.2	47.6	36.2	63.2	87.6	35.4	18.4	33.8	56.4	8.2	439.6
1989	8.4	8.6	14.8	6.6	47.7	28.8	73.8	40	36	19.8	67.2	30.4	351.7
1990	20.4	18.4	19.2	3.4	12	38.8	35.2	36	25.8	33.4	60.2	37.6	302.8
1991	32.8	19.4	32	10.2	11.2	77.2	110.2	21.8	28.2	39.4	37.6	31.8	420
1992	10	44.6	18.8	9.2	20.8	91.8	39	62.4	82.8	29.2	27.8	3.8	436.4
1993	5.6	13.4	5.7	18.2	31.4	65.4	90.2	36.4	25.2	9			
1994													
1995								109	13	2	15		
1996		5	14	3	9	46	62	66.5	109.5	14.5	5	5	
1997	13.5	9	11	4.5	21.4	37.4	105	75.5	145.5	31	11.5	7.5	465.3
1998	7.5	6	4	14	16.5	31.5	112.9	34.5	27.5	2.5	16	5.5	272.9
1999	10	4	2.9	11	31.5	37.5	67.5	30.9	30.2	7.5	33.5	11	266.5
2000	13.5	1	8	4.5	42.7	39.5	49	64	39.5	21	6.5	14	289.2
2001	5.5	7.0	6.5	1.5	32.4	15.6	55.5	33.7	38.0	12.0	18.5	9.6	235.8
2002	10.9	9.7	7.7	12.7	12.7	27.3	78.0	41.0	87.5	16.5	9.0	13.0	326.0
N	79	77	77	72	81	79	84	83	79	77	84	81	50 *
Mean	18.2	16.1	17.2	18.4	24.5	40.0	57.2	44.4	40.3	25.0	24.8	20.9	346.21 *
StDev	9.5	13.0	9.3	12.8	15.9	24.0	38.6	23.9	26.9	18.0	14.8	13.2	73.02 *

- Mean of total precipitation calculated using only years with complete record.

The recent weather observation program (Station #3072658) was expanded in 1994 to include 24 hour wind speed and direction. The current observing program suite includes hourly temperatures, humidity, wind direction and wind speed, and daily precipitation. Solar radiation was collected for a short period of time in the early 1990's but the collection stopped when the special forestry project that funded the collection was completed in 1994.

Tables 2 and 3 show the mean monthly temperature and precipitation, respectively, for Fort Chipewyan for the period 1883 to 2002. During the past few years, several researchers have used different methods to generate gridded fields of climatic parameters. The most common technique utilizes inverse distance weighting. Hopkinson (2000), using a grid spacing of 50 km by 50 km, created gridded monthly mean temperature and precipitation arrays for Canada for the period since 1880 using an inverse distance technique. Figure 2 shows the gridded annual temperature data, for the grid point closest to Fort Chipewyan, for the period 1917 - 2000 including a 'best fit' trendline. This trendline indicates a statistically significant increase in mean annual temperatures at the 95% confidence level. Figure 3 shows the gridded annual precipitation, for the grid point nearest to Fort Chipewyan, for the period 1917-2000 including a 'best fit' trendline. This trendline shows a statistically significant increase in annual total precipitation at the 95% confidence level. In fact, both these trends are significant at the 99% confidence level.

Environment Canada calculates climatic 'normals' based on 30 years of data. The current 'normals' are based on data from 1961-1990. However, climate information was not collected at Fort Chipewyan in 1961, therefore, the period from 1962- 1990 was used as the 'normals' period in this study. Data analysis for the periods 1962-1990 and 1991-2000, abstracted from Table 3, are summarized in Table 4 below. This table reveals a shift in the temporal distribution of rainfall when comparing the latest decade against the 'normals' period. In the latest decade, the June to September period was wetter by 19% while the October to April period was 34% drier. Comparison of the total annual precipitation for the two periods shows slightly less precipitation fell during the last decade. This recent short term trend in precipitation is opposite to the trend of the long-term precipitation record (Figure 3).

Table 4. *Mean Monthly Precipitation (mm of water equivalent).*

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
1962-1990	21.3	15.4	18.3	20.8	28.8	48.4	64.8	49.7	42.5	33.7	26.6	22.4	392.7
1991-2000	14.9	14.8	14.1	10.9	21.7	63.6	79.0	50.8	52.0	18.1	17.8	12.1	369.8
Difference	-6.4	-0.6	-4.2	-9.9	-7.1	+15.2	+14.2	+1.1	+9.5	-15.6	-8.8	-10.3	-22.9

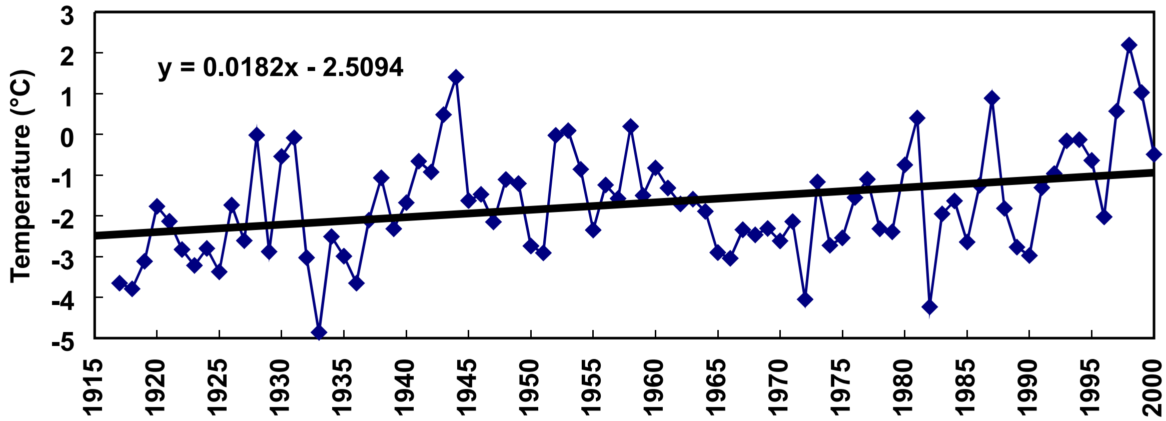


Figure 2. *Mean annual temperature for Fort Chipewyan, AB (from gridded data).*

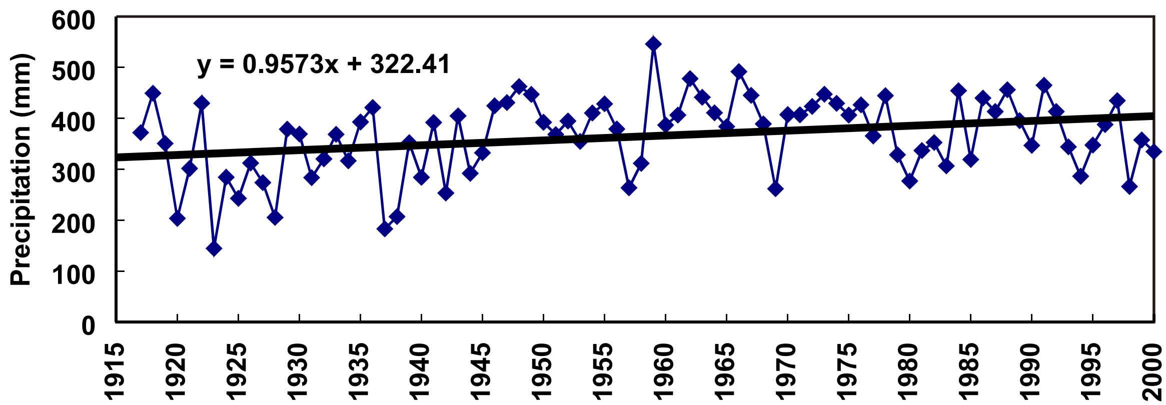


Figure 3. *Annual precipitation for Fort Chipewyan, AB (from gridded data).*

Ecosystem Goal 2 – Water Quality

Goal

Water quality is maintained within historic limits to support indigenous flora and fauna, and consumptive uses by people.

Surface water from lakes and rivers in the Delta is used for drinking water.

Indicators

Water from the Peace and Athabasca rivers should be free of contaminants and toxic substances, and levels of nutrients, major ions, and metals should be within natural ranges and limits. Specifically, concentrations should not exceed 0.4 mg/L total dissolved phosphorus, 39 mg/L dissolved sulphate (SO_4), and not less than 8.0 mg/L dissolved oxygen in ≥ 90% of all samples.

Total dissolved solids (TDS) should not exceed 272 and 148 mg/L for the Athabasca and Peace rivers, respectively, also in not more than 1 in 10 samples.

Indicator Measures

Water quality parameters are measured each month on the Athabasca River above Embarras Portage (Station Number AL07DD0001) and on the Peace River at Peace Point (Station Number AL07K0001). Water quality is assessed at other locations in the Delta as opportunities occur in other environmental programs.

Status

The Ecosystem Goal for water quality is not being met for some parameters. From 1996 to 2001 there were exceedances of the dissolved sulphate and total dissolved solids objective for the Athabasca River. Increases in total nitrogen, a nutrient parameter, in the Athabasca River were probably caused by a methods change in 1993. Most of the other water quality objectives for the Peace and Athabasca rivers were met. Published NRBS reports from the mid 1990s indicate that fish in the lower Peace and Athabasca rivers have low levels of pulp mill contaminants.

Background

Water quality has been monitored for the Athabasca River above Embarras Portage and for the Peace River at Peace Point from August 1989 to the present. Water quality data summaries for these sites are presented in Tables 5 and 6, respectively. The 10th (oxygen) or 90th percentiles (sulphate, total dissolved solids, and total dissolved phosphorus) from the data summaries were used as the parameter specific indicators identified in 1996 (Donald *et al.*, 1996). The concentration of specific parameters that are identified for this Ecosystem Indicator can be altered by municipal and industrial (pulp mill) effluents or land-use practices (agriculture and forestry). The water quality Indicators were selected to assess potential future impact of municipal and industrial effluents on the Delta. Seasonal specific water quality Indicators should be developed in the future. Repeated and consistent statistical increases in the specific and other water quality parameters (decrease for oxygen) constitute a compromise of ecosystem integrity. Low levels of contaminants from pulp mills are present in fish from both the lower Peace and Athabasca rivers (Pastershank and Muir, 1995; Pastershank and Muir, 1996) suggesting that this Ecosystem Indicator (2) is currently being compromised.

Table 5. *Water Quality of the Athabasca River above Embarras Portage, Alberta (AL07DD0001) (August 1989 to September 2001).*

Parameter (mg/L unless otherwise specified)	Valid N	Mean	Median	Minimum	Maximum	10th Percentile	90th Percentile	Standard Deviation
ALUMINUM DISSOLVED	19	0.0119	0.0100	0.0100	0.0460	0.0100	0.0100	0.0083
ALUMINUM TOTAL	61	1.1636	0.5460	0.0370	7.1400	0.0490	2.6900	1.4974
AMMONIA DISSOLVED	101	0.0571	0.0380	0.0025	0.6300	0.0070	0.1080	0.0722
ARSENIC DISSOLVED	102	0.0003	0.0003	0.0001	0.0010	0.0002	0.0004	0.0001
BARIUM DISSOLVED	19	0.0519	0.0490	0.0370	0.0730	0.0390	0.0720	0.0102
BARIUM TOTAL	100	0.0735	0.0618	0.0400	0.2000	0.0400	0.1105	0.0343
BERYLLIUM DISSOLVED (µg/L)	19	0.2500	0.2500	0.2500	0.2500	0.2500	0.2500	0.0000
BERYLLIUM TOTAL (µg/L)	59	0.0848	0.0250	0.0250	0.5100	0.0250	0.2000	0.0947
BICARBONATE (CALCD.)	96	140.3827	130.4000	87.2000	197.5000	106.2000	184.0690	30.1295
BORON DISSOLVED	101	1.0358	0.0260	0.0010	101.0000	0.0110	0.0670	10.0464
CADMIUM DISSOLVED	19	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0000
CADMIUM TOTAL	100	0.0002	0.0001	0.0001	0.0016	0.0001	0.0005	0.0003
CALCIUM DISSOLVED/FILTERED	99	35.4949	32.8000	21.3000	51.3000	26.8000	45.5000	7.2297
CARBON DISSOLVED ORGANIC	104	8.9257	8.4800	2.5400	19.6000	5.2500	13.6000	3.2839
CARBON PARTICULATE ORGANIC	104	2.2803	1.0800	0.2020	16.9000	0.2590	5.3700	3.0325
CARBON TOTAL ORGANIC (CALCD.)	100	11.3252	9.8350	3.3910	29.5000	6.2200	19.1350	5.4955
CARBONATE (CALCD.)	96	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
CHLORIDE DISSOLVED	100	18.1978	13.2000	1.8000	53.7000	4.6200	36.8500	13.0691
CHROMIUM DISSOLVED	19	0.0007	0.0005	0.0005	0.0040	0.0005	0.0005	0.0008
CHROMIUM TOTAL	61	0.0024	0.0012	0.0002	0.0210	0.0002	0.0051	0.0033
COBALT DISSOLVED	19	0.0005	0.0005	0.0005	0.0010	0.0005	0.0005	0.0001
COBALT TOTAL	100	0.0010	0.0004	0.0001	0.0069	0.0002	0.0025	0.0013
COLOUR TRUE (Rel Units)	107	38.0841	30.0000	2.5000	125.0000	10.0000	80.0000	25.2338
COPPER DISSOLVED	19	0.0010	0.0010	0.0005	0.0020	0.0005	0.0020	0.0005
COPPER TOTAL	100	0.0034	0.0019	0.0003	0.0188	0.0009	0.0074	0.0036
FLUORIDE DISSOLVED	99	0.1091	0.1100	0.0700	0.1500	0.0900	0.1300	0.0185
FREE CO_2 (CALCD.)	90	6.9434	1.6975	0.0500	160.3000	0.5200	10.4750	21.5865
HARDNESS NON-CARB. (CALCD.)	92	11.5559	11.2040	0.0000	27.4000	5.6000	17.3000	5.0670
HARDNESS TOTAL $CACO_3$ (CALCD.)	93	125.7214	118.7900	75.2000	182.0000	94.5000	161.2000	26.2409
HYDROXIDE (CALCD.)	96	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
IRON DISSOLVED	19	0.1101	0.1050	0.0070	0.2610	0.0160	0.2060	0.0678
IRON EXTRACTABLE	38	1.4160	0.5745	0.3940	11.5000	0.4110	3.5400	2.3396
IRON TOTAL	59	2.4389	1.1400	0.3610	13.9000	0.4570	5.8400	2.7925
LEAD DISSOLVED	19	0.0018	0.0010	0.0010	0.0100	0.0010	0.0040	0.0021
LEAD TOTAL	100	0.0024	0.0008	0.0001	0.0864	0.0001	0.0043	0.0087
LITHIUM DISSOLVED	19	0.0056	0.0050	0.0030	0.0090	0.0030	0.0080	0.0020
LITHIUM TOTAL	59	0.0128	0.0118	0.0044	0.0245	0.0073	0.0208	0.0047

NOTE: In all calculations, values of less than detection limit have been interpreted as detection limit/2.

Table 5. (cont'd) *Water Quality of the Athabasca River above Embarras Portage, Alberta (AL07DD0001) (August 1989 to September 2001).*

Parameter (mg/L unless otherwise specified)	**Valid N**	**Mean**	**Median**	**Minimum**	**Maximum**	**10th Percentile**	**90th Percentile**	**Standard Deviation**
MAGNESIUM DISSOLVED/FILTERED	99	9.4815	8.9500	5.3400	14.4000	6.7400	12.8000	2.2743
MANGANESE DISSOLVED	19	0.0043	0.0010	0.0005	0.0290	0.0005	0.0130	0.0071
MANGANESE EXTRACTABLE	38	0.0805	0.0430	0.0240	0.5230	0.0280	0.1830	0.1002
MANGANESE TOTAL	59	0.0867	0.0644	0.0171	0.4490	0.0246	0.1510	0.0818
MERCURY TOTAL (µg/L)	98	0.0093	0.0050	0.0025	0.0510	0.0025	0.0200	0.0100
MOLYBDENUM DISSOLVED	19	0.0014	0.0010	0.0005	0.0030	0.0005	0.0020	0.0007
MOLYBDENUM TOTAL	59	0.0010	0.0007	0.0001	0.0052	0.0004	0.0021	0.0008
NICKEL DISSOLVED	19	0.0017	0.0010	0.0010	0.0050	0.0010	0.0030	0.0010
NICKEL TOTAL	100	0.0038	0.0019	0.0007	0.0274	0.0011	0.0081	0.0045
NITROGEN DISSOLVED	41	0.2291	0.2350	0.0580	0.4210	0.1000	0.3870	0.1070
NITROGEN DISSOLVED NO_3 & NO_2	102	0.0777	0.0400	0.0050	0.2920	0.0050	0.2010	0.0813
NITROGEN PARTICULATE	104	0.1909	0.1050	0.0130	1.3400	0.0270	0.4070	0.2317
NITROGEN TOTAL (CALCD.)	101	0.5390	0.5200	0.1500	1.7000	0.2200	0.8600	0.2940
NITROGEN TOTAL DISSOLVED	63	0.4196	0.4390	0.1100	0.6320	0.2360	0.5740	0.1316
OXYGEN DISSOLVED	99	10.2712	10.4700	7.2000	16.0000	8.0000	12.8000	1.9214
PH (pH Units)	96	7.7874	7.8000	7.1700	8.1700	7.5000	8.0300	0.1962
PHOSPHORUS PARTICULATE (CALCD.)	103	0.0864	0.0340	0.0050	0.5890	0.0100	0.2240	0.1197
PHOSPHORUS TOTAL	106	0.1016	0.0445	0.0140	0.6000	0.0250	0.2440	0.1179
PHOSPHORUS TOTAL DISSOLVED	107	0.0158	0.0160	0.0010	0.0310	0.0070	0.0240	0.0064
POTASSIUM DISSOLVED/FILTERED	99	1.2517	1.2300	0.6100	2.5400	0.8000	1.7200	0.3652
RESIDUE FIXED NONFILTRABLE	107	87.4430	25.8000	0.5000	716.0000	1.6000	248.0000	141.2092
RESIDUE NONFILTRABLE	106	96.6425	29.6000	1.5000	774.0000	2.6000	272.0000	152.9016
SELENIUM DISSOLVED	102	0.0002	0.0001	0.0001	0.0004	0.0001	0.0003	0.0001
SILVER TOTAL	16	0.0002	0.0001	0.0001	0.0010	0.0001	0.0003	0.0002
SIO_2	99	6.2963	5.5800	0.1000	10.4000	3.4900	9.6100	2.3506
SODIUM DISSOLVED/FILTERED	98	19.5353	14.0500	4.2200	48.0000	8.2100	36.2000	11.3451
SODIUM PERCENTAGE (CALCD.)	92	22.5177	21.0000	7.6010	38.6000	14.2000	32.0000	6.8895
SPECIFIC CONDUCTANCE	92	440.1903	313.5000	2.5100	3907.0000	210.0000	491.0000	579.2764
SPECIFIC CONDUCTANCE	98	339.6704	304.5000	186.0000	577.0000	225.0000	492.0000	104.7399
STRONTIUM DISSOLVED	19	0.2258	0.1960	0.1320	0.3840	0.1420	0.3710	0.0739
STRONTIUM TOTAL	59	0.2241	0.2180	0.1170	0.3870	0.1490	0.3120	0.0604
SULPHATE DISSOLVED	98	25.8337	25.3500	7.1000	50.9000	15.0000	38.9000	8.9549
TEMPERATURE WATER (Deg. C)	106	8.5462	8.5000	0.0000	23.5000	0.0000	19.9000	7.7612
TOTAL DISSOLVED SOLIDS (CALCD.)	98	183.2081	166.3863	104.7500	304.6800	123.5500	263.1300	55.0200
TURBIDITY (NTU)	107	53.8159	16.1000	2.8000	452.0000	3.9000	145.0000	84.6248
VANADIUM DISSOLVED	19	0.0009	0.0005	0.0005	0.0050	0.0005	0.0010	0.0010
VANADIUM TOTAL	100	0.0028	0.0012	0.0003	0.0177	0.0003	0.0078	0.0034
ZINC DISSOLVED	19	0.0012	0.0010	0.0010	0.0030	0.0010	0.0020	0.0005
ZINC TOTAL	100	0.0087	0.0046	0.0007	0.0535	0.0018	0.0195	0.0097

NOTE: In all calculations, values of *less than detection limit* have been interpreted as *detection limit/2*.

Table 6. *Water Quality of the Peace River at Peace Point, Alberta (AL07KC0001) (August 1989 to September 2001).*

Parameter (mg/L unless otherwise specified)	**Valid N**	**Mean**	**Median**	**Minimum**	**Maximum**	**10th Percentile**	**90th Percentile**	**Standard Deviation**
ALKALINITY TOTAL $CACO_3$	99	96.3374	95.6000	60.3000	116.0000	88.2000	106.0000	7.6876
ALUMINUM DISSOLVED	17	0.0117	0.0100	0.0100	0.0390	0.0100	0.0100	0.0070
ALUMINUM TOTAL	61	3.2209	0.5050	0.0710	68.7000	0.1040	7.2900	9.0004
AMMONIA DISSOLVED	100	0.0240	0.0120	0.0025	0.6950	0.0050	0.0380	0.0693
ARSENIC DISSOLVED	92	0.0003	0.0003	0.0001	0.0012	0.0001	0.0005	0.0002
BARIUM DISSOLVED	17	0.0477	0.0490	0.0400	0.0570	0.0400	0.0560	0.0057
BARIUM TOTAL	99	0.1040	0.0668	0.0391	0.3790	0.0400	0.2240	0.0821
BERYLLIUM DISSOLVED (μg/L)	17	0.2500	0.2500	0.2500	0.2500	0.2500	0.2500	0.0000
BERYLLIUM TOTAL (μg/L)	60	0.1831	0.0250	0.0250	2.2400	0.0250	0.4950	0.3236
BICARBONATE (CALCD.)	96	117.3830	116.4000	73.5060	141.4040	107.5000	129.2140	9.4630
BORON DISSOLVED	93	0.0606	0.0090	0.0010	4.0000	0.0040	0.0350	0.4139
CADMIUM DISSOLVED	17	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0000
CADMIUM TOTAL	99	0.0005	0.0001	0.0001	0.0063	0.0001	0.0016	0.0009
CALCIUM DISSOLVED/FILTERED	99	32.8222	32.9000	20.1000	39.5000	30.2000	36.2000	2.6497
CARBON DISSOLVED ORGANIC	97	5.9544	5.1100	2.1400	14.7000	2.9100	11.7000	3.2331
CARBON PARTICULATE ORGANIC	96	3.4378	0.9190	0.1230	32.6000	0.1950	10.9000	5.5943
CARBON TOTAL ORGANIC (CALCD.)	92	9.2782	6.6230	2.6600	43.2000	3.4500	20.6500	7.7645
CARBONATE (CALCD.)	96	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
CHLORIDE DISSOLVED	99	2.5154	2.0000	1.1400	19.0000	1.6600	3.1300	2.2490
CHROMIUM DISSOLVED	17	0.0006	0.0005	0.0005	0.0010	0.0005	0.0010	0.0002
CHROMIUM TOTAL	61	0.0046	0.0010	0.0001	0.0768	0.0003	0.0116	0.0104
COBALT DISSOLVED	17	0.0006	0.0005	0.0005	0.0010	0.0005	0.0010	0.0002
COBALT TOTAL	99	0.0020	0.0006	0.0001	0.0189	0.0002	0.0057	0.0029
COLOUR TRUE (Rel. Units)	99	31.4899	20.0000	2.5000	140.0000	5.0000	90.0000	31.7233
COPPER DISSOLVED	17	0.0016	0.0010	0.0005	0.0050	0.0010	0.0030	0.0011
COPPER TOTAL	99	0.0064	0.0025	0.0007	0.0556	0.0012	0.0156	0.0085
FLUORIDE DISSOLVED	98	0.0743	0.0700	0.0400	0.2500	0.0500	0.1100	0.0273
FREE CO_2 (CALCD.)	94	4.0765	2.2600	0.1200	61.2500	0.8000	7.6100	6.9157
HARDNESS NON-CARB. (CALCD.)	95	16.5922	15.9000	4.2310	31.5000	10.8060	24.3000	5.3617
HARDNESS TOTAL (CALCD.) $CACO_3$	95	113.2638	112.7000	91.9310	134.3260	103.1000	126.3000	8.1917
HYDROXIDE (CALCD.)	96	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
IRON DISSOLVED	17	0.0525	0.0440	0.0070	0.1370	0.0090	0.1360	0.0432
IRON EXTRACTABLE	38	2.0033	0.8275	0.1210	19.1000	0.1570	3.6100	3.6693
IRON TOTAL	60	5.7652	1.0600	0.1560	61.7000	0.2390	16.5500	9.8865
LEAD DISSOLVED	17	0.0016	0.0010	0.0010	0.0040	0.0010	0.0040	0.0012
LEAD TOTAL	99	0.0034	0.0013	0.0001	0.0458	0.0002	0.0094	0.0057
LITHIUM DISSOLVED	17	0.0033	0.0030	0.0010	0.0080	0.0010	0.0070	0.0021
LITHIUM TOTAL	60	0.0099	0.0065	0.0019	0.1150	0.0029	0.0187	0.0150

NOTE: In all calculations, values of *less than detection limit* have been interpreted as *detection limit/2.*

Table 6. (cont'd). *Water Quality of the Peace River at Peace Point, Alberta (AL07KC0001) (August 1989 to September 2001).*

Parameter (mg/L unless otherwise specified)	Valid N	Mean	Median	Minimum	Maximum	10th Percentile	90th Percentile	Standard Deviation
MAGNESIUM DISSOLVED/FILTERED	99	7.4832	7.4500	4.7700	9.8100	6.6500	8.6000	0.7298
MANGANESE DISSOLVED	17	0.0009	0.0010	0.0005	0.0020	0.0005	0.0010	0.0004
MANGANESE EXTRACTABLE	38	0.0678	0.0320	0.0040	0.5870	0.0060	0.2430	0.1140
MANGANESE TOTAL	60	0.0990	0.0337	0.0058	0.6790	0.0074	0.3135	0.1371
MERCURY TOTAL (µg/L)	99	0.0126	0.0050	0.0025	0.1300	0.0025	0.0300	0.0217
MOLYBDENUM DISSOLVED	17	0.0011	0.0010	0.0005	0.0020	0.0005	0.0020	0.0005
MOLYBDENUM TOTAL	60	0.0008	0.0008	0.0001	0.0045	0.0005	0.0012	0.0006
NICKEL DISSOLVED	17	0.0016	0.0010	0.0010	0.0040	0.0010	0.0030	0.0009
NICKEL TOTAL	99	0.0064	0.0026	0.0003	0.0638	0.0009	0.0158	0.0091
NITROGEN DISSOLVED	42	0.1652	0.1480	0.0750	0.4650	0.0980	0.2400	0.0818
NITROGEN DISSOLVED NO_3 & NO_2	96	0.0708	0.0685	0.0010	0.3940	0.0050	0.1150	0.0641
NITROGEN PARTICULATE	96	0.3304	0.0885	0.0050	3.5100	0.0200	1.0300	0.5300
NITROGEN TOTAL (CALCD.)	92	0.5380	0.2600	0.1200	4.0430	0.1650	1.2700	0.5921
NITROGEN TOTAL DISSOLVED	55	0.2593	0.2200	0.1310	0.7500	0.1560	0.4470	0.1259
OXYGEN DISSOLVED	89	11.4700	11.9000	7.4000	17.7000	8.2100	14.5000	2.2925
PH (pH Units)	98	7.8336	7.8600	7.2000	8.1300	7.6100	8.0200	0.1631
PHOSPHORUS PARTICULATE (CALCD.)	95	0.1469	0.0300	0.0020	1.2150	0.0060	0.4810	0.2324
PHOSPHORUS TOTAL	99	0.1683	0.0500	0.0070	1.3800	0.0120	0.5470	0.2608
PHOSPHORUS TOTAL DISSOLVED	97	0.0100	0.0070	0.0010	0.0600	0.0020	0.0180	0.0101
POTASSIUM DISSOLVED/FILTERED	99	0.9466	0.6800	0.4000	13.8000	0.5100	1.3000	1.3813
RESIDUE FIXED NONFILTRABLE	99	180.6869	36.0000	0.5000	1940.0000	4.0000	652.0000	314.0818
RESIDUE NONFILTRABLE	100	194.8900	42.3000	2.0000	2120.0000	4.9500	640.0000	338.9132
SATURATION INDEX (CALCD.)	94	64.1899	-0.3045	-1.7070	6066.1700	-1.3000	0.5550	625.7138
SELENIUM DISSOLVED	92	0.0003	0.0003	0.0001	0.0007	0.0002	0.0004	0.0001
SILVER TOTAL	18	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0000
SIO_2	99	3.9860	4.0800	0.5400	5.2800	3.2400	4.6900	0.6568
SODIUM DISSOLVED/FILTERED	99	4.5394	4.1700	2.1900	20.4000	3.0700	6.1100	1.9991
SODIUM PERCENTAGE (CALCD.)	95	7.8633	7.4000	5.3000	25.3890	6.0000	9.8000	2.5065
SPECIFIC CONDUCTANCE	98	238.1429	235.5000	152.0000	331.0000	217.0000	265.0000	21.5713
STRONTIUM DISSOLVED	17	0.1376	0.1240	0.1130	0.2230	0.1200	0.1740	0.0278
STRONTIUM TOTAL	60	0.1479	0.1410	0.1150	0.2430	0.1250	0.1775	0.0263
SULPHATE DISSOLVED	99	21.1495	20.3000	12.4000	34.7000	15.7000	29.7000	5.2607
TEMPERATURE WATER (Deg. C)	99	7.4222	2.5000	0.0000	25.0000	0.0000	19.0000	8.0012
TOTAL DISSOLVED SOLIDS (CALCD.)	99	130.2500	130.1400	63.0200	188.5900	117.2600	147.1300	14.5100
TURBIDITY (NTU)	99	157.7818	29.0000	3.4000	1840.0000	5.7000	490.0000	283.7814
VANADIUM DISSOLVED	17	0.0006	0.0005	0.0005	0.0010	0.0005	0.0010	0.0002
VANADIUM TOTAL	99	0.0068	0.0013	0.0003	0.2010	0.0003	0.0154	0.0209
ZINC DISSOLVED	17	0.0041	0.0010	0.0010	0.0320	0.0010	0.0130	0.0078
ZINC TOTAL	99	0.0240	0.0079	0.0009	0.2790	0.0021	0.0716	0.0397

NOTE: In all calculations, values of *less than detection limit* have been interpreted as *detection limit/2*

Table 7 summarizes exceedances in water quality indicators from August 1989 to December 1995 and from January 1996 to October 2001. There has been a small number of exceedances of the dissolved sulfate objective in the Athabasca River and the TDS objective in the Peace River (> 1 in 10 samples). The total dissolved phosphorus objective was met in both rivers in all years. Dissolved sulphate in the Athabasca River exceeded the 39 mg/L objective four times between 1996 and 2001 (10.5%), all occurring during the winter months under low-flow conditions with the maximum concentration 48.3 mg/L. Exceedance for total dissolved solids occurred on the Peace River where some of the highest recorded concentrations were during the fall of 2001. Total dissolved solids concentrations were 160 mg/L and 189 mg/L in September and October of 2001 respectively. For both parameters, exceedances were relatively minor and were aggravated by lower than normal water levels.

Table 7. *Summary of exceedances for indicators of water quality from 1989 to 1995 and from 1996 to 2001.*

Location	**Month-Year**	**Dissolved Oxygen (<8 mg/L)**			**Total Dissolved Phosphorus (>0.4 mg/L)**		
		N	**Exceedances**	**%**	**N**	**Exceedances**	**%**
Athabasca R.	**Aug 89-Dec 95**	53	5	9.4	60	0	0.0
	Jan 96-Oct 01	44	3	6.8	45	0	0.0
Peace R.	**Aug 89-Dec 95**	88	4	4.5	96	0	0.0
	Jan 96-Oct 01	32	2	6.3	35	0	0.0

Location	**Month-Year**	**Dissolved Sulphate (>39 mg/L)**			**Total Dissolved Solids (272 mg/L Athabasca, >148 mg/L Peace)**		
		N	**Exceedances**	**%**	**N**	**Exceedances**	**%**
Athabasca R.	**Aug 89-Dec 95**	61	5	8.2	59	3	5.1
	Jan 96-Oct 01	38	4	10.5	27	1	3.7
Peace R.	**Aug 89-Dec 95**	140	11	7.9	62	5	8.1
	Jan 96-Oct 01	39	0	0.0	24	3	12.5

Analysis of the long-term water quality data at Embarras Portage shows a statistically significant increase in total nitrogen on the Athabasca River since 1989 (Figure 4). However, the analytical method for nitrogen changed in 1993, and the positive trend was influenced by this change in the analytical procedure. Water samples analyzed by both methods in 1993 indicated that the newer method gave slightly higher concentrations to dissolved nitrogen. Moreover, there was no significant trend in total nitrogen concentration (dissolved + particulate nitrogen) when only data from 1993 to 2001 were used in the analysis. Linear regression analyses with seasonality as a covariant were conducted on total nitrogen concentrations for both the Athabasca and Peace rivers. Data was examined and determined to be heteroscedacic and thus log-transformed prior to analysis. In the Peace River, seasonality is more important with spring and summer months (April – August) contributing significantly ($p < 0.001$) to the trends in nitrogen concentration. However, total nitrogen does not appear to be increasing in the Peace River through time as the overall time trend was not significant in this river ($p = 0.072$). For both rivers, an analytical method change for total nitrogen occurred in fall 1993 that could have influenced the trends. Thus, trends for total nitrogen need to be carefully monitored in future years.

Any change over time in the water quality for the Athabasca River may reflect increased pulp mill activity in the Athabasca River drainage basin as well as an increase in municipal wastewater effluents. Four new pulp mills have been built in the Athabasca basin since 1988 (Table 8) and the population in the Fort McMurray area has increased from around 35,000 people in 1986 to approximately 41,500 in 2001 (Statistics Canada, 1986, 2001). There was no significant change in total nitrogen in the Athabasca River over this period of time (Figure 4). The Athabasca River has an average annual discharge of 24,692,688 dam^3 which is about three times less than the average annual discharge of 66,540,960 dam^3 for the Peace River. Thus, the dilution factor for the Athabasca River is much less than the Peace River. The Athabasca River should be more vulnerable to increases in industrial and municipal effluents than the Peace River.

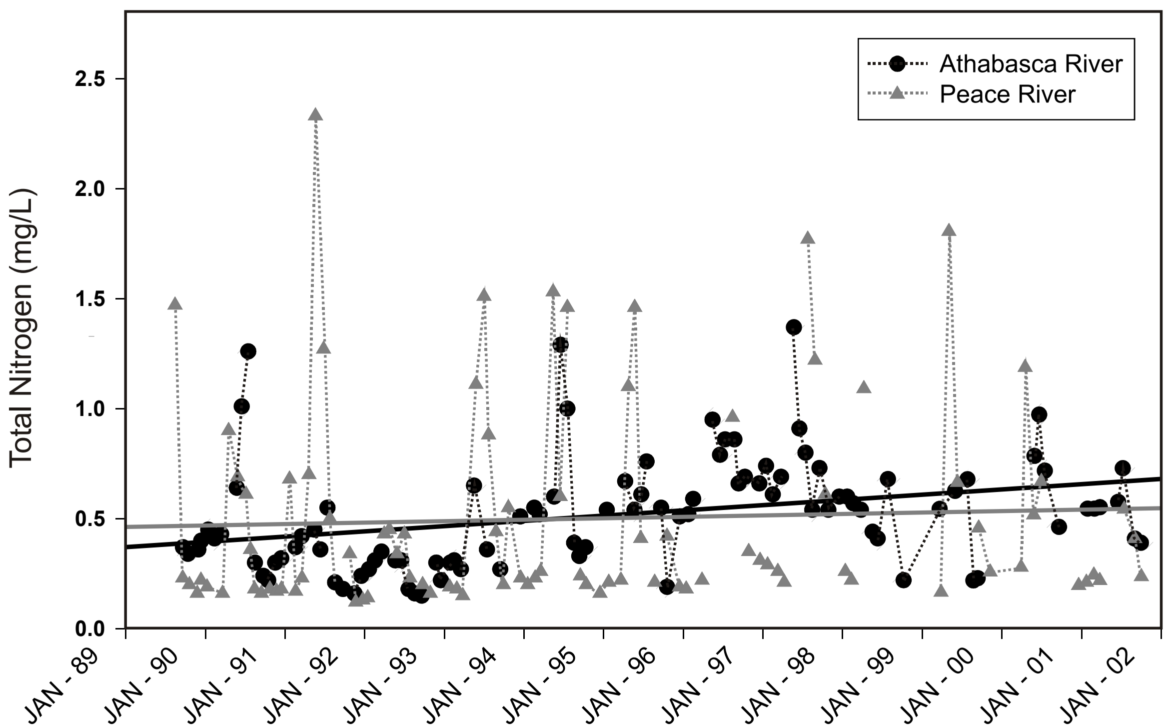


Figure 4. *Trend Analysis for the Total Nitrogen for the Peace (grey triangles and lines) and Athabasca (black circles and lines) rivers for the period of data analysis (1989-2001). Trend line is indicated as solid line.*

Table 8. *New Pulp Mills in the Athabasca River Basin, 1988 to present.*

Mill	Town	Process Type	Start-Up Date
Alberta Pacific	Athabasca	Bleached Kraft	September 1993
Slave Lake	Slave Lake	Chemi-Thermo Mechanical Pulp	December 1990
Millar Western	Whitecourt	Chemi-Thermo Mechanical Pulp	July 1988
Alberta Newsprint Co.	Whitecourt	Thermo-Mechanical Pulp	August 1990

The Peace-Athabasca Delta has three principal sources of water; the Peace, Athabasca and Birch rivers (Figure 5). Principal Component Analyses were performed to determine if these sources had distinct chemical characteristics. The seven basic water quality parameters used to distinguish these rivers were calcium, sodium, magnesium, bicarbonate, sulphate, chloride and total dissolved solids. Other parameters (e.g. sediments, nutrients) may also contribute to distinguishing these rivers, but were not consistently available for this analysis. In the spring and summer months (May-August) between 1989-2001, the Peace and Athabasca rivers had distinct water quality characteristics (Figure 5A). The first two axes of the PCA explained 82% of the variability in these samples with the separation of the two river systems largely occurring on the second PC axis (PC2). This axis was dominated by sodium and chloride concentrations, with the Peace River exhibiting lower concentrations of these ions. Although only limited historic data was available for the Birch River (Figure 5B), this datum indicated a chemical characteristic very different from either the Athabasca or the Peace rivers. Higher levels of total dissolved solids, sodium, chloride and sulphate were observed in the Birch River.

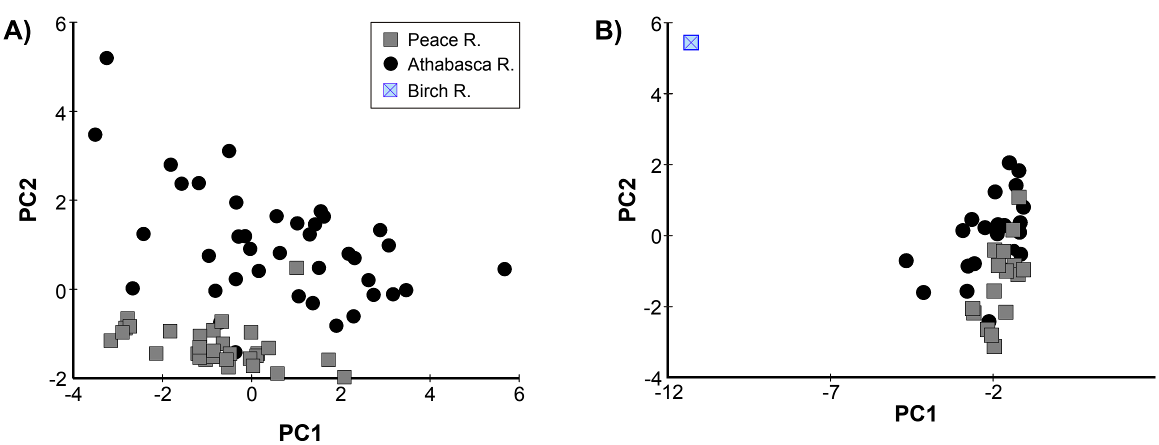


Figure 5. *Principle Component Analysis of water quality data available from the Peace – Athabasca Delta: A) Recent (1989-2001) data from the Peace River (Peace R.) and Athabasca River (Atha R.), B) Peace and Athabasca river data in context with available Birch River (Birch R.) historic data.*

With the distinct chemical characteristics of these rivers, a final PCA (Figure 6) was performed to determine if sites within the two main lakes (Lake Claire and Mamawi Lake) and additional sites throughout the Delta exhibited basic chemical characteristics attributable to the source rivers (see Figures 7-11 for site locations). The first two axes of this PCA explained 90 % of the variability within all sites with the first axis (PC1) dominated by decreasing levels of total dissolved solids, sodium, chloride and sulphate and the second axis (PC2) dominated by increasing levels of bicarbonate and magnesium. The historic water quality data from Lake Claire was spread along the first axis, these samples were closest to the characteristics of the Birch River, particularly on PC2. The data for Mamawi Lake and other Delta sites were more recent (1999 and 2000) and perhaps more comparable with the Athabasca and Peace river data. As expected, the three sites in the southern portion of Mamawi Lake overlapped completely with the Athabasca River samples. The remainder of the Delta sites did not exhibit characteristics that could be easily attributable to any of the rivers despite the observed differences in Peace and Athabasca river water quality. Sites relatively close geographically were separated on the PCA while several sites closely associated in the PCA were geographically separated. Despite a general lack of close associations between Delta sites and the source rivers, this analysis revealed that with a short list of parameters, river chemistry was distinct. If a consistent set of parameters within overlapping time frames were available, sites within the Delta may be more closely associated with their source river.

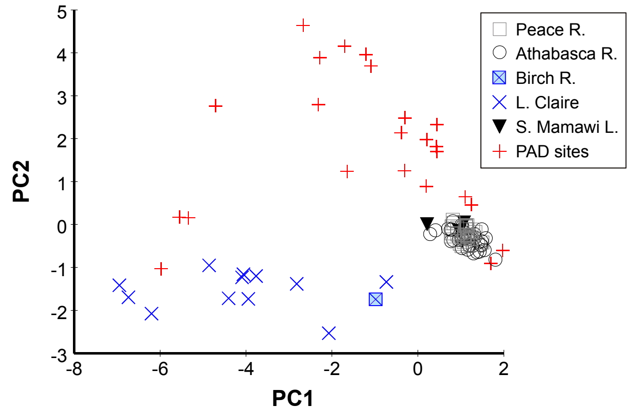
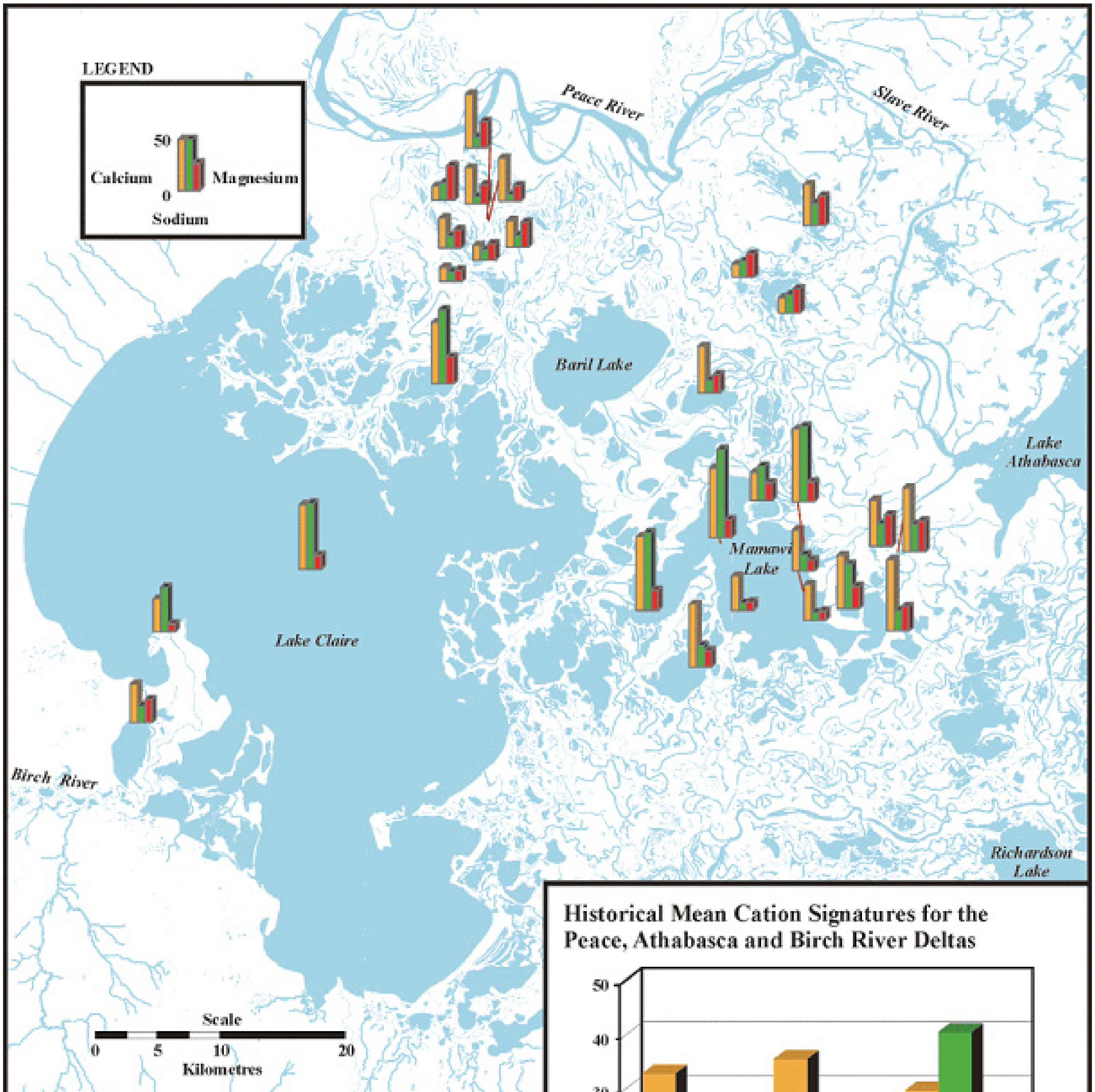


Figure 6. *Principle Component Analysis of water quality data available from the Peace -Athabasca Delta. Data includes Peace and Athabasca River data, the historic data available from Lake Claire and Birch River, three sites in the south portion of Mamawi Lake, and 23 additional sites located throughout the Delta.*

In addition to the ion chemistry of Delta waters, percent sodium, dissolved organic carbon, total nitrogen, and total phosphorus all show non-uniform spatial patterns within the Delta (Figures 7-11). These patterns suggest that the Birch, Peace, and Athabasca rivers influence water quality in the Delta, but that smaller perched and connected basins also contribute to the quality characteristics of surface waters.

The complexity and non-uniformity of the Delta's water chemistry has implications for monitoring programs and predictive models required for ongoing assessments of Delta ecosystems. Water chemistry analyses could delineate special patterns for contaminants from oilsands development and processing in the Athabasca River Delta. Spatial analysis of the aerial extent of future large flood events in the Delta could also be determined from Delta water chemistry. Important goldeye spawning and rearing habitat in Lake Claire and Mamawi Lake normally would not be affected by Peace and Athabasca river water quality.



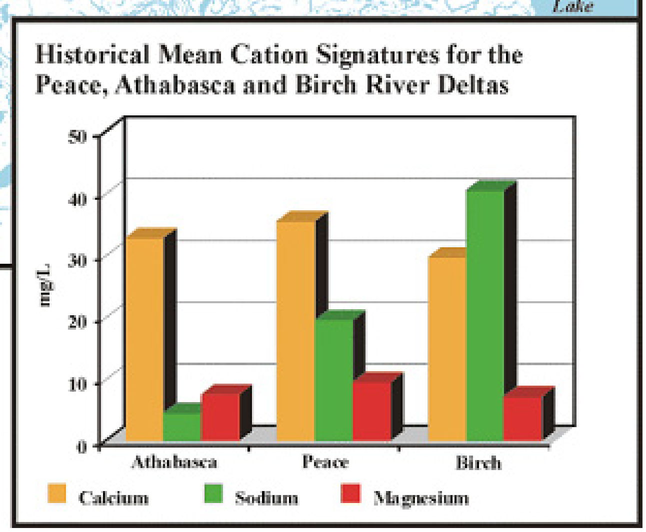
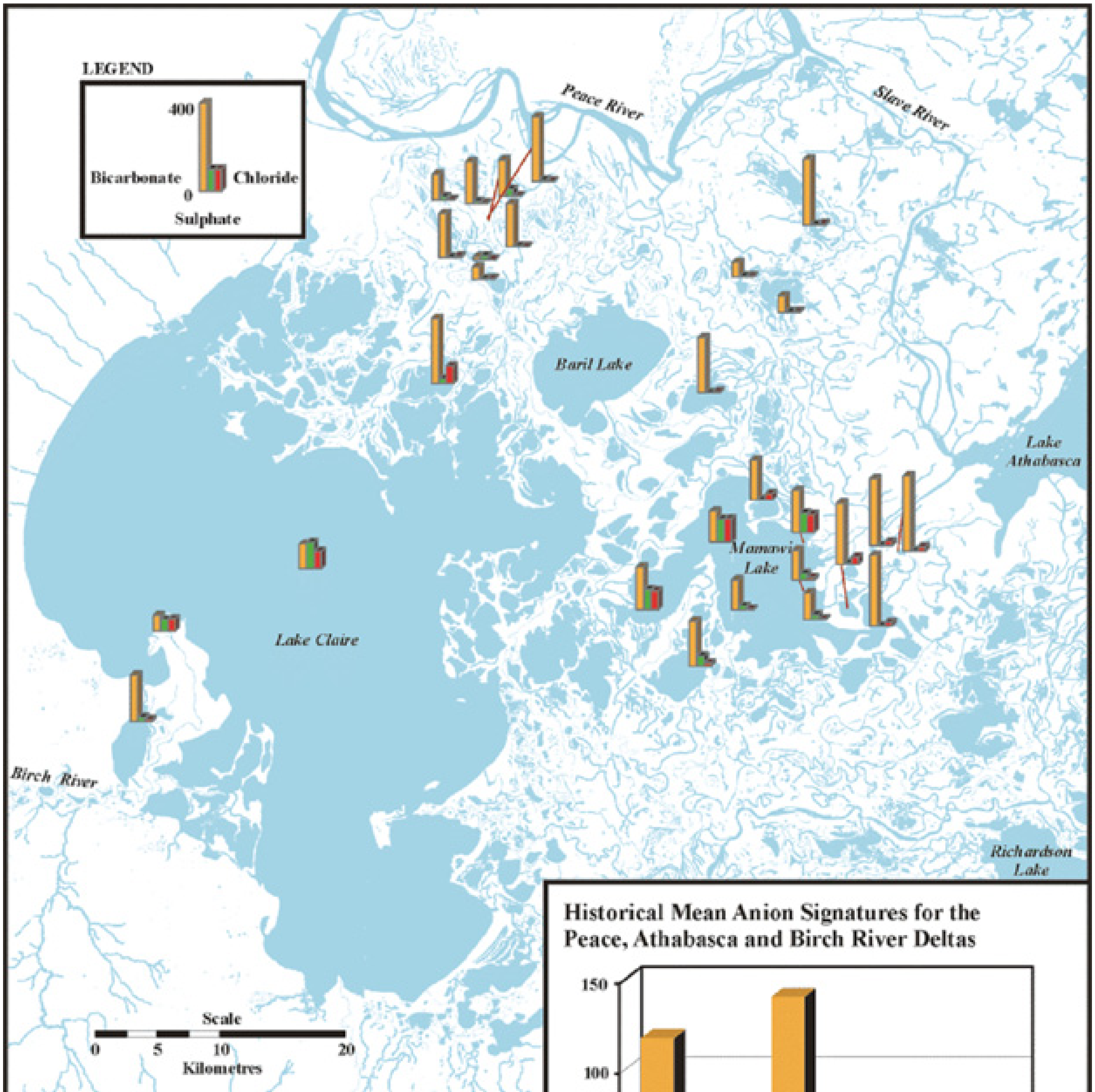


Figure 7. *Water Chemistry of the Peace-Athabasca Delta: Cations (calcium, sodium, magnesium)*



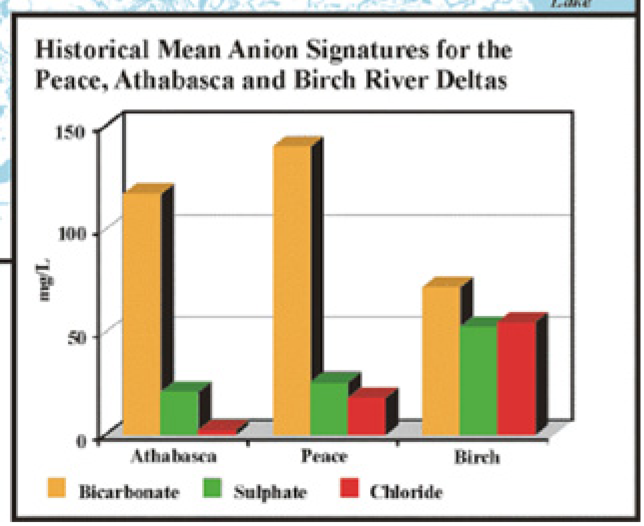
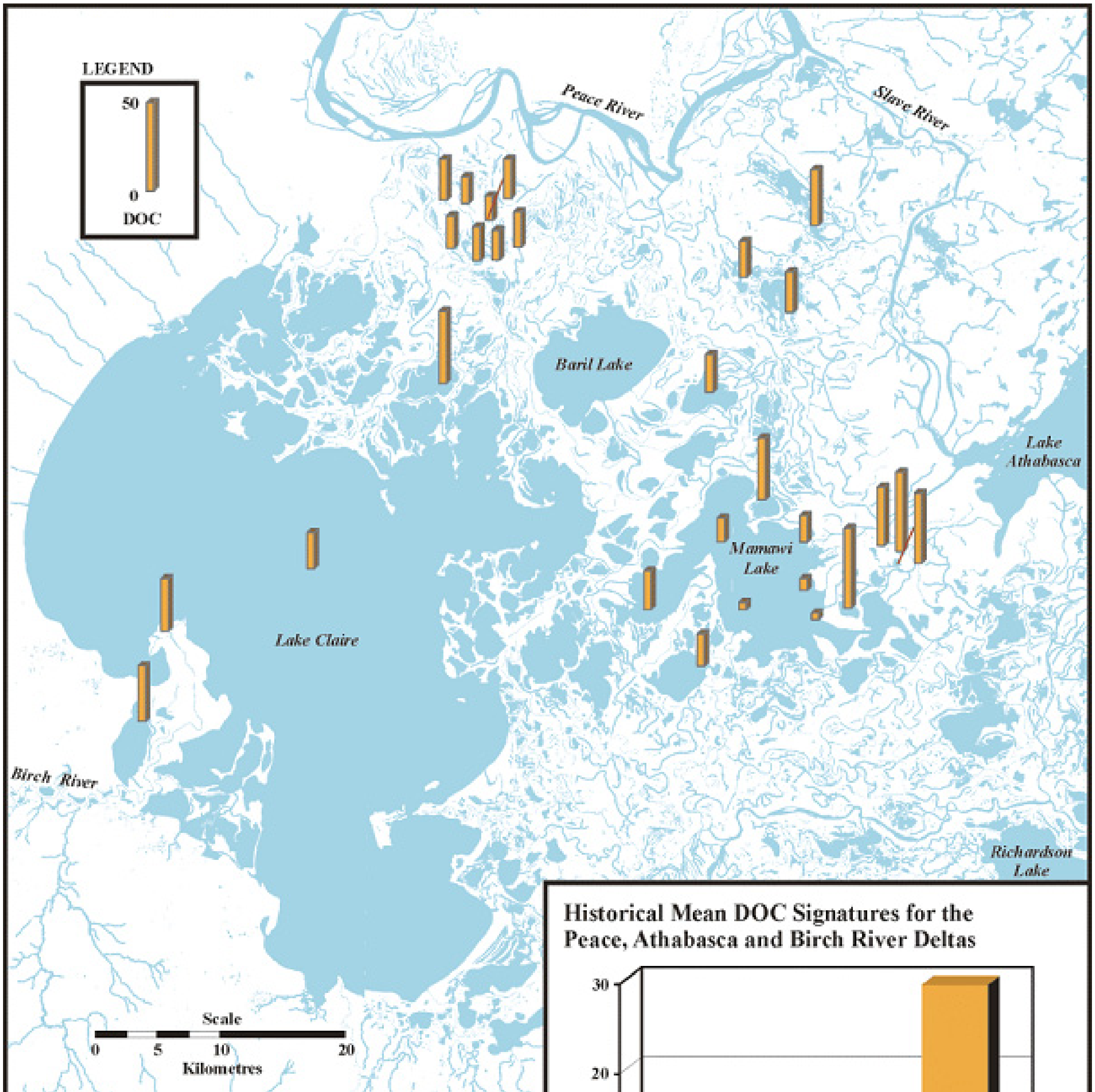


Figure 8. *Water Chemistry of the Peace-Athabasca Delta: Anions (bicarbonate, sulphate, chloride).*



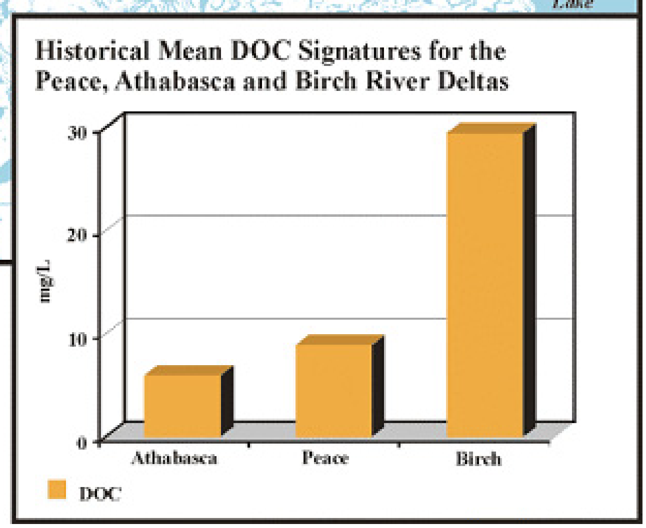


Figure 9. *Water Chemistry of the Peace-Athabasca Delta: Dissolved organic carbon (D.O.C.).*

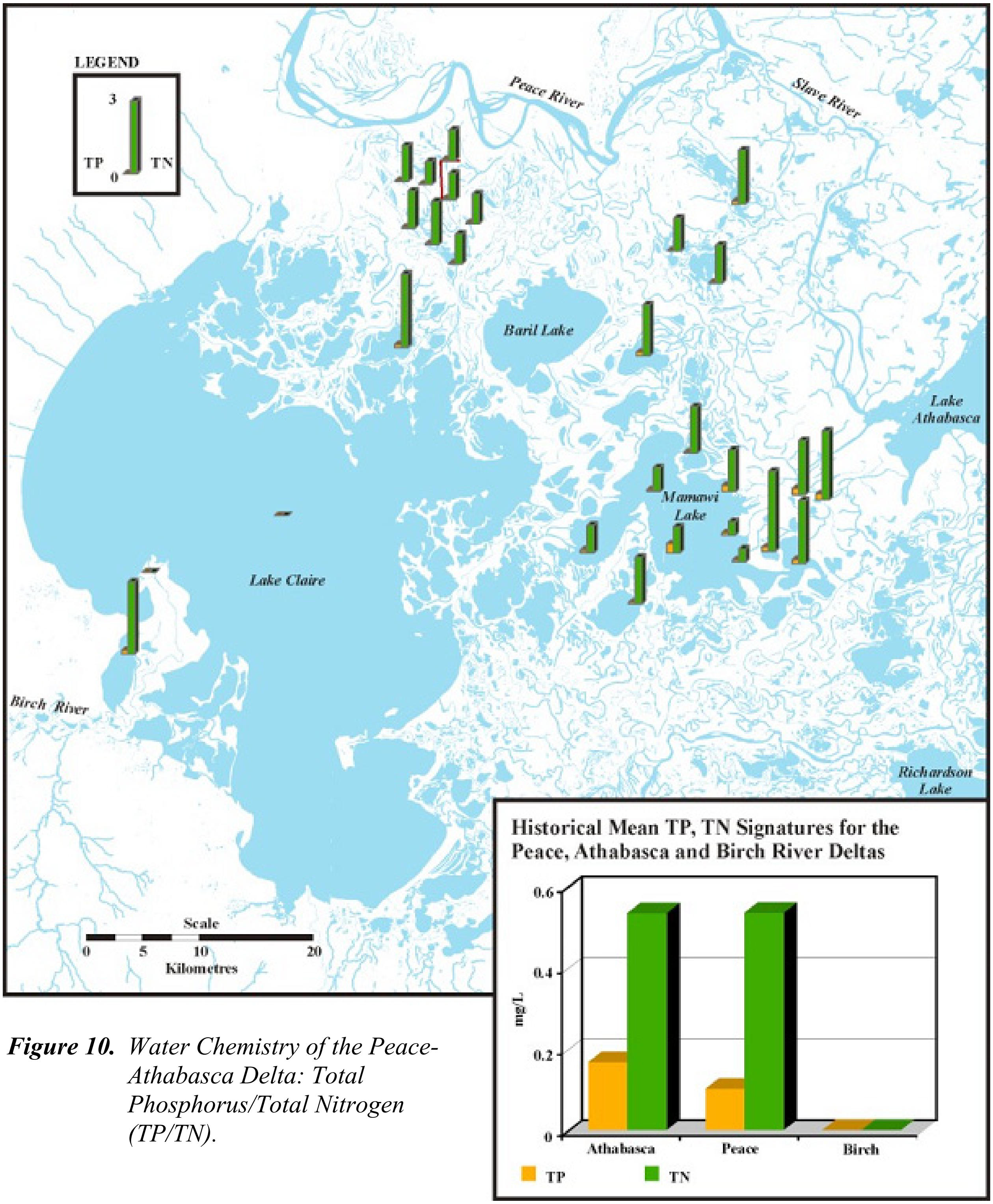


Figure 10. *Water Chemistry of the Peace-Athabasca Delta: Total Phosphorus/Total Nitrogen (TP/TN).*

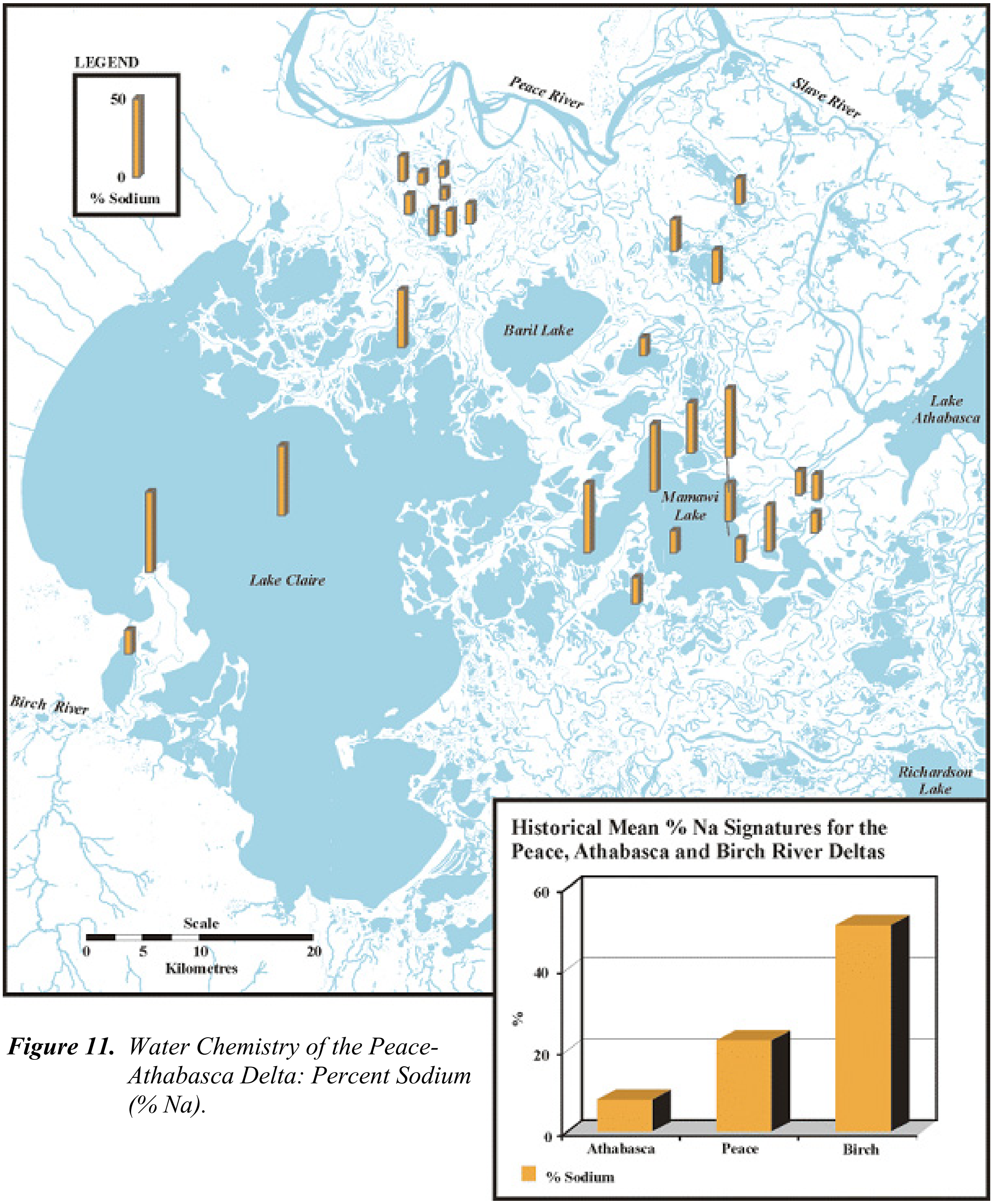


Figure 11. *Water Chemistry of the Peace-Athabasca Delta: Percent Sodium (% Na).*

Ecosystem Goal 3 - Water Level

Goal

Water levels are maintained in the Peace-Athabasca Delta to provide quality habitat for aquatic life and to allow regional boat and barge transportation.

Indicator

The environmental indicator for water levels were levels in Lake Claire. Water levels for Lake Claire, the largest lake in the Peace-Athabasca Delta, should follow annual and long-term natural patterns and elevations, and should be unaffected by flow regulation on the Peace or other rivers; or natural levels are maintained by structures in or near the Delta.

Indicator Measure

Water level is measured each day for Lake Claire at the Prairie River outlet to Mamawi Lake throughout the year (Station Number 07KF002).

Status

Water levels in Lake Claire have remained within the historic range recorded post Bennett Dam (1970-2000). Therefore, the requirements of this environmental indicator are generally being met. However, the annual water level fluctuations (Figure 12) of 1.5 m to 2.0 m that were common in the 1960's and 1970's were reduced significantly during the early 1980's when summer precipitation in the headwaters of the Peace and Athabasca rivers was relatively light. High flows and ice jams on the Peace River during the mid 1980's elevated Lake Claire levels. These higher levels generally declined until 1996 when a structural problem at the W.A.C. Bennett Dam forced the operators to lower Williston Lake. The resulting increased flows on the Peace River raised Lake Claire levels and they remained relatively high for almost 2 years.

Background

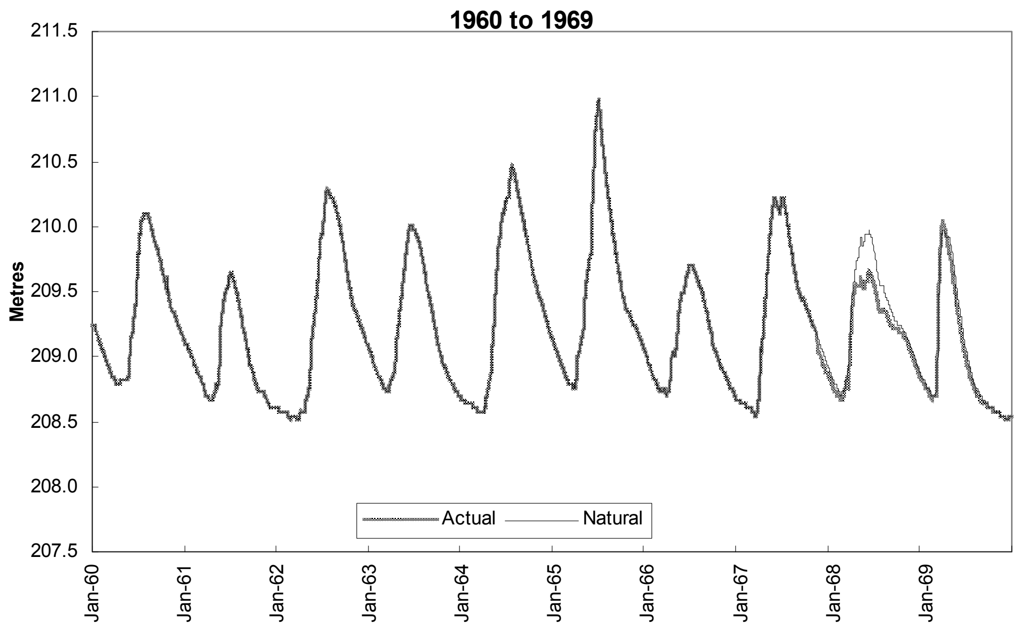
At present, water levels in the Delta are altered by regulation of the Peace River in British Columbia at the W.A.C. Bennett Dam, but these altered levels have been partly restored to the natural condition by weirs on Rivière des Rochers and Revillon Coupe (Aitken and Sapach, 1994). Because of the weirs, water levels in Lake Claire are higher than the natural regime from September to May, but lower than the natural regime by about 0.2 metres from June to August (Figure 12). Water levels in Mamawi Lake are higher than natural conditions from September to May by up to 0.3 m, and are lower from June to August. The W.A.C. Bennett Dam has also reduced the probability of flooding in spring from ice jam formation in the lower Peace and Slave rivers. Thus, the requirements of Ecosystem Goal 3 are not currently being met, ecosystem integrity of the delta may be compromised, and additional water regulation or manipulation may be required in the future.

Water level and/or discharge has been measured at four sites (Peace Point on the Peace River, Lake Athabasca, the Athabasca River below Fort McMurray, and the Slave River at Fitzgerald) from the 1960s to the present. Seven other hydrometric stations were established within the Peace-Athabasca Delta in the early 1970s and have been in operation since that time. Hydrometric data have also been collected at regular intervals at the Mamawi Creek channel into Mamawi Lake beginning in 1982 when this channel first developed (Peace-Athabasca Delta Implementation Committee, 1987). The hydrometric site at the outlet of Lake Claire has been in operation since 1970. Water levels in Lake Claire are directly related to complex relationships among water levels (stage) and discharge from the Peace River, Lake Athabasca, the Birch River, and the Athabasca River including the Mamawi Creek link. These relationships are well understood (Peace-Athabasca Delta Project Group, 1973; Peace-Athabasca Delta Implementation Committee, 1987). Water levels at Lake Claire differ from those in Mamawi Lake by no more than 30 cm.

From 1960 to 2000, water level for Lake Claire has ranged from 208.45 m (January - February 1982) to 210.98 m (July 1965) above sea level. The long-term mean water level for Lake Claire is 209.22 m asl. The mean monthly minimum water level occurs in early winter (January) and the mean monthly maximum water level in August. These long-term and annual changes in water level are remarkable given that the mean maximum depth for Mamawi Lake and Lake Claire is about 1.5 and 3 m, respectively.

Annual variation in water level for Lake Claire would influence distribution and abundance of submergent and emergent aquatic plants along the near shore zone and within bays of the lakes. Annual variation in water levels also affect abundance of some freshwater invertebrate species which are in turn important foods of fish such as goldeye (Kennedy and Sprules, 1967; Donald and Kooyman, 1977a). For example, *Daphnia magna*, a freshwater crustacean that is usually associated with shallow ephemeral ponds, was present in Mamawi and Claire lakes in summer 1971 when water levels were low (Gallup *et al*., 1973; Donald and Kooyman, 1977a) and large portions of the lake bottom were dry. For example, *D. magna* was not found in 1972 or 1994 when water levels were higher. Mean June water level in 1971, 1972, and 1994 was 208.77, 209.83, and 209.40 m asl, respectively. Water levels in the inner Delta are not related to recruitment success of goldeye (Donald, 1997), although continuous high water levels may be associated with higher-than-normal recruitment of pike (Figure 12 and Table 10). Pike were especially abundant in 1999, following two years with higher than normal lake levels. High water levels may increase spring spawning habitat for pike and increase their survival during winter in connecting channels within the Delta. Empirical relationships should be developed between annual variations in the seasonal water levels for Lake Claire and the abundance of aquatic biota. These relationships would permit assessment of the potential impact of changes in water level patterns on aquatic biota.

Figure 12. Annual mean daily water level for Lake Claire (1960 to 2000). *The thick dark line is determined from hydrometric data collected from the Delta and nearby rivers, the thin line is simulated natural water levels without regulation by the W.A.C. Bennett Dam and weirs on the Rivière des Rochers and Revillon Coupe. The Dam was operational in 1968, the weirs in 1976.*



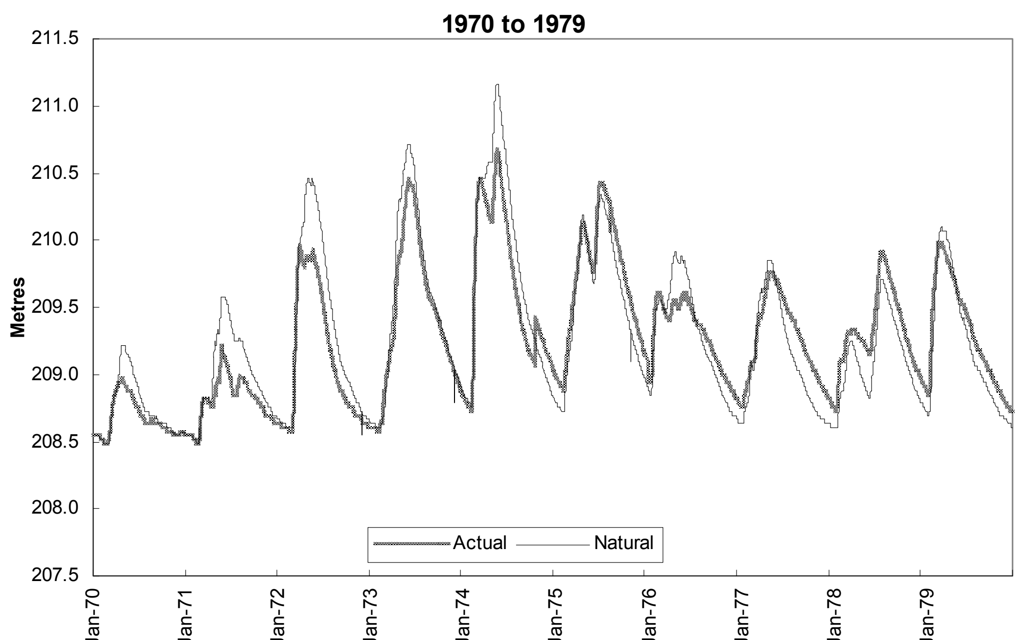
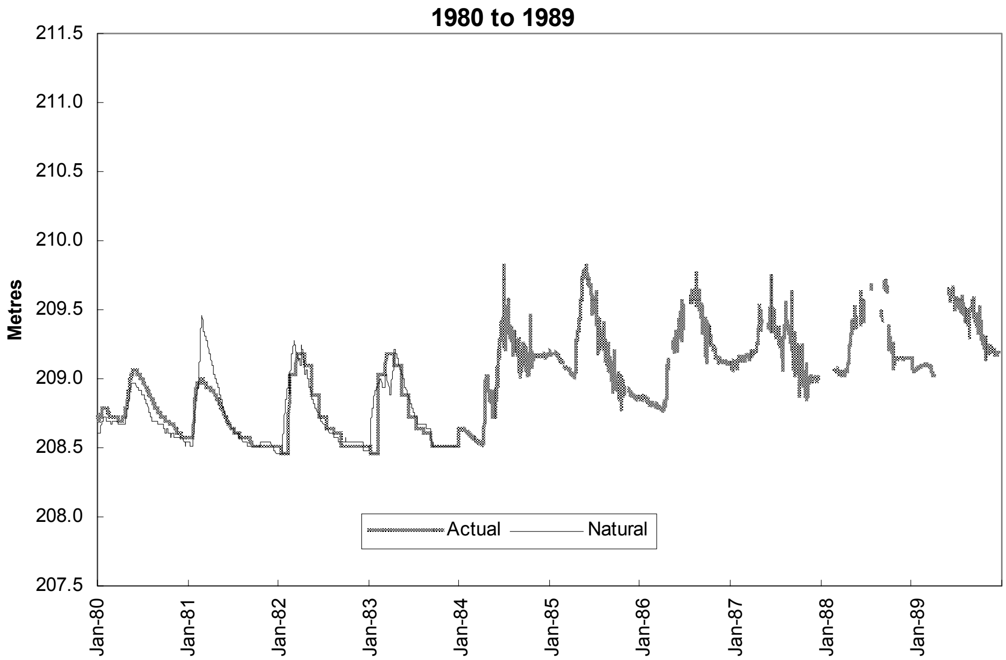
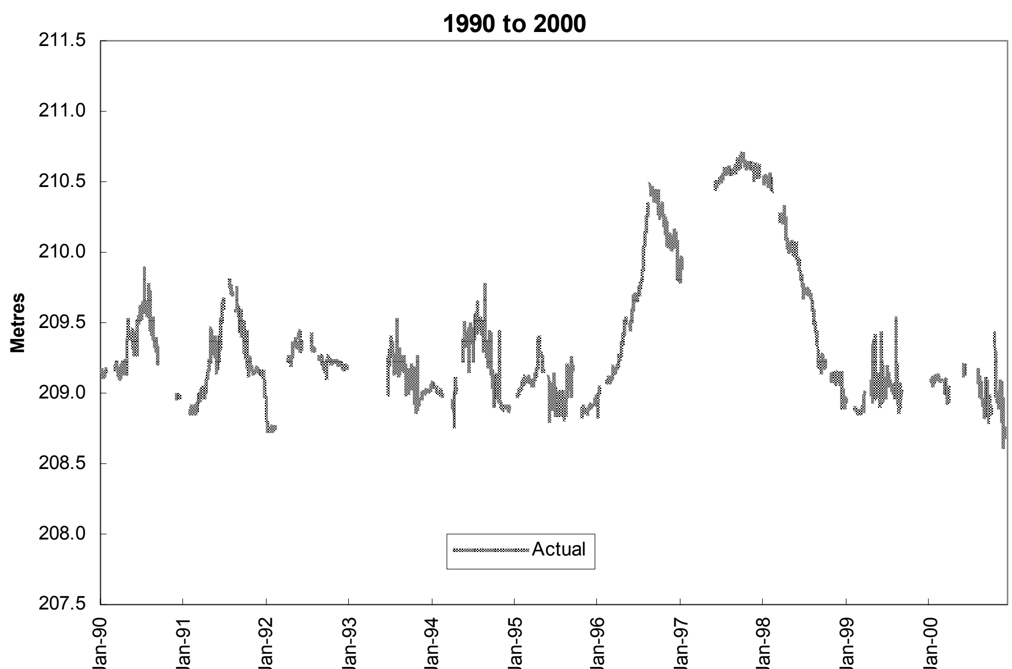


Figure 12. (cont'd) Annual mean daily water level for Lake Claire (1960 to 2000). *The thick dark line is determined from hydrometric data collected from the Delta and nearby rivers, the thin line is simulated natural water levels without regulation by the W.A.C. Bennett Dam and weirs on the Rivière des Rochers and Revillon Coupe. The Dam was operational in 1968, the weirs in 1976.*





Ecosystem Goal 4 - Benthic Invertebrate Community

Goal

The abundance and diversity of aquatic benthic invertebrates is maintained in the Peace-Athabasca Delta.

Benthic invertebrates are important foods of fish, and through the food chain, invertebrates can be an important source of the contaminant burden of fish.

Indicator

The freshwater clam shrimp *Caenestheriella belfragei* maintains a viable population within Mamawi Lake.

Indicator Measure

Population density estimates of the clam shrimp *Caenestheriella belfragei* are determined at 50 sites on Mamawi Lake at the end of June with an Ekman grab and a 1 mm^2 sediment sieve.

Status

The benthic invertebrate Ecosystem Indicator species, clam shrimp, was not present in Mamawi Lake in 2000 or 2002. In 1999 only 2 specimens were collected in 36 samples from 18 different locations (Appendix C). No clam shrimp were collected in 2000 or 2002 from a total of 60 Ekman grab samples. In 2000 none were found in 50 samples at 25 sites (Table 9).

Background

The clam shrimp *C. belfragei* (Conchostraca) is a large freshwater crustacean with average adult shell size 7.5 mm long, 6 mm wide, and 3.8 mm thick (Edmondson, 1959). The geographic range for this species is primarily the central United States north to South Dakota (Donald, 1989). In Canada, this species only occurs in the Peace-Athabasca Delta, extending the geographic range of this species north by 1000 km. It is an important food of goldeye, and when abundant is on average 28% of their diet during summer, July to September (Donald and Kooyman, 1977a). In 1994, the mean density of *C. belfragei* was $16/m^2$ for the northern half of Mamawi Lake (SD = 14.3, N = 24), but this species was rare or absent from the southern half (N = 23). This difference may indicate that this species is affected by subtle changes in water quality. Water quality in the southern portion of Mamawi Lake is influenced by the Mamawi Creek inlet and water from the Athabasca River. Water quality in the northern half of Mamawi Lake is influenced primarily by inflow from Prairie River which has water from Lake Claire and its principal inlet the Birch River. Water from the southern and northern parts of Mamawi Lake does not seem to mix over a wide area (Donald *et al.*,1996).

A long-term record of the abundance of _C. belfragei_ in Mamawi Lake, and information on the life history of this species (environmental requirements, longevity, fecundity, growth) needs to be obtained before a more precise Indicator can be developed. However, in some aspects _C. belfragei_ is an ideal benthic invertebrate indicator because it is randomly distributed (mean less and or equal to the standard deviation), and it is large (cost effective to collect and count).

Development of the eggs of some aquatic crustacean species are stimulated by low sediment oxygen concentrations during winter. Perhaps development and hatching of the eggs of _C. belfragei_ is inhibited by high winter oxygen concentrations that would be present in Mamawi Lake near the Mamawi Creek inlet. Five of the eight common benthic taxa identified for Mamawi Lake show significant differences in abundance between the northern and southern parts of Mamawi Lake (Donald *et al*., 1996).

Other invertebrate species were considered but rejected as suitable indicators of ecosystem integrity. Invertebrate species were rejected if they were relatively rare in the grab samples, were costly to sample and count (small species), had a clumped or patchy distribution (zooplankton), or were known to be an unimportant link in food webs (Sphaeriidae). In general, the benthic fauna of Mamawi Lake is unusually sparse with a low diversity of species (Donald *et al*., 1996).

The benthic fauna of lakes is typically dominated by Chironomidae, Pelecypoda, and Amphipoda with densities often from a few to several thousand per square metre (Brinkhurst, 1974). For Mamawi Lake, chironomid density was $222/m^2$, pelecopod density $469/m^2$, and amphipods were essentially absent (June 18-26, 1994, sieve mesh aperture 0.6 mm). The reduced macroinvertebrate fauna of Mamawi Lake is probably due to the shallow depth of this lake (maximum depth 1.5 m) which results in winter anoxia over large areas and deep freezing into the lake sediments (Reeder and Fee, 1973). Furthermore, the relatively large mesh used to sieve lake sediment from the grab samples would not retain small chironomid instars, and would under-estimate abundance of this invertebrate group relative to other studies.

C. belfragei belongs to the Family Conchostraca, a group of crustaceans known to have eggs that that can remain in a torphid state in sediments for years. The resting eggs of Conchostraca may remain unhatched until conditions such as temperatures, oxygen concentration, and salinity are optimal in the spring. Under ideal conditions large numbers of eggs hatch and the population flourishes that year. However in other years sub-optimal conditions may prevent egg development and hatching, and few or no adults will be present in the population.

Long-term annual surveys for clam shrimp will be required before this species provides a useful environmental indicator. The key environmental factors and conditions that promote clam shrimp population development in Mamawi Lake need to be identified.

Table 9. ***Distribution of C. belfragei in Mamawi Lake.*** *Comparison of the number of C. belfragei collected in the northern and southern portions of Lake Mamawi in the years 1994, 1999, 2000 and 2002*

	North					South				
Date & Year	**Number of sites**	**Number of Ekman samples per site**	**Total Number of Ekman samples**	**Mean per square metre**	**Std. Dev.**	**Number of sites**	**Number of Ekman samples per site**	**Total Number of Ekman samples**	**Mean per square metre**	**Std. Dev.**
June 20, 1994	24	1	24	16	14.3	23	1	23	0	-
July 3, 1999	11	2	22	3.9	8.7	7	2	14	0	-
June 28, 2000	15	2	30	0	-	10	2	20	0	-
July 10, 2002	9	2	18	0	-	1	2	2	0	-

NOTE: 6 inch square Ekman grab used in 1994, 1999, 2000; 9 inch square Ekman grab used in 2002.

Ecosystem Goal 5 - Fish Community Structure

Goal

The fish community structure of the Peace-Athabasca Delta is maintained.

Fish populations of the Delta have both social and economic value. Residents of the Peace-Athabasca Delta participate in a productive regional commercial, domestic, and sport fishery. Walleye, lake whitefish, pike, and goldeye are the preferred species in these fisheries.

Indicator

The fish community in Mamawi - Claire lakes of the Peace-Athabasca Delta during early summer is dominated by goldeye; the other fish species in order of decreasing relative abundance are: northern pike > lake whitefish = flathead chub > walleye > longnose suckers > white suckers > burbot.

Indicator Measure

The fish community composition of Mamawi - Claire lakes is assessed every 3-5 years at 10 sites (Figure 13) with multi-filament nylon gill-nets 1.8 m deep. Each net has six panels of equal length consisting of 3.8, 5.1, 6.4, 7.6, 8.9, and 10.1 cm mesh net (stretch measure).

Status

The Ecosystem Goal for fish community, as measured by the community in Mamawi and Claire lakes, is being met. The long-term relative abundance of fish species in the catch from Mamawi and Claire lakes has remained remarkably stable and constant over time. The catch from 1999 and 2002 was dominated by goldeye followed by northern pike, with lake whitefish and walleye equally abundant (Table 10).

Background

Pike were more abundant (39 % of the catch) in 1999 compared with all other years (Table 10). The catch-per-unit-effort for pike in 1999 was 9.3 fish per 100 m of net per hour. This increase in abundance of pike in 1999 was associated with high water levels from 1996 to 1998. High water levels may have provided optimal spawning habitat in spring and enhanced overwintering habitat in the connecting channels within the Delta.

No burbot or flathead chub were caught in 1999. Burbot are usually rare or absent from the catch but in past years lake chub have comprised up to 8% of the total catch (Table 10).

Foreign and exotic fish species have not been caught in the Delta, although some are present in the headwaters of the Peace and Athabasca river basins (brook trout, cutthroat trout).

Table 10. *Fish Community Structure, percent composition by species in Mamawi and Claire Lakes.*

Year Gill-net Size	**1947** 10.2	**1949** 9.5	**1954** 8.9-10.2	**1976** 3.8-8.9	**1977** 3.8-8.9	**1992** 3.8-10.1	**1994** 3.8-10.2	**1999** 3.8-10.2	**2002** 3.8-10.2
Fish Species									
Goldeye	56	61	92	79	67	60	71	51	71
Northern Pike	20	21	4	15	19	19	11	39	23
Flathead chub	0	0	0	0	2	8	6	0	0
Lake Whitefish	7	7	0	2	8	5	8	5	2
Walleye	8	3	2	2	2	5	3	5	3
Suckers	10	8	2	2	2	3	1	1	1
Burbot	0	0	0	0	+	+	0	0	0
Catch	204	108,954	563	4158	1154	725	744	815	901

+ Denotes presence

The first surveys of the fish community of Mamawi and Claire lakes were conducted in the late 1940s in anticipation of the development of a commercial fishery on Lake Claire (Table 10). Thereafter, the species composition of the fish community in these lakes was determined in the 1950s, 1970s, 1990s and in 2002. Although the gear (mesh size) and reporting method (number or weight) have not been consistent over this historical period, the catch data indicate that the composition of the fish community of the Mamawi - Claire lakes system has generally remained stable over the historical period (1947 to 2002). In summer, goldeye are the dominant species, northern pike are subdominant, and other species are relatively rare. The absence of lake chub in the catches from the 1940s and 1954 is probably the result of the large mesh size of gill nets used during these years. The maximum length and weight for lake chub in the Delta is 37 cm and 510 g, and consequently this fish species is mostly caught in 6.4 cm mesh-net (Kristensen, 1980).

A three to five year interval between fish community assessment in the Mamawi-Claire lakes system is recommended because of the concern for unnecessary mortality of fish in a National Park, and because a significant change for this Ecosystem Indicator is not anticipated. More frequent assessment (annual) could be implemented should a significant change in the community structure be documented or anticipated (for example accidental release of toxic chemicals into either the Peace or Athabasca rivers or colonization of the Delta by an exotic fish species).

The regional domestic fishery harvests lake whitefish, walleye, and goldeye for human consumption. Thus, the fish community Indicator (5) is an ecological link between the aquatic ecosystem and the economic and social well-being of the residents of Fort Chipewyan. Any long-term change in the relative abundance of the fish species identified in this Indicator would constitute an unacceptable change in the ecological integrity of the Peace-Athabasca Delta in general, and the Mamawi-Claire lakes ecosystem in particular.

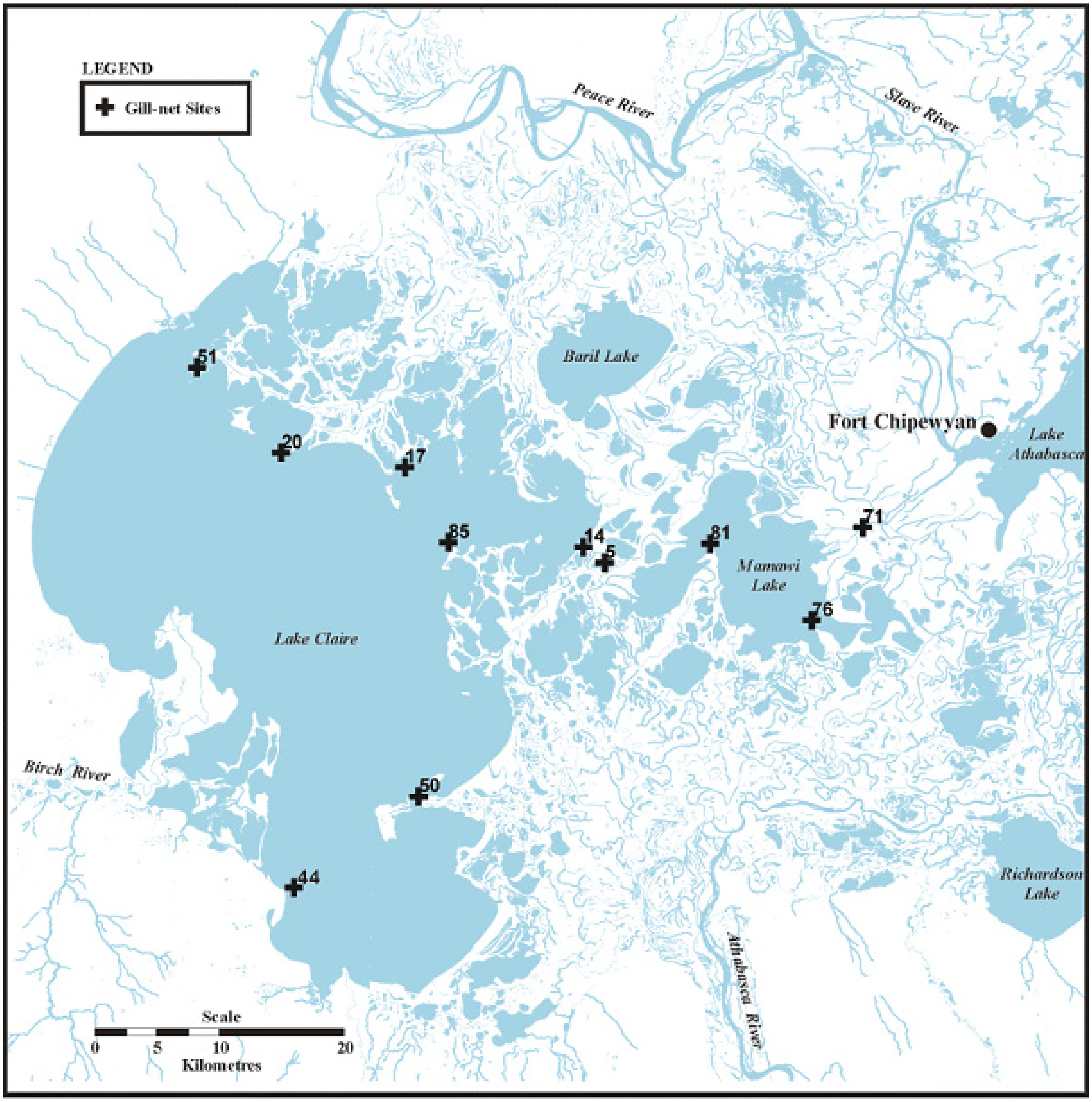


Figure 13. *Gill-net sites on Mamawi and Claire lakes .*

Ecosystem Goal 6 - Goldeye Abundance

Goal

The goldeye population of the Peace-Athabasca Delta is maintained at historic levels of abundance. Goldeye are an important part of the catch of the regional domestic fishery and the commercial fishery in western Lake Athabasca.

Indicator

The mean catch-per-unit-effort (CPUE) of goldeye during late June in Mamawi-Claire lakes is not significantly less than 10 goldeye per hour for a 100 m survey gill-net (SD = 6).

Indicator Measure

Goldeye abundance is determined with gill-nets every 3 to 5 years in late June from 10 established sites near the shore of Mamawi Lake and Lake Claire (Figure 13). Gill-nets are 1.8 m deep, and have 6 panels, 10 m each, of 3.8, 5.1, 6.4, 7.6, 8.9, and 10.1 cm mesh net.

Status

The Ecosystem Goal for goldeye abundance is being met. The CPUE for goldeye in 1999 and 2002 was similar to the CPUE in 1973 (16.9) but greater than the CPUE in 1987, 1992, and 1994 (Table 11). Statistical analyses of mean CPUE indicate that there has been so significant change in the goldeye catch from 1973 to 2002. Since the late 1960s there has been 5 years with dominant year-classes (1971, 1982, 1989, 1994, and 1996), and many years with poor or failed year class (mid 1970's, 1985 and 1993). The number of years between dominant year-classes ranges from 2 to 11 years (Figures 14 and 15).

Table 11. *Catch per unit effort (CPUE) for goldeye from Mamawi and Claire lakes in June and July, 1973 to 2002 (determined from gill-nets with mesh size ranging from 3.8 to 10.2 cm).*

Year	Mean CPUE*	Standard Deviation	Number of Sites	Total Number of Hours Fished
1973	16.9	14.7	8	147
1987	11.6	7.7	5	31
1992	11.9	7	9	74
1994	9.9	5.7	10	92
1999	13.0	12.2	10	54
2002	15.1	14.2	10	87

* - mean number of goldeye caught per 100 metres of mixed-mesh net per hour

Background

Goldeye abundance was determined in June with survey gill-nets at established sites in Mamawi and Claire lakes in 1973, 1987, 1992, 1994, 1999 and 2002 (Table 11). During those years, mean catch-per-unit-effort (CPUE) ranged from 9.9 to 16.9 and no significant difference in abundance was detected for those years (ANOVA, $F = 0.59$, $df = 4$ and 31, $p = 0.67$).

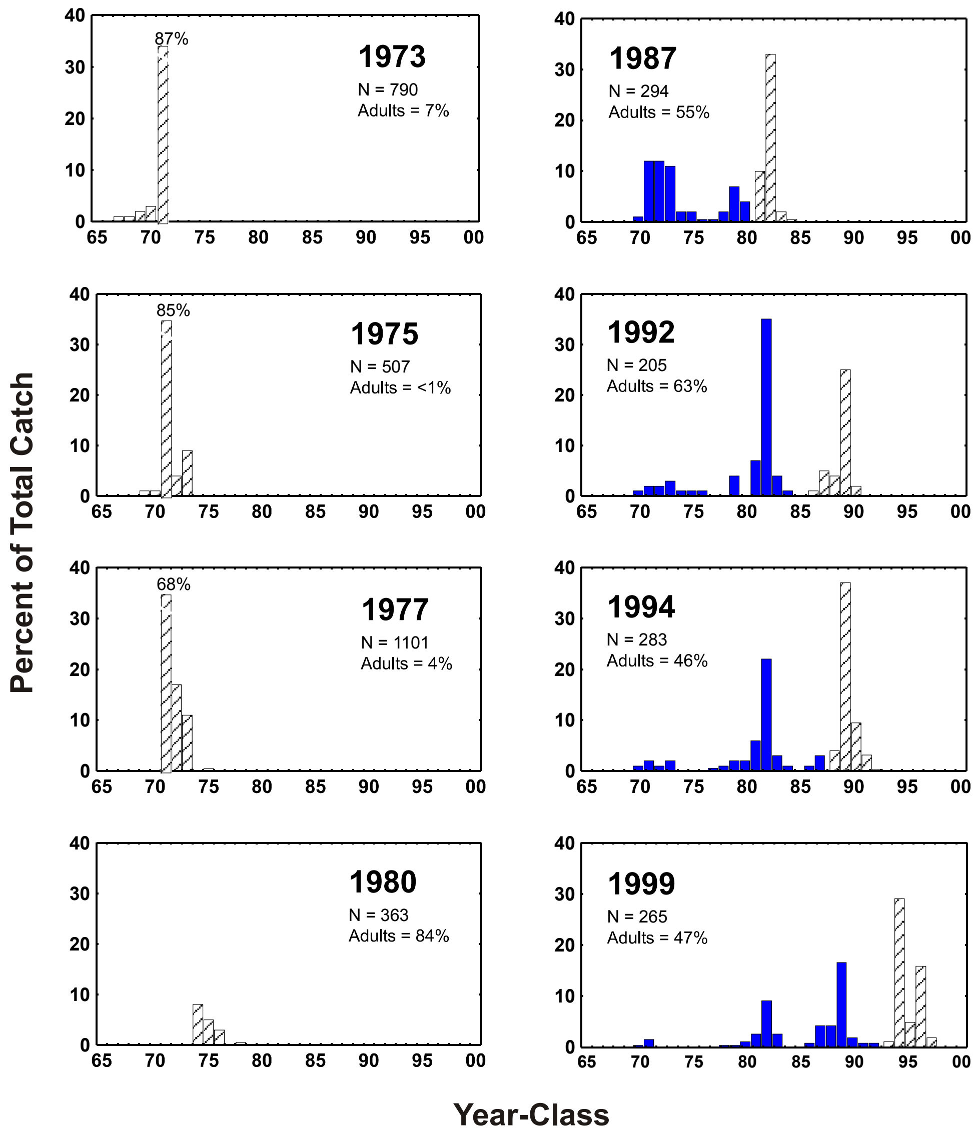


Figure 14. Year-class strength of goldeye determined from catches using survey gill-nets, 38 mm to 102 mm mesh. *Age of immature goldeye, those fish from age 1 to 6, were determined from scales (open); age of adult goldeye, those age 7 and older, were determined from opercula (closed). Data from 1975, 1977, and 1980 are from Kristensen and Summers (1978), and Kristensen (1981 and 1983 unpublished). Year-class frequency for adults in catches from 1973 to 1980 are not shown because scales were used to determine age of adults, and these are unreliable (Donald* et al.*, 1992).*

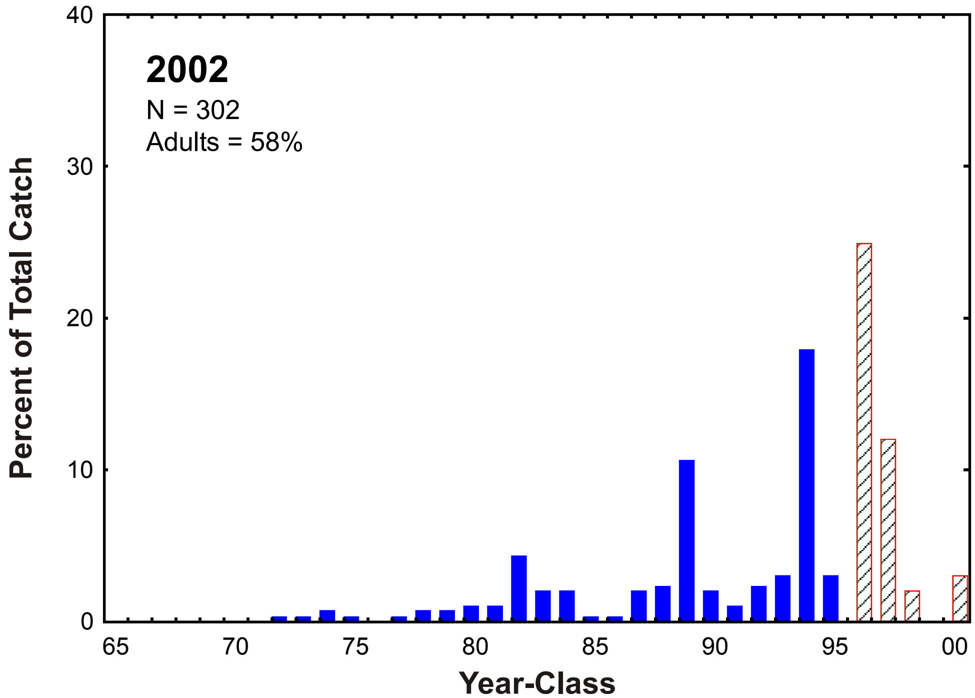


Figure 15. *Year-class strength for goldeye determined from catches using survey gill-nets, 38 mm to 102 mm in early July 2002.*

The standard deviation of the catches for the four years ranged from 58% to 94% of the mean. Using the former value to calculate a standard deviation, we determined that a mean CPUE of about 5.5 (calculated SD = 3.19, N = 10 sites) would be required before a significant decline in the population could be demonstrated ($t = 2.1$, $p < 0.05$, $df = 18$). A statistically demonstrated decline in goldeye abundance would constitute a compromise of the ecological integrity of the Mamawi-Claire lakes ecosystem.

The Ecosystem Goal for goldeye abundance is closely linked to Goal 1 (climate). Recruitment for goldeye is related to two density independent factors, temperature and wind intensity during the early life stages of this species. Year-class strength for goldeye from the Mamawi-Claire lakes system is highly variable with dominant year-classes occurring 1.7 times per decade on average, while other year-classes fail completely (for example the 1985 year-class, Figure 14, Donald,1997). Dominant year-classes were > 20% of the catch from survey nets, abundant year-classes were 5% to 20% of the catch, and week year-classes were < 5% of the catch. If conditions for development of dominant year-classes were significantly altered, the population size of goldeye would be reduced. Year-class strength (recruitment) for goldeye is related to the number of warm days with mean daily air temperature > 15°C from May 1 to July 31 (Figure 16, $r = 0.61$, $N = 31$, $p < 0.0005$, $\log Y = 0.052X - 1.350$ where Y = year-class strength index and X = days with mean daily air temperature > 15°C). This three month period includes the spawning migration, spawning, egg development and hatching, and growth to a 1.9 g fingerling. In addition to the requisite of warm temperatures, dominant and abundant year-classes develop when wind intensity, the number of hours with wind speed equal to or greater than 20 km/h, is reduced (Figure 17). For this report, “wind” was the total number of hours with strong wind (≥ 20 km/hr) during 0800 to 2300 hours summed for the period each year when the degree days > 0° C were from 300 to 675. This period was generally from late May through much of June, but for all years combined was from May 9 (1980) to July 5 (1969). On average, 27.6 days passed for the degree days to increase from 300 to 675 (range 23 to 34 days). This period spans the time when the semi-buoyant eggs and newly hatched larvae of goldeye were present in the delta lakes. When dominant year-classes developed conditions were generally calm, especially when compared with many of the weak year-classes.

It is hypothesized that warm weather in late spring and early summer increases food production, promotes growth and development of young goldeye, and thereby enhances their survival. In the shallow delta lakes, strong winds may cause mortality by dispersing the semi-buoyant eggs and larval goldeye to offshore and other unfavourable habitats far from the near-shoreline locations where young goldeye are usually found (Donald and Kooyman, 1977b), and adults probably spawn. The first foods eaten by goldeye fry are small crustaceans (Donald and Kooyman, 1977a). Wind-driven turbulence might also cause high mortality of larval goldeye by disrupting their feeding during those critical days when their nutritional source changes from the yolk to small crustaceans.

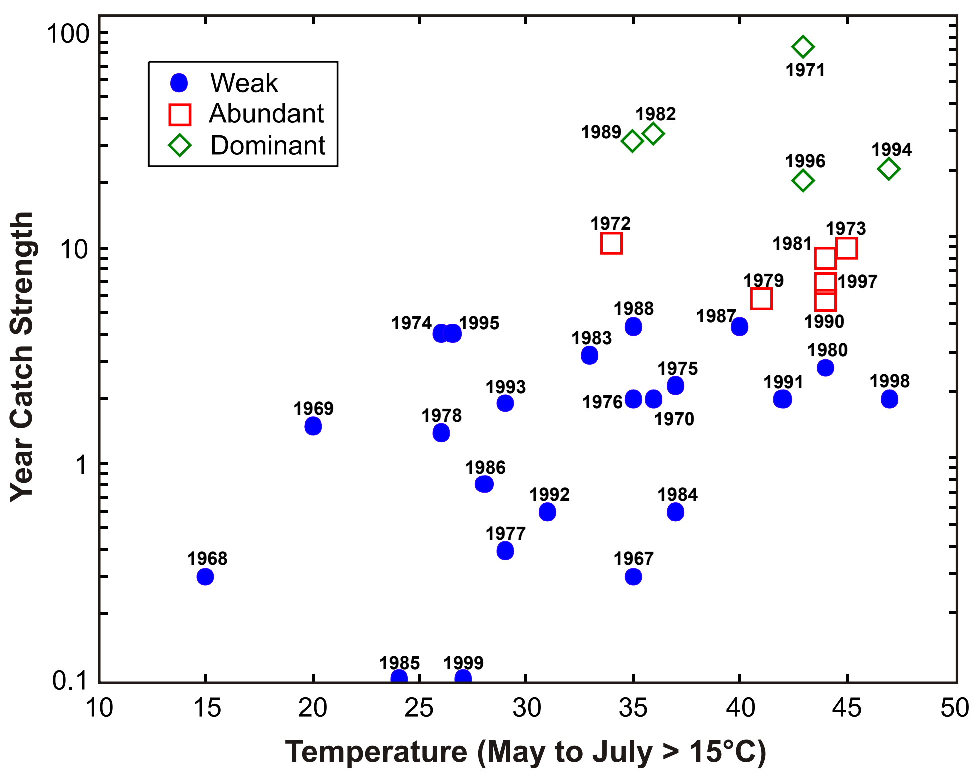


Figure 16. Relationship between goldeye year-class strength and summer temperature (number of days during May 1 to July 31 with mean daily temperature > 15ºC).

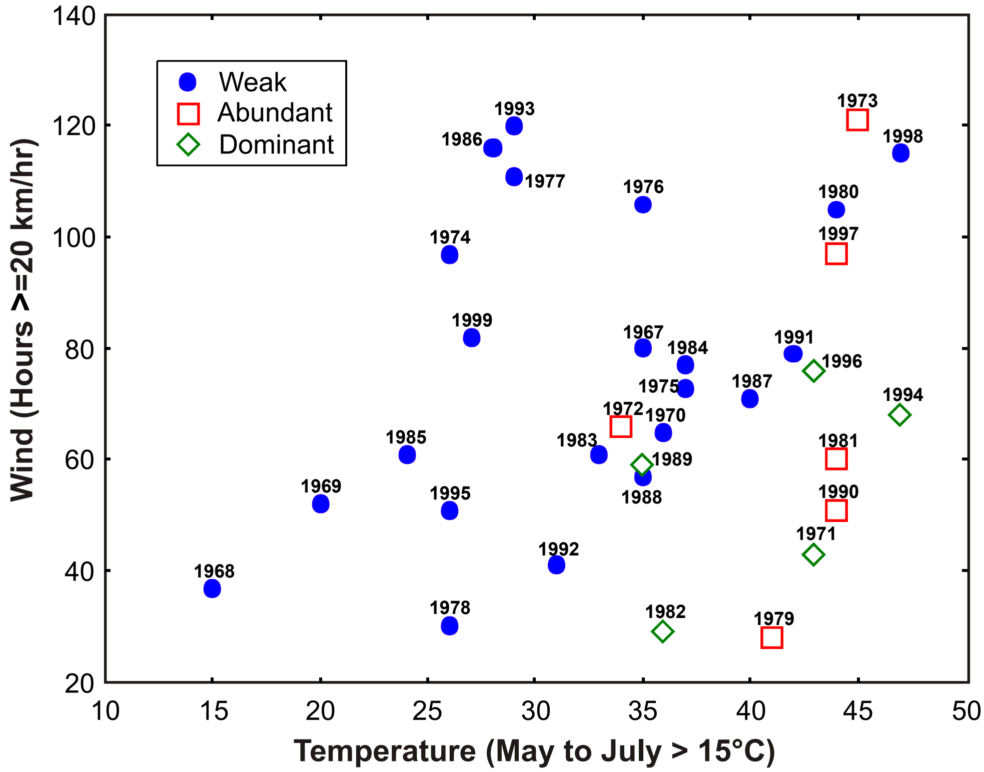


Figure 17. Scatter diagram showing weather conditions associated with dominant (◇), abundant (□), and weak (●) year-classes for goldeyes. Temperature is the number of days with mean daily temperature greater than 15ºC from May 1 to July 31. Wind is the total number of hours with strong wind (20 km/hr) during 0800 to 2300 hours summed for the period each year when the degree days > 0°C were from 300 to 675. For all years combined, this period was from May 9 (1980) to July 5 (1969).

Ecosystem Goal 7 - Walleye and Goldeye Fishery

Goal

Walleye and goldeye commercial catches in western Lake Athabasca are maintained.

Walleye and goldeye are the most important fish species in the commercial fishery and are an important part of the domestic and sport fish catch. Walleye and goldeye are an economic and nutritional resource to the residents of the Fort Chipewyan area.

Indicator

The annual commercial quota for walleye from the Alberta portion of Lake Athabasca is 45,400 kg in at least 7 of 10 years. The annual quota of 45,400 kg is set by Alberta Sustainable Resource Development Branch. The annual commercial catch of goldeye should not exceed 20,000 goldeye or about 10,200 kg. Contaminant levels in fish will: A) not significantly affect the mortality, growth, and fecundity of the walleye and goldeye, and B) not affect their "table" quality for human consumption.

Indicator Measure

The commercial harvest of walleye and other fish species for the Alberta portion of Lake Athabasca is recorded each year. Levels for toxic substances such as mercury, dioxins, furans, and pesticides are determined in fish muscle tissue at regular intervals.

Status

The commercial catch limits identified for Ecosystem Goal 7 are being met. During the 1990s, 7 of 10 annual catches for walleye were between 45,400 kg and 79,950 kg. All annual catches of goldeye during the 1990s were equal to or less that 10,200 kg. In recent years, information on contaminant levels in fish have not been collected.

Background

The annual commercial harvest of fish from the Alberta portion of Lake Athabasca from 1943 to 2000 is shown in Table 12. Records for walleye and goldeye are from commercial sales of fish to the Freshwater Fish Marketing Board; records for other species are best estimates by fisheries officers or are based on previous catches. Walleye are the most important fish species in this gill-net fishery, providing the greatest economic return to the licensed fishermen. Goldeye are also a significant part of the commercial catch. Northern pike, lake whitefish, and occasionally burbot have also been harvested for commercial sale in some years, especially during winter, but their commercial value is typically much less than walleye. All fish species are caught each year, but unless a suitable price is offered by a marketing agency, they are culled at the catch site and are not included in the annual catch statistics.

Table 12. *Annual commercial fisheries harvest from western Lake Athabasca.*

Year	Walleye	Goldeye	Lake whitefish	Northern pike	Burbot	Sucker	Lake trout	Total
1943	82,248		9,356	3,701				95,304
1944	72,599							72,599
1945	44,166		23,655				57,290	125,110
1948	6,037		42,498				42,177	90,621
1954	3,612		8,602				31,085	43,299
1955	5,057		7,277				32,675	45,008
1957	4,446						43,744	48,190
1958	25,111						113,491	138,602
1959	60,256						78,803	139,059
1960	55,316	2,350	9,568				76,212	143,446
1961	48,531	456	7,728	19,652			483	80,883
1962	100,107	6,141		40,533				146,781
1963	53,195	3,102		36,324				92,620
1964	97,401	628	722	77,867				176,618
1965	58,435	177		70,631				129,243
1966	61,492	748	1,361	77,461				141,062
1967	60,727	129		47,539				108,395
1968	96,337	334	1,665	127,881	170	79		226,467
1969	42,863	125	42,283	71,625	3,594	1,251		161,741
1970	17,076	190	69,760	18,146	2,370	957		108,499
1971	24,202	286	54,116	8,338	1,293	1,558		89,791
1972	44,308	254	25,265	17,580	6,066	37,594	567	131,635
1973	28,863		68,218	27,357	5,714	4,526	34	134,712
1974	24,826		66,545	17,853	5,578	16,417		131,219
1975	12,849		1,190	9,421	816	7,029		31,306
1976	28,337		2,948	9,751	91	8,707		49,834
1977	81,478		1,587	3,878		2,948		89,891
1978	61,179		8,163	2,766		3,401		75,510
1979	46,984		3,855	2,041		2,993		55,873
1980	29,651		3,084	1,542				34,277
1981	49,371		1,400	1,200				51,971
1983	1,100		6,500	2,100	220			9,920
1984	74,015		50,550	78,050		25,000		227,615
1985	72,858	3,485	24,056	220,474	615	420,048	225	741,761
1986	69,121	3,485	10,456	209,124	300	418,248		710,766
1987	81,690	4,845	12,724	25,448	391	41,825		166,923
1988	80,938		13,297	41,368				135,603
1989	80,167		35,345	14,690	3,054	12,218		145,475
1990	52,995	1361	6,818	3,005	470	1,361		66,010
1991	43,400			20,000				63,400
1992	79,180		2,633	33,959				111,993
1993	61,727	4,800	20,092	38,040				137,338
1994	44,171							44,171
1995	73,235	10242		39,000				122,477
1996	54,644	2391						57035
1997	79,950	1900		40,000				121850
1998	77,072	8275						85347
1999	34,393	9520	10106	2538			5178	61735
2000	43,666	3356						47022
2001								

The commercial quota for walleye for the Alberta portion of Lake Athabasca is 45,400 kg/year (quota of the Alberta Sustainable Resource Development Branch). From 1990 to 1999, the quota was obtained in 7 years. The quota for walleye may not be obtained in some years because of a low price for walleye (effort by commercial fishermen is less), poor weather during the commercial fishing season (May/June), or low numbers of walleye of commercial size.

Walleye and goldeye as Ecosystem Indicators provide a direct ecological link from ambient water quality (potentially affected by industrial effluents), to fish health (contaminant levels, taste, odour), and to the residence of Fort Chipewyan (nutrition, economic well-being). Moreover, recruitment for walleye may be related to optimal temperature regimes during their early life history stages (Ecosystem Goal 1, climate). In eastern Canada, walleye recruitment in lakes is related to optimal temperature regimes (Koonce *et al.,* 1977). Any significant reduction in the long-term commercial catch, or contaminant induced changes in walleye and goldeye mortality, growth, fecundity, or "table" quality, would compromise the Ecosystem Goal.

Calculation of a Sustainable Annual Commercial Catch for Goldeye

From 1995 to 2000, the commercial catch of goldeye from western Lake Athabasca ranged from 1900 to 10,242 kg with an average annual catch for those six years of 5950 kg (Table 12). These fish are caught in June and early July in 4 inch mesh gill-nets (stretch measure) which on average entangle goldeye that weigh 510 g (Kennedy and Sprules, 1967). Converting catch in kilograms to fish suggests that the large catch in 1995 removed about 20,000 goldeye from the Peace-Athabasca Delta population. The mean annual harvest from 1995 to 2000 was about 12,000 goldeye. To ensure these catches are sustainable, their impact on the long-term vitality and productivity of the goldeye population was determined.

In the following analyses, we provide an estimate for a maximum annual commercial catch for the Peace-Athabasca Delta goldeye population that provides long-term assurance of population stability. To estimate a sustainable annual catch, the following information was obtained to develop and support a stock-yield model for goldeye:

1) age and weight of goldeye vulnerable to commercial nets (4 inch mesh nets),
2) age at first spawning,
3) recruitment potential (egg production),
4) natural mortality,
5) fishing mortality,
6) annual recruitment into the commercial stock,
7) commercial stock size (number), and
8) impacts of different exploitation levels on the commercial stock.

Age and weight of goldeye vulnerable to commercial nets

Adult goldeye from the Peace-Athabasca Delta population remain vulnerable to the 4-inch mesh net of the commercial fishery for much of their life span (Figure 18). Thus, the population and commercial catch model developed herein was not adjusted to take into consideration adult age and weight-related vulnerable to the fishing gear. Goldeye growth rate was about 50 to100 g per year between age 2 and age 9 and thereafter was about 10 g per year (Figure 18). Maximum vulnerability to 4 inch gill nets occurs at 510 g (Kennedy and Sprules, 1967). However, the 90% weight limits of the 4-inch net catch (368 to 708 g) indicate that most individuals from age 8 to 30 are vulnerable to the 4-inch commercial fishing gear used in western Lake Athabasca. Maximum recorded longevity was 30 years (female 607 g); the maximum recorded mass was 850 g for a 20-year-old female goldeye.

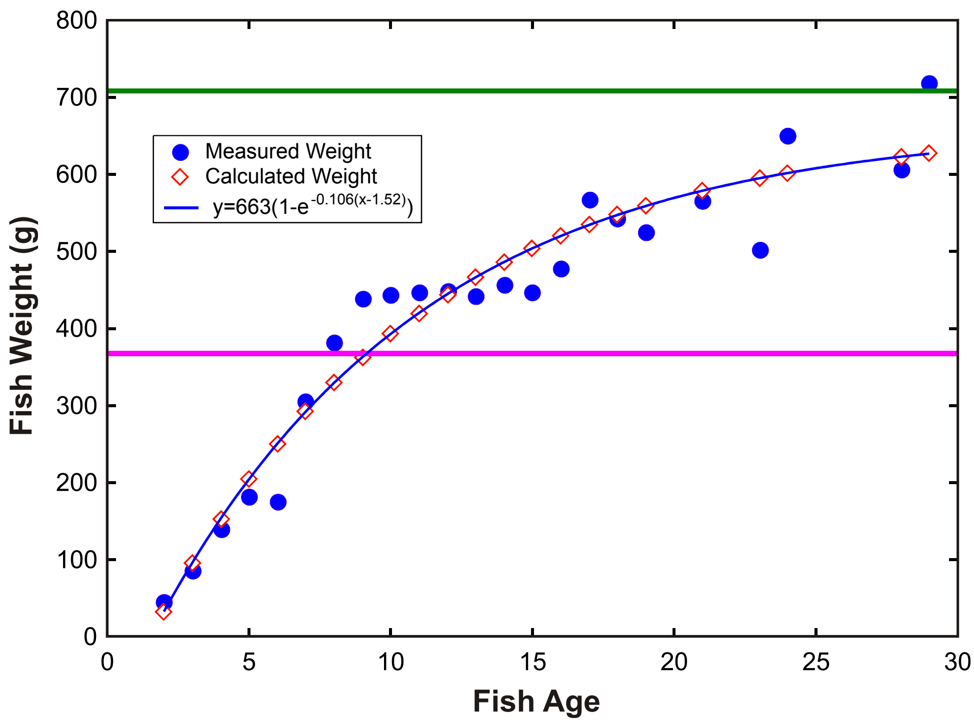


Figure 18. *Von Bertalanffy growth curve for goldeye of the Peace-Athabasca delta (N=993). For ages 2 to 23 sample size (N) was ≥ 5. Horizontal lines are the 90% catch limits for goldeye mass in 4 inch mesh gill-nets.*

Age at First Spawning

Goldeye reach sexual maturity, and are vulnerable to 4-inch gill nets at about the same age. Therefore, the spawning and commercial portion of the population were of similar mass and age. Thus, the stock-yield model was not adjusted for recruitment factors related to age and fish mass at maturity. Most male goldeye of the Peace-Athabasca Delta population first spawn at age 7; most females at age 8 (Kennedy and Sprules 1967). Goldeye in this population apparently spawn each year once they become mature.

Recruitment Potential

Female goldeye have high fecundity. At 500 g, females produce about 10,000 eggs (Kennedy and Sprules 1967). Theoretically and under ideal conditions, adult populations of only a few hundred individuals could produce millions of individuals to commercial catches. Because of this high individual fecundity, we did not adjust the model to include stock-fecundity relationships.

Natural Mortality

In the model, natural mortality was set at a constant annual rate of 20% to accommodate the known longevity of this population. This value (20%) was obtained from the formula:

$$Py = P(1 - M)^{Y} \text{ where:}$$

P = initial population (1 million), Py = population "y" years later, M = percent annual mortality rate, and Y = number of years. Using this formula, there were 1550 age-30 goldeye in a population starting with 1 million age-1 fish. The total population size for the catchable portion of this theoretical population, those fish age 8 and older, was 1,040,000 goldeye. Natural mortality would include those fish caught in the domestic fishery, fish culled during the Lake Athabasca commercial fishery, predation, and death from diseases. An annual mortality rate of 15% resulted in a theoretical population with more than 10,000 fish age 30; a rate of 25% gave maximum survival ages less than the known longevity for this population.

Fishing Mortality

Commercial catch records from the 1948 to 1966 Lake Claire fishery were obtained from Donald and Kooyman, 1977b. Catch records for the Lake Athabasca fishery were obtained from the Freshwater Fish Marketing Board.

Annual Recruitment

Goldeye recruitment was highly variable with exceptional strong year-classes occurring once or twice a decade and with many years with poor and failed recruitment (Figure 14). Dominant year-classes occurred in 1971, 1982, 1989, 1994, and 1996. The interval between dominant year classes ranged from 2 to 11 years. Dominant and abundant year classes developed during warm springs when mean daily air temperature was > 15 °C from May 1 to July 31 combined with calm weather in May and June. These months spanned the early development period from egg hatching to a 1.9 g goldeye.

Relative annual recruitment (year-class strength index) was determined from the age structure of the population determined from long-term catch data (1973 to 2002, Figures 14, 15, and 19). The year-class strength index for each year-class (1966 to 2002) was calculated as the mean percent composition for the two years in which the relative abundance of a particular year-class was greatest in the catches when these fish were young, 13 years-old or less (Donald, 1997). For example, the index for the 1971 year-class was 86, the mean of 87% of the catch for that year-class in the 1973 catch and 85% of the catch in 1975.

An important assumption of our method for calculating annual recruitment was that without commercial exploitation the total population of young and old goldeye, and goldeye habitat quality, remained relatively stable over time. It was assumed that strong year-classes saturated all available and suitable habitat with goldeye. Catch data during the last decades of the twentieth century support the assumption that total goldeye abundance was relatively stable. However at times, the total population could include mostly young fish, as was the case during much of the 1970s (Figure 14). During six years from 1973 to 2002, catch-per-unit effort (CPUE) at 5 to 10 common gill-netting sites ranged from 9.9 to 16.9 goldeye per 100 m of survey net per hour. The standard deviation ranged from 58% to 94% of the mean annual catch (Table 11). There was no significant difference in mean annual catch during this period (ANOVA $F = 0.99$, $df = 2$ and 49, $p = 0.63$) suggesting that large natural fluctuations in total population number (young and adult fish combined) do not occur.

Stock-Yield Model Development

The number of goldeye in the commercial stock was modelled for 1947 to 2004 using:

A. the known population restrictions of the commercial harvest of goldeye from Lake Claire from 1948 to 1966 (Table 13),

B. the known restrictions of the total number of fish in the commercial stock in 1972 to 1974,

C. a realistic pattern for recruitment into the commercial stock from 1947 to 1971. And, the known recruitment pattern from 1967 to 1996 moved eight years forward to 1972 to 2004 to match the age and weight when goldeye first become vulnerable to the commercial fishery. This provided the stock-recruitment pattern into the commercial stock for 1972 to 2004.

D. the model $\mathbf{P_t = P_{t-1} + (R_t \quad R_c) - Mn_{20\%} - Mf}$ where: P_t was the commercial stock at time t, R_t was the stock-recruitment index value at time t, R_c was a recruitment constant, Mn was 20% annual natural mortality, and Mf was the fishing mortality at time t, and

E. repeated entry into the model of both realistic stock-recruitment patterns for the 1947 to 1971 period and a recruitment constant at 1946 until the model met the restrictions identified in A and B above, (provided sufficient fish for the 1948 to 1966 commercial catch and matched the total commercial stock number in 1972, respectively).

The model was restricted by the known commercial catch of goldeye from Lake Claire from 1948 to 1966 (Table 13). During this period there were five years without commercial fishing. For the model to operate, the number of goldeye taken in the commercial catch in any given year could not exceed the total number of catchable fish in the population. The commercial harvest data in kilograms were converted to number of fish with the addition of a 10% increase in number of fish caught to account for spoilage and shrinkage of the catch (Schultz, 1955). Gill-nets used for the Lake Claire fishery were 3 ¾ inch mesh nets which were most efficient at catching 397 g goldeye (Kennedy and Sprules,1967), the factor used to convert Lake Claire catch in kilograms to number of goldeye.

The model was restricted by the total size of the commercial stock in 1972 to 1974. During these years, population estimates were obtained by mark-recapture methods (Table 13, Petersen and Bailey's triple catch methods – Ricker, 1975; data from Donald and Kooyman, 1977b). From 1972 to 1975 a total of 4,375 goldeye were caught in 3 ¾ and 4 inch mesh nets and marked with Floy tags, 7683 were examined for tags, resulting in a total of 311 recaptured fish that were marked. For the model restriction, the modelled number of goldeye in 1972 had to closely match the known size of the stock in that year (100,588 fish ± 14,729).

From 1964 to 1966, weather conditions in the Delta would not have produced dominant and abundant year-classes. For these three years, the number of days with mean daily temperature > 15 °C ranged from 32-43 from May 1 to July 31, with the number of windy days (≥ 20 km/hr) ranging from 58 to 107. Therefore, a stock-recruitment index value of 0.1 was arbitrarily assigned to the years 1972 to 1974 (recruitment index values moved forward by eight years). Weather conditions in 1963, the first year with adequate weather records, may have been suitable for goldeye recruitment. An abundant, but not dominant, year class may have been produced that year (warm days = 48; windy days = 90). The 1963 year-class would begin to spawn in 1970.

A realistic stock-recruitment pattern for 1947 to 1971 was required to develop the stock-yield model. Recruitment for this period was unknown. Continuous block segments of the recruitment index for 1964 to 2000 were used for 1947 to 1971. We assumed that at least one of the patterns of recruitment for 1964 to 2000 would be similar to the unknown pattern for 1948 to 1971, although the exact annual recruitment rates were probably different (Table 13).

Table 13. *Stock-yield model for goldeye of the Peace-Athabasca Delta; commercial catch, natural mortality, recruitment, the calculated and actual total commercial population.*

Actual Year	Lake Claire Commercial Catch plus 10% wastage (# of fish)	Lake Athabasca Commercial Catch plus 10% wastage (# of fish)	Mortality Natural (20%) (# of fish)	Population Recruitment (Year)	Stock Recruitment (Index)	Recruitment (index x constant) (# of fish)	Stock Increase or decrease (# of fish)	Calculated Total Stock (# of fish)	
								1600000	<< Recruitment Constant
1947			320000	1969	1.5	24000	-296000	1304000	
1948	149939		260800	1970	2.0	32000	-378739	925261	
1949	302397		185052	1971	86.0	1376000	888551	1813812	
1950	89969		362762	1972	10.5	168000	-284732	1529080	
1951			305816	1973	10.0	160000	-145816	1383264	
1952			276653	1974	4.0	64000	-212653	1170611	
1953			234122	1975	2.3	36800	-197322	973289	
1954	302397		194658	1976	2.0	32000	-465055	508234	
1955			101647	1977	0.4	6400	-95247	412987	
1956	222197		82597	1978	1.4	22400	-282395	130592	
1957	167600		26118	1979	5.8	92800	-100918	29674	
1958			5935	1980	2.8	44800	38865	68539	
1959	177956		13708	1981	8.9	142400	-49263	19276	
1960	128719	5068	3855	1982	33.8	540800	403157	422433	
1961	118039	983	84487	1983	3.2	51200	-152309	270125	
1962	129683	13245	54025	1984	0.6	9600	-187353	82771	
1963	27719	6690	16554	1985	0.0	0	-50964	31808	
1964	1828	1354	6362	1986	0.8	12800	3257	35064	
1965	59039	381	7013	1987	4.3	68800	2367	37432	
1966	34747	1613	7486	1988	4.3	68800	24953	62385	
1967		278	12477	1989	5.0	80000	67245	129630	**Total**
1968		720	25926	1990	5.7	91200	64554	194184	**Commercial**
1969		269	38837	1991	2.0	32000	-7106	187078	**Stock**
1970		409	37416	1992	0.6	9600	-28225	158854	**(# of fish)**
1971		616	31771	1993	1.9	30400	-1987	156867	
1972		547	31373	1964	0.1	1600	-30320	126546	100588
1973			25309	1965	0.1	1600	-23709	102837	37231
1974			20567	1966	0.1	1600	-18967	83870	18190
1975			16774	1967	0.3	4800	-11974	71896	
1976			14379	1968	0.3	4800	-9579	62317	
1977			12463	1969	1.5	24000	11537	73853	
1978			14771	1970	2.0	32000	17229	91083	
1979			18217	1971	86.0	1376000	1357783	1448866	
1980			289773	1972	10.5	168000	-121773	1327093	
1981			265419	1973	10.0	160000	-105419	1221674	
1982			244335	1974	4.0	64000	-180335	1041339	
1983			208268	1975	2.3	36800	-171468	869872	
1984			173974	1976	2.0	32000	-141974	727897	
1985		7516	145579	1977	0.4	6400	-146695	581202	
1986		7516	116240	1978	1.4	22400	-101356	479845	
1987		10450	95969	1979	5.8	92800	-13619	466226	
1988			93245	1980	2.8	44800	-48445	417781	
1989			83556	1981	8.9	142400	58844	476625	
1990		2935	95325	1982	33.8	540800	442540	919165	
1991			183833	1983	3.2	51200	-132633	786532	
1992			157306	1984	0.6	9600	-147706	638826	
1993		10352	127765	1985	0.0	0	-138117	500708	
1994			100142	1986	0.8	12800	-87342	413367	
1995		22090	82673	1987	4.3	68800	-35963	377403	
1996		5157	75481	1988	4.3	68800	-11838	365566	
1997		4098	73113	1989	31.0	496000	418789	784355	
1998		17848	156871	1990	5.7	91200	-83519	700836	
1999		20533	140167	1991	2.0	32000	-128700	572136	
2000		7238	114427	1992	0.6	9600	-112065	460070	
2001			92014	1993	1.9	30400	-61614	398456	
2002			79691	1994	23.4	374400	294709	693165	
2003			138633	1995	4.0	64000	-74633	618532	
2004			123706	1996	20.4	326400	202694	821226	
				1997	6.8				
				1998	2.0				
				1999	0.0				
				2000	3.0				

Best Fit Stock-Yield Model

The stock-yield model was developed by repeated entry of continuous block segments of the recruitment pattern from 1964 to 2000 (12 options) into the 1947 to 1971 period while simultaneously adjusting the recruitment index by 100,000 intervals with each trial. Both direct chronology and reverse chronology of the index were used. These trials indicated that the model was mostly influenced and restricted by the large catch from 1948 to 1950 (1,540,000 goldeye) and the small stock number in 1972 (100,000 goldeye). Model trials showed that the large catch from 1948 to 1950 required exceptional stock-recruitment about 1950 to maintain and meet the demands of the commercial catch during that decade. And, a long period with poor stock-recruitment in the 1960s to match the known small total stock number in the 1970s. Actual catch data from 1954 suggest adult goldeye were abundant in the early 1950s (Table 10).

The stock-yield model that required the least manipulation of the recruitment pattern was insertion of the 1969 to 1993 recruitment pattern into the 1947 to 1971 period with the reduction of 1967 recruitment from 31% to 5% (Table 13). The best fit recruitment constant was 1,600,000. This trial of the model closely matched most of the known population characteristics of the commercial stock including the high catches in the early 1950s, the small total stock in the early 1970s, and the negligible stock recruitment identified here (Figure 20) and by Donald and Kooyman (1977b) for most of the 1960s and 1970s.

Goldeye Population History (1947 to 2002)

In 1947 before initiation of commercial exploitation there was a modelled estimate of 1,304,000 goldeye in the commercial portion of the population. From 1948 to 1950, 542,305 goldeye were harvested; the model provided 1.58 million new recruits to the stock during this same three-year period. Intense commercial exploitation and poor recruitment in the 1960s reduced the commercial stock to 18,000 goldeye by 1974. The model gave a population of 83,000 commercial goldeye that year. The poor stock-recruitment in the 1960s was evident in total population catches from the 1970s when mature fish (> age 7) were less then 10% of the population (Figure 14). However, in the 1970s goldeye were abundant (record CPUE in 1973, Table 11), but most of the population consisted of a single year-class from 1971. By the mid 1980s and during the 1990s, there was a more balanced ratio between juvenile and adult fish with adults ranging from 46% to 63% of the total population. The 1971 year-class persisted in the catches to the 21st century. Between 1980 and 2002, the modelled annual commercial stock ranged from 365,000 to 1,320,000 goldeye.

Maximum Sustainable Catch

Maximum sustainable catch estimates were calculated for the Delta population by removing from the model the actual commercial catches from Lake Claire and Lake Athabasca (Table 13), and entering constant annual catches of 20,000, 50,000 and 100,000 goldeye (Figure 20). Catches of 100,000 goldeye reduced the modelled commercial stock to zero by 1964, and a catch of 50,000 goldeye reduced the stock to zero by 1972.

The stock-yield model suggested that the maximum sustainable catch for the Delta population is 20,000 goldeye or 10,200 kg per year (number of fish x 510 g). The catch of 20,000 goldeye per year was sustainable through all years including the mid 1970s when the modelled stock reached a low of 1,600 goldeye following removal of 20,000 goldeye by the commercial catch (Figure 20).

An annual catch of 20,000 goldeye was only 2.8% of the long-term (1947 to 2002) mean stock number. It can be concluded that fish populations with irregular annual recruitment can only sustain a relatively small consistent annual exploitation rate to prevent stock depletion during decade-long periods with low rates of annual recruitment.

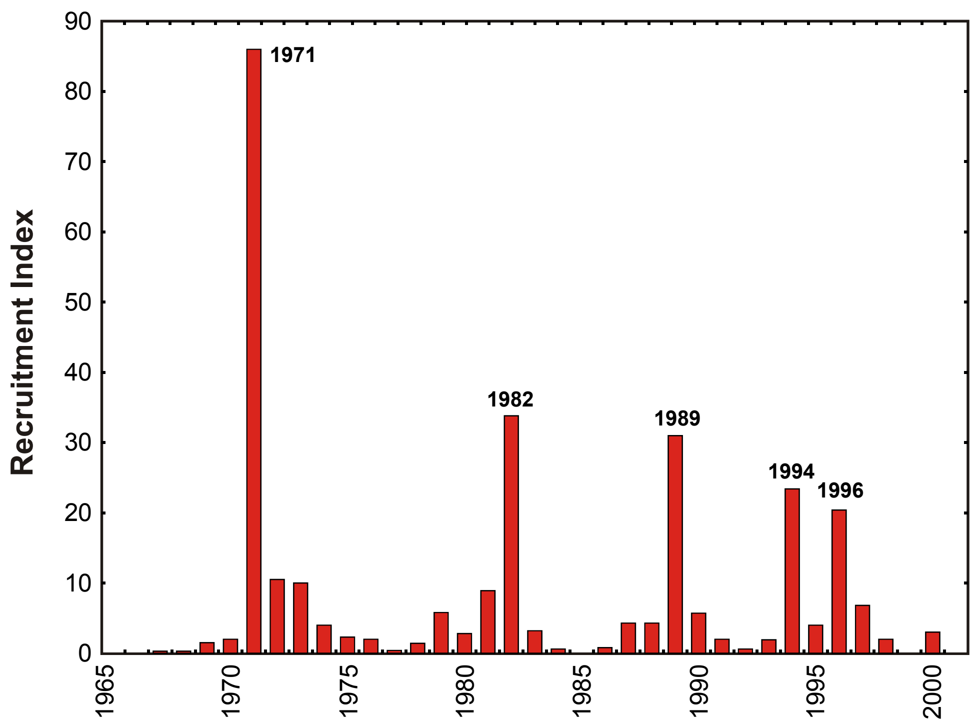


Figure 19. *Goldeye long-term recruitment index, 1967 to 2000.*

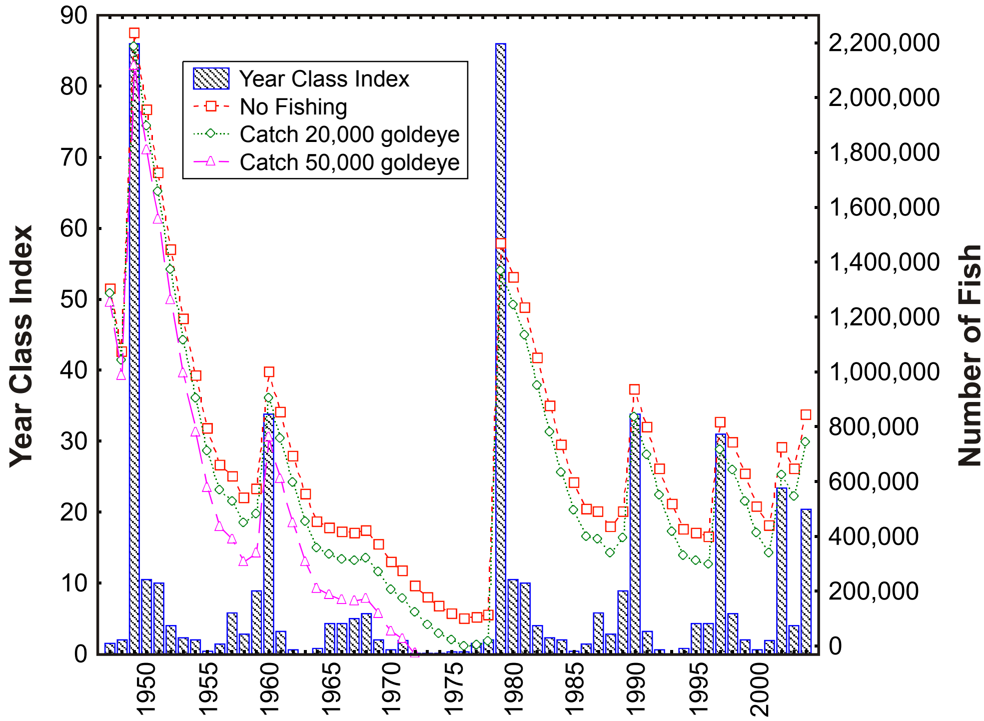


Figure 20. *Goldeye stock-yield model, 1947 to 2004.*

ACKNOWLEDGEMENTS

This project was generously supported by the Northern Rivers Ecosystem Initiative. Parks Canada provided logistical support and field accommodation in the Delta. We appreciated the cooperation and support of Ducks Unlimited for the water quality survey of basins in the Peace-Athabasca Delta in 2000. We also thank Bob Crosley and Reggie MacKay for their enthusiasm in the field.

REFERENCES

Aitken, B., and R. Sapach. 1994. Natural and modified flow modelling of the Peace-Athabasca Delta. Manuscript report prepared by Environment Canada for the Northern River Basins Study. 44 pp.

Banff-Bow Valley Study. 1995. Ecological Outlook. Cumulative Effects Assessment and Futures Modelling, Workshop Summary Report. Edited by Charlie Pacas, Jeff Green, and Suzanne Bayley for the Banff-Bow Valley Task Force, Banff, Alberta. 27 pp.

Brinkhurst, R.O. 1974. The benthos of lakes. MacMillan Press Ltd. London. 190 p.

Cash, K., F.J. Wrona and W. Gummer. 1996. Ecosystem health and integrated monitoring in the northern river basins. Northern River Basins Study Synthesis Report No. 10. Northern River Basins Study, Edmonton, Alberta. 75 pp.

Donald, D.B. 1989. First Canadian record of the Clam Shrimp *Caenestheriella belfragei* (Crustacea: Conchostraca) Can. Field-Nat. **103**: 593-594.

Donald, D.B. 1997. Relationship between year-class strength for goldeyes and selected environmental variables during the first year of life. Trans. Am. Fish. Soc. **126**: 361-368.

Donald, D.B. and A.H. Kooyman. 1977a. Food, feeding habits, and growth of goldeye, *Hiodon alosoides* (Rafinesque), in waters of the Peace-Athabasca Delta. Can. J. Zool. **55**: 1038-1047.

Donald, D.B. and A.H. Kooyman. 1977b. Migration and population dynamics of the Peace-Athabasca Delta goldeye population. Canadian Wildlife Service Occasional Paper 31.

Donald, D.B., F.J. 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. 56 pp.

Donald, D.B., J.A. Babaluk, J.F. Craig and W.A. Musker. 1992. Evaluation of the scale and operculum methods to determine the age of adult goldeyes with special reference to a dominant year-class. Trans. Am. Fish. Soc. **121**: 792-796.

Edmondson, W.T., Editor. 1959. Fresh-water biology. Second Edition. John Wiley and Sons., New York. 1248 p.

Flett, F., L. Bill and J. Crozier. 1996. A report of wisdom synthesis from the traditional knowledge component studies. NRBS Synthesis Report No. 12. Northern River Basins Study, Edmonton, Alberta.

Gallup, D.N., P. Van der Giesssen and H. Boerger. 1973. A survey of plankton and bottom invertebrates of the Peace-Athabasca Delta region. *In* Volume Two, Ecological Investigations, Peace-Athabasca Delta Project. 36 pp.

Johnson, R.K., T. Wiederholm and D.M. Rosenberg. 1993. Freshwater biomonitoring using individual organisms, populations, and species assemblages of benthic macroinvertebrates. *In* Rosenberg, D.M. and V.H. Resh (eds.), Freshwater biomonitoring and benthic macroinvertebrates. Chapman and Hall, New York.

Hopkinson, R.F. 2000. Canadian Gridded Climate Data. http://www.cics.uvic.ca/climate/data.htm

Kennedy, W.A. and W. M. Sprules. 1967. Goldeye in Canada. Bull. Fish. Res. Board Can. **161**. 45 pp.

Koonce, J.F., T.B. Bagenal, R.F. Carline, K.E.F. Hokanson and M. Nagiec. 1977. Factors influencing year-class strength of percids: a summary and a model of temperature effects. Journal of the Fisheries Research Board of Canada. **34:** 1900-1909.

Kristensen J., and S. A. Summers. 1978. Fish populations in the Peace-Athabasca Delta and the effects of water control structures on fish movements. Canada Fisheries and Marine Service Manuscript Report 1465.

Kristensen, J. 1980. Large flathead chub (*Platygobio gracilis*) from the Peace-Athabasca Delta, Alberta, including a Canadian record. Can. Field-Nat. **94**: 342.

Kristensen, J. 1981. Investigations of goldeye and other fish species in the Wood Buffalo National Park section of the Peace-Athabasca Delta, 1977. Canadian Manuscript Report of Fisheries and Aquatic Sciences. 1560.

Kristensen. J., and J.P. Parkinson. 1983. Biological and engineering studies to determine functional fishway designs for the Peace-Athabasca Delta. Report prepared for Alberta Environment by LGL Ltd. and ELJON. 169 p.

Pastershank, G.M. and D.C.G. Muir. 1995. Contaminants in environmental samples: PCDDs and PCDFs downstream of bleached kraft mills Peace and Athabasca rivers, 1992. Northern River Basins Study Project Report No. 44. Northern River Basins Study, Edmonton, Alberta.

Pastershank, G.M. and D.C.G. Muir. 1996. Polychlorinated biphenyls, and organochlorine pesticides and chlorinated phenols, Peace, Athabasca, and Slave river basins, 1992 to 1994. Northern River Basins Study Project Report No. 101. Northern River Basins Study, Edmonton, Alberta.

Peace-Athabasca Delta Implementation Committee. 1987. Peace-Athabasca Delta water management works evaluation. Final Report. A report prepared under the Peace-Athabasca Delta Implementation Agreement of Canada, Alberta, and Saskatchewan. 63 pp. + Appendices.

Peace-Athabasca Delta Project Group. 1973. The Peace-Athabasca Delta Project, Technical Report. A report prepared for Environment Ministers of Canada, Alberta, and Saskatchewan. Queen's Printer, Edmonton. 176 pp. + Appendices.

Reeder, S. and P. Fee. 1973. Water quality. *In* Volume One. Hydrologic Investigations, Peace-Athabasca Delta Project Technical Appendices. 120 pp. + Appendices.

Ricker, W.E. 1975. Computation and interpretation of biological statistics of fish populations. Fisheries Research Board of Canada, Bulletin **191**. 382 p.

Schultz, F.H. 1955. A report of investigations of the 1954 goldeye fishery in Lake Claire, Wood Buffalo National Park, Alberta. Canadian Wildlife Service Report. 17 pp.

Statistics Canada. 1987. Population and Dwelling Characteristics – Census Divisions and Subdivisions. Canada Census 1986, Alberta: Part 1. Ottawa. Catalogue No. 94-117

Statistics Canada. 2004. Profile of Census Divisions and Subdivisions in Alberta. Canada Census 2001. Ottawa. Catalogue No. 95-223-XPB

Stribling, J.B. 1994. Development environmental indicators in the context of an inter-agency selection framework. *In* Proceedings of the workshop on development of ecosystem health indicators. Report prepared for the Canadian Council of Ministers of the Environment.

Appendix A *Water chemistry data for Mamawi Lake, Peace-Athabasca Delta, 1994 and 1999.*

Station ®	Pelican Creek			Beaver Ass Point			North Channel			(Mamawi?) Cree Creek			Poplar Island		
Latitude ®	58 35 24.9			58 38 22.3			58 38 17.9			58 35 26.4			58 35 01.8		
Longitude ®	111 37 01.5			111 24 07.7			111 24 06.8			111 29 08.4			111 23 08.3		
Date ®	20-Jun-94	15-Sep-94	1-Jul-99	20-Jun-94	15-Sep-94	1-Jul-99	20-Jun-94	15-Sep-94	1-Jul-99	20-Jun-94	15-Sep-94	1-Jul-99	20-Jun-94	15-Sep-94	1-Jul-99
TDS* 00201L mg/L	261.000	313.000	432.600	260.000	311.000	424.000	231.000	313.000	175.800	138.000	169.000	141.3	143.000	169.000	142.300
Sat Index* 00210L pH Units	-1.145	-0.608		-1.158	-0.519		-1.013	-0.563		-1.109	-0.531		-1.157	-0.445	
Stab Index* 00211L pH units	9.760	8.760		9.750	8.660		9.620	8.690		9.820	8.800		9.860	8.640	
Cond. 02041L usie/cm	469.000	548.000	777.000	459.000	546.000	767.000	417.000	549.000	315.000	244.000	311.000	243.000	258.000	296.000	254.000
B-diss 100211 mg/L	0.062	0.066	0.107	0.054	0.032	0.091	0.042	0.070	0.034	0.022	0.024	0.015	0.018	0.025	0.013
Chlorophyll - a µg/L	145.470			137.610	---		121.620	---		43.920	---		485.920	---	
TOC* 06002L mg/L	20.200	21.370		15.450	20.090		15.570	19.390		15.870	6.770		8.770	12.680	
DOC 06104L mg/L	15.000	17.000	21.900	10.400	16.900	15.300	11.900	16.500	6.670	10.700	6.230	4.210	6.700	10.500	3.800
HCO3* 06201L mg/L	116.800	135.300	193.800	124.300	136.500	192.600	121.900	139.000	136.500	115.700	132.900	136.500	116.500	152.400	121.700
CO3* 06301L mg/L	0.000	0.000		0.000	0.000		0.000	0.000		0.000	0.000		0.000	0.000	
Free CO2* 06401L mg/L	6.280	6.190		7.330	5.190		4.960	6.070		4.600	3.820		5.210	4.280	
POC 06901L mg/L	5.200	4.370	3.240	5.050	3.190	7.760	3.670	2.890	2.230	5.170	0.539	11.600	2.070	2.180	1.840
NO3+NO2 07110L mg/L	L0.01	L.002	L0.01	L0.01	L.002	L0.01	L0.01	L.002	L0.01	0.094	L.002	0.108	L0.01	0.002	L0.01
TN* 07603L mg/L	1.000	1.090	1.131	1.280	0.950	1.719	0.960	0.930	0.555	0.850	0.310	1.078	0.560	0.690	0.543
DN 07657L mg/L	1.240	0.524	0.656	0.441	0.525	0.639	0.393	0.537	0.238	0.485	0.229	0.264	0.263	0.455	0.297
PN 07901L mg/L	0.767	0.562	0.475	0.834	0.420	1.080	0.569	0.392	0.317	0.364	0.082	0.814	0.301	0.236	0.246
OH* 08501L mg/L	0.000	0.000		0.000	0.000		0.000	0.000		0.000	0.000		0.000	0.000	
F-diss 09117L mg/L	0.160	0.240	0.270	0.150	0.240	0.250	0.160	0.240	0.120	0.090	0.130	0.110	0.090	0.130	0.110
Alk-tot 10111L mg/L	95.800	111.000	159.000	102.000	112.000	158.000	100.000	114.000	0.112	94.900	109.000	112.000	95.600	125.000	99.800
pH 10301L pH units	7.470	7.540	7.740	7.430	7.620	7.680	7.590	7.560	7.790	7.600	7.740	7.780	7.550	7.750	7.800
Hard-tot* 10602L mg/L	148.900	171.300		148.100	173.200		140.800	175.900		108.500	122.500		111.300	126.900	
Hard-nonCO3 10650L mg/L	53.100	60.300		46.100	61.200		40.800	61.900		13.600	13.500		15.700	1.900	
%Na* 11250L %	35.400	35.500	44.000	34.200	35.500	44.000	31.700	34.900	24.000	16.400	22.800	14.000	16.300	18.500	15.000
SiO2 14108L mg/L	3.430	4.030	0.6	3.580	3.380	0.990	3.610	2.930	2.910	5.130	4.320	4.610	3.800	1.680	3.910
P-diss ortho 15265L mg/L	0.006	0.005	0.003	0.005	0.005	0.002	0.004	0.005	0.002	0.006	0.002	0.005	0.003	0.004	0.002
P-tot 15423L mg/L	0.222	0.173	0.112	0.203	0.121	0.267	0.146	0.102	0.093	0.148	0.022	0.373	0.061	0.078	0.073
P-diss 15465L mg/L	0.009	0.013	0.014	0.010	0.014	0.011	0.009	0.013	0.011	0.009	0.008	0.013	0.010	0.013	0.009
P-part* 15901L mg/L	0.213	0.160	0.098	0.193	0.107	0.256	0.137	0.089	0.082	0.139	0.014	0.360	0.051	0.065	0.064
SO4-diss 16306L mg/L	60.900	79.600	91.400	59.500	78.600	89.300	47.900	79.300	30.100	20.200	23.300	17.300	24.200	22.600	24.000
Cl-diss 17206L mg/L	46.000	55.200	85.700	45.400	53.600	83.500	36.900	53.800	12.900	6.000	15.200	4.680	6.650	9.910	4.950
Mn-diss 100204 mg/l	L.001	L.001	0.079	L.001	L.001	0.175	L.001	L.001	0.060	0.001	L.001	0.307	L.001	L.001	0.055
Fe-diss 100202 mg/L	0.026	0.009	0.857	0.023	0.010	1.950	0.015	0.016	0.835	0.109	0.025	3.720	0.033	0.068	0.656
Al-diss 100195 mg/L	L.02	L.02	0.158	L.02	L.02	0.334	L.02	L.02	0.164	L.02	L.02	0.867	L.02	L.02	0.148
Ba-diss 100196 mg/L	0.041	0.050	0.081	0.046	0.053	0.099	0.046	0.057	0.066	0.047	0.052	0.113	0.046	0.061	0.058
Be-diss 100197 mg/L	L.5	L.5	L.5	L.5	L.5	L.5	L.5	L.5	L.5	L.5	L.5	L.5	L.5	L.5	L.5
Cd-diss 100198 mg/L	L.001	L.001	L.001	L.001	L.001	L.001	L.001	L.001	L.001	L.001	L.001	L.001	L.001	L.001	L.001
Co-diss 100199 mg/L	0.001	L.001	0.002	L.001	L.001	0.002	L.001	0.001	0.001	L.001	0.001	0.003	L.001	L.001	L.001
Cr-diss 100200 mg/L	0.001	L.001	0.002	L.001	L.001	0.001	L.001	0.001	L.001	L.001	L.001	0.002	L.001	L.001	L.001
Cu-diss 100201 mg/L	0.003	0.003	0.005	0.002	0.003	0.006	0.002	0.003	0.002	0.001	L.001	0.006	0.001	0.001	0.002
Li-diss 100203 mg/L	0.020	0.024	0.032	0.019	0.024	0.031	0.015	0.025	0.008	0.006	0.008	0.005	0.006	0.008	0.004
Mo-diss 100205 mg/L	0.001	0.001	0.002	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	L.001	0.001	0.001	0.001
Ni-diss 100206 mg/L	0.002	L.002	0.005	0.002	0.002	0.005	0.002	0.003	0.002	0.002	L.002	0.006	L.002	L.002	0.002
Pb-diss 100207 mg/L	0.002	0.004	0.004	L.002	L.002	0.004	L.002	L.002	L.002	L.002	L.002	0.007	L.002	L.002	0.002
Sr-diss 100208 mg/L	0.225	0.280	0.371	0.237	0.286	0.371	0.211	0.291	0.233	0.178	0.233	0.229	0.188	0.218	0.198
V-diss 100209 mg/L	L.001	L.001	0.002	L.001	L.001	0.002	L.001	L.001	0.001	L.001	L.001	0.004	L.001	L.001	0.001
Zn-diss 100210 mg/L	0.002	L.002	0.004	0.003	L.002	0.008	L.002	L.002	0.003	0.002	L.002	0.018	L.002	L.002	0.003
Ca-diss 100212 mg/L	36.200	46.400	66.600	39.000	47.500	65.300	35.000	48.200	36.900	27.800	34.400	31.400	28.300	34.000	32.600
Mg-diss 100213 mg/L	9.300	11.800	18.400	9.700	12.000	17.900	8.200	12.400	9.810	6.200	8.500	7.890	6.800	8.400	8.620
Na-diss 100214 mg/L	32.800	41.200	70.300	32.800	41.500	68.200	25.900	42.100	14.500	8.800	15.800	6.880	8.500	12.000	7.230
K-diss 100215 mg/L	1.600	2.000	3.860	1.600	2.000	3.760	1.400	2.000	1.300	0.700	0.800	0.750	0.800	1.000	0.960

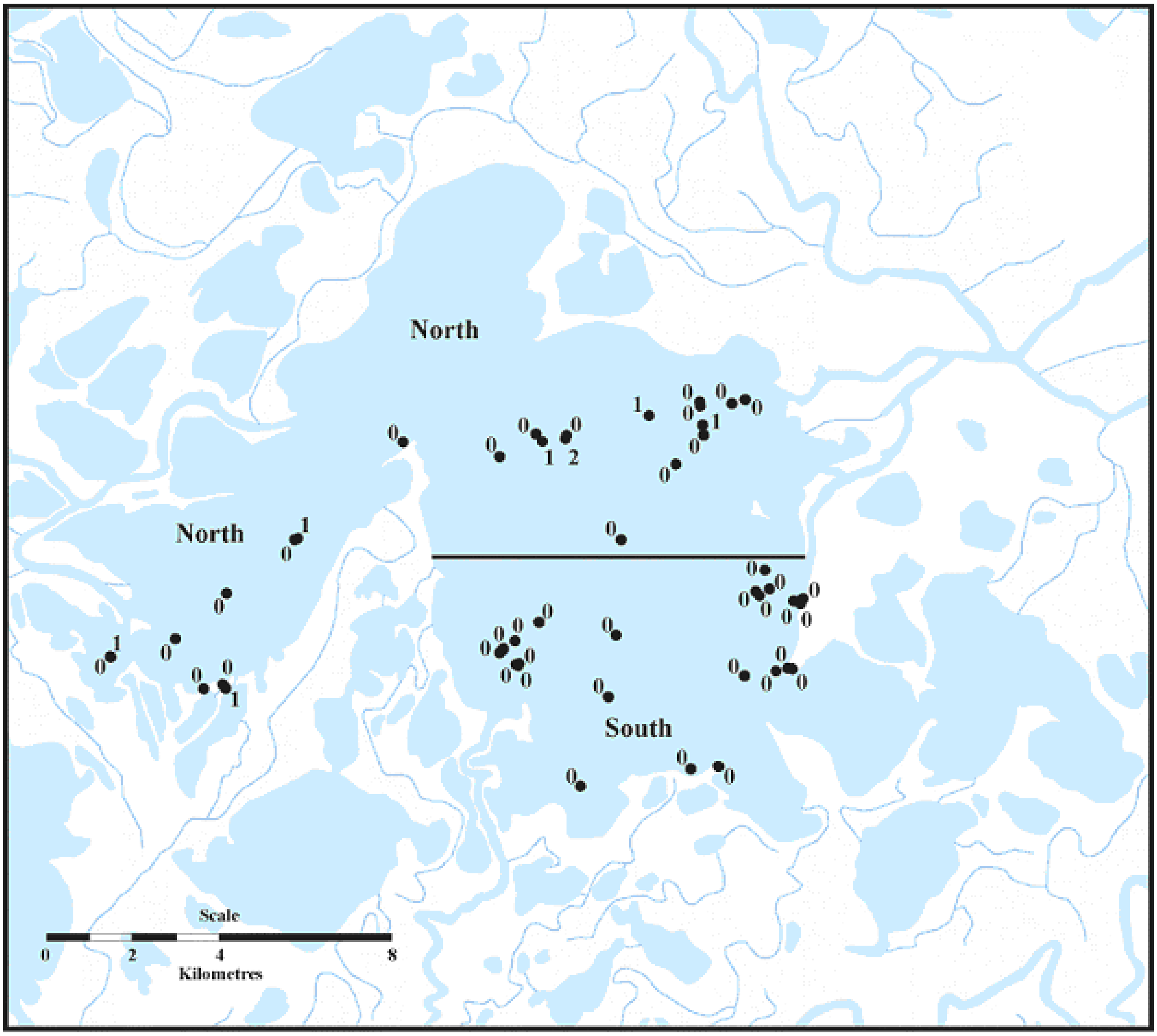
Appendix B *Water Chemistry of connected perched basins in the Peace-Athabasca Delta, 2000 (Source – Ducks Unlimited and Environment Canada).*

Field Sample Number	Location	Location Latitude	Location Longitude	Sample Date	ALKALINITY PHENOLPHTHALEIN $CACO_3$	ALKALINITY TOTAL $CACO_3$	BICARBONATE (CALCD.)	CALCIUM DISSOLVED/FILTERED	CARBON DISSOLVED ORGANIC	CARBON PARTICULATE ORGANIC	CARBON TOTAL ORGANIC (CALCD.)	CARBONATE (CALCD.)	CHLORIDE DISSOLVED	FLAG	CHLOROPHYLL A	FLAG	COLOUR TRUE	FLUORIDE DISSOLVED	HARDNESS NON-CARB. (CALCD.)
					MG/L	MG/L	MG/L	MG/L	MG/L	MG/L	MG/L	MG/L	MG/L		MG/L		REL UNITS	MG/L	MG/L
2000PN040301	SNYE EIGHTEEN	58.51.32.83	111.53.46.82	6/27/2000 10:00	8.8	182	200.404	27.4	18.2	0.501	18.701	10.56	5.75		0.001		40	0.17	0
2000PN040302	SNYE SIXTEEN	58.50.29.004	111.51.34.66	6/27/2000 10:01	29.3	105	56.562	13.1	19.2	2.64	21.84	35.16	4.3		0.001		45	0.23	0
2000PN040303	SNYE TWENTY	58.50.28.07	111.49.57.43	6/27/2000 10:02	45.3	102	13.897	13.5	16.9	0.42	17.32	54.36	3.08	L	0.001		8	0.17	0
2000PN040304	SNYE FOUR	58.51.02.70	111.48.09.18	6/27/2000 10:03	7.6	176	196.015	24.2	20	0.466	20.466	9.12	1.75		0.001		15	0.14	0
2000PN040305	SNYE TWENTY SIX	58.52.16.10	111.50.40.63	6/27/2000 10:04	NA	241	293.779	48.4	22.2	1	23.2	0	3.14		0.003		30	0.17	0
2000PN040306	SNYE ONE	58.52.11.032	111.50.34.26	6/27/2000 10:05	2.8	140	163.834	38.8	13.7	0.402	14.102	3.36	1.25	L	0.001		30	0.13	15.345
2000PN040307	SNYE TWELVE	58.52.53.33	111.52.35.11	6/27/2000 10:06	3	161	188.945	32.5	15.2	0.335	15.535	3.6	2.47		0.001	L	5	0.14	0
2000PN040308	SNYE SEVENTEEN	58.53.01.36	111.54.23.80	6/27/2000 10:07	50.1	197	117.999	12.9	23.3	0.397	23.697	60.12	3	L	0.001		25	0.15	0
2000PN040309	LYNX STAND BAY	58.45.05.94	111.54.14.65	6/27/2000 10:08	NA	241	293.779	55.3	40.9	1.38	42.28	0	80.2	L	0.001		90	0.36	0
2000PN040310	MOUSE LAKE	58.30.15.70	112.18.45.32	6/27/2000 10:09	NA	173	210.887	34.6	31.6	5.32	36.92	0	9.16		0.004		65	0.21	0
2000PN040311	OTTER LAKE	58.32.58.99	111.32.35.02	6/27/2000 10:10	5.6	181	206.986	57	18.4	4.85	23.25	6.72	14.6		0.004		80	0.21	23.084
2000PN040312	POPULAR POINT LAKE	58.35.32.32	111.20.26.38	6/27/2000 10:11	NA	228	277.932	48.3	45.3	1.66	46.96	0	34.9		0.001		110	0.24	0
2000PN040313	FOUR FOLKS LAKE	58.44.49.70	111.32.03.26	6/27/2000 10:12	NA	205	249.895	42.2	21.5	3.37	24.87	0	6.19		0.001		110	0.16	0
2000PN040314	EGG LAKE	58.52.05.45	111.23.21.52	6/28/2000 10:00	NA	246	299.874	37.3	31.7	0.504	32.204	0	7.97		0.001		70	0.22	0
2000PN040315	WEST PUSHUP	58.49.50.30	111.29.17.45	6/28/2000 10:01	45.5	146	67.045	11.9	20.3	0.328	20.628	54.6	4.64	L	0.001		20	0.17	0
2000PN040316	PUSHUP	58.48.19.19	111.25.25.46	6/28/2000 10:02	45.9	153	74.603	13.3	23	0.42	23.42	55.08	4.17		0.001		25	0.18	0
2000PN040317	JEMIS	58.40.11.60	111.27.38.41	6/28/2000 10:03	NA	150	182.85	25.6	35.2	1.1	36.3	0	29.4		0.002		65	0.25	0
2000PN040318	QUATRE FOURCHES FOUR	58.37.29.57	111.16.16.10	6/28/2000 10:04	NA	266	324.254	64.6	39.7	0.41	40.11	0	18.2		0.001		120	0.18	0
2000PN040319	QUATRE FOURCHES THREE	58.38.00.38	111.16.18.30	6/28/2000 10:05	NA	282	343.758	57.8	44.8	0.718	45.518	0	20.4		0.001		140	0.24	0
2000PN040320	QUATRE FOURCHES SEVEN	58.38.14.82	111.17.42.29	6/28/2000 10:06	NA	250	304.75	42	33.2	0.386	33.586	0	19.6		0.001		90	0.14	0
2000PN040321	BEAVER ASS POINT VICINITY	58.38.21.33	111.31.00.41	6/28/2000 10:07	1.1	119	142.379	63	13.7	1.93	15.63	1.32	107		0.005		80	0.25	105.83

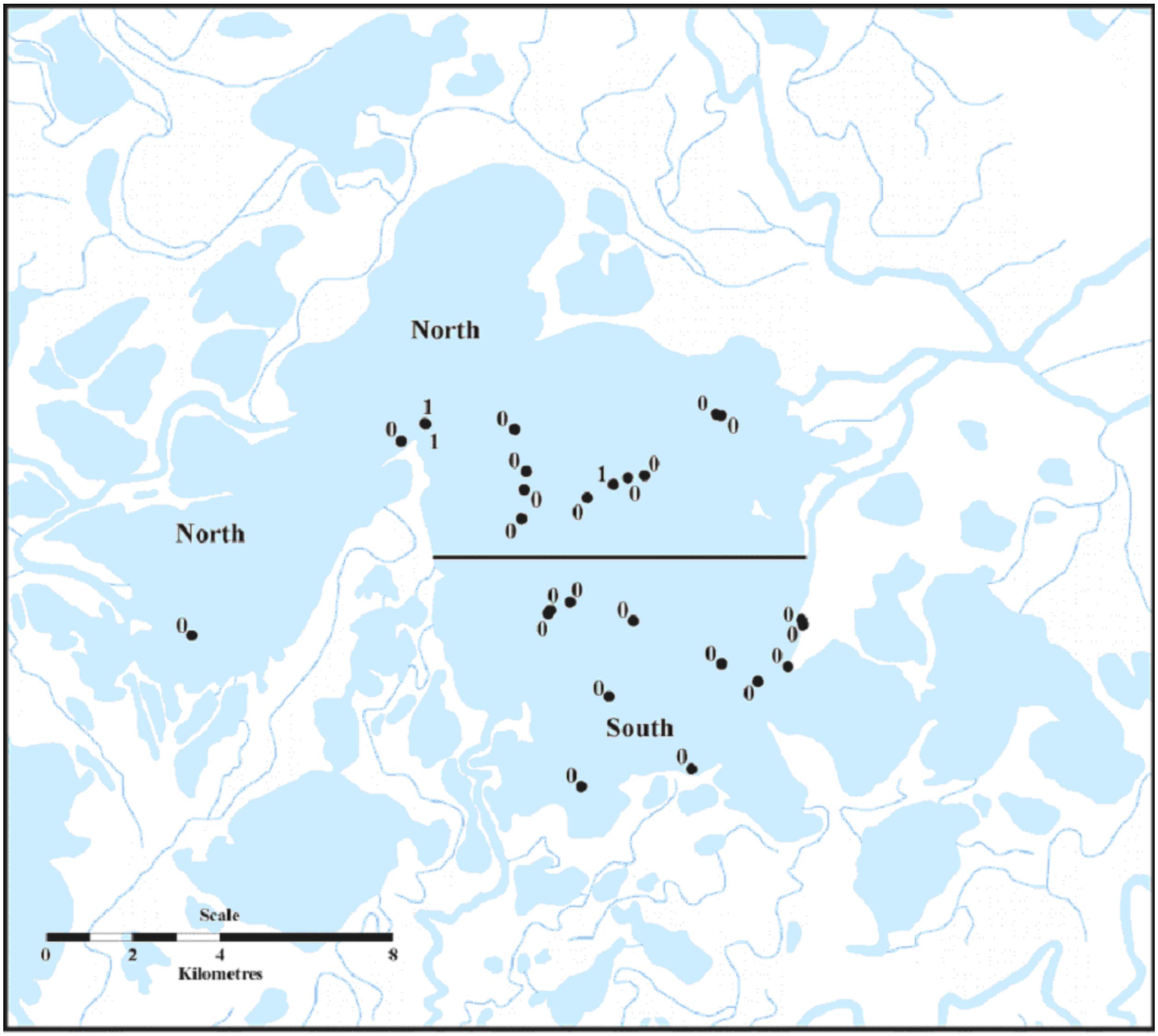
Appendix B (cont'd) *Water Chemistry of connected perched basins in the Peace-Athabasca Delta, 2000 (Source – Ducks Unlimited and Environment Canada).*

Field Sample Number	HARDNESS TOTAL (CALCD.) $CACO_3$	HYDROXIDE (CALCD.)	MAGNESIUM DISSOLVED/FILTERED	FLAG	NITROGEN DISSOLVED NO_3 & NO_2	NITROGEN PARTICULATE	NITROGEN TOTAL (CALCD.)	NITROGEN TOTAL DISSOLVED	PH	FLAG	PHOSPHOROUS DISSOLVED ORTHO	PHOSPHOROUS PARTICULATE (CALCD.)	PHOSPHOROUS TOTAL	PHOSPHOROUS TOTAL DISSOLVED	POTASSIUM DISSOLVED/FILTERED	FLAG	RESIDUE FIXED NONFILTRABLE	FLAG	RESIDUE NONFILTRABLE	SIO_2	SODIUM DISSOLVED/FILTERED	SODIUM PERCENTAGE (CALCD.)	SPECIFIC CONDUCTANCE	SULPHATE DISSOLVED	TOTAL DISSOLVED SOLIDS (CALCD.)	TURBIDITY
	MG/L	MG/L	MG/L		MG/L	MG/L	MG/L	MG/L	PH UNITS		MG/L	MG/L	MG/L	MG/L	MG/L		MG/L		MG/L	MG/L	MG/L	%	USIE/CM	MG/L	MG/L	NTU
2000PN040301	137.172	0	16.7	L	0.01	0.048	1.538	1.49	8.9		0.01	0.013	0.044	0.031	23		1.4		3.4	0.84	11	12.567	355	2	196.104	3.1
2000PN040302	76.763	0	10.7	L	0.01	0.268	1.798	1.53	9.97		0.011	0.017	0.053	0.036	16.4		2		4.8	0.79	9.08	16.821	226	3.4	121.044	5.6
2000PN040303	95.053	0	14.9	L	0.01	0.057	1.237	1.18	10.5		0.004	0.008	0.031	0.023	10.6	L	1		1.8	0.94	9.47	15.953	260	18.3	132.204	1.44
2000PN040304	153.883	0	22.7	L	0.01	0.08	1.23	1.15	8.85		0.004	0.011	0.03	0.019	6.29	L	1		1.6	0.47	10.8	12.678	326	2.6	174.594	1.64
2000PN040305	219.251	0	23.9	L	0.01	0.148	1.268	1.12	8.1		0.004	0.032	0.054	0.022	12.7		2.8		6	0.6	9.93	8.407	459	8.1	251.584	4
2000PN040306	155.345	0	14.2	L	0.01	0.047	1.097	1.05	8.57		0.006	0.014	0.039	0.025	10.8		1		2.4	0.94	5.91	7.068	344	30.9	186.974	2.2
2000PN040307	152.377	0	17.3	L	0.01	0.058	0.951	0.893	8.55	L	0.002	0.01	0.02	0.01	9.03	L	1	L	1	0.25	6.49	7.935	324	9.7	174.524	0.8
2000PN040308	162.309	0	31.6	L	0.01	0.076	1.466	1.39	9.91		0.003	0.012	0.032	0.02	12.7		1.2		2.6	0.29	16	16.323	361	15.6	210.484	2.2
2000PN040309	238.127	0	24.3	L	0.01	0.203	3.033	2.83	7.93		0.023	0.042	0.124	0.082	9.4		1.8		5.8	1.91	67.1	36.865	757	22.4	405.614	3.9
2000PN040310	172.442	0	20.9		0.013	0.623	2.973	2.35	7.96		0.028	0.087	0.157	0.07	4.11		23.6		39.2	4.04	14.8	15.348	384	17.9	209.578	18.3
2000PN040311	204.084	0	15	L	0.01	0.585	1.925	1.34	8.62	L	0.002	0.051	0.073	0.022	5.03		11.2		24.4	6.75	19.6	16.852	474	47.1	273.934	18.9
2000PN040312	204.592	0	20.4	L	0.01	0.232	3.292	3.06	7.9		0.082	0.043	0.179	0.136	6.14		5.6		11.2	10.4	40.5	29.328	549	6.9	304.624	6.6
2000PN040313	174.127	0	16.7	L	0.01	0.471	2.111	1.64	8.29		0.018	0.088	0.15	0.062	13.8		6		14	0.6	11.7	11.723	400	1.6	215.994	10.6
2000PN040314	203.885	0	26.9	L	0.01	0.066	2.236	2.17	8.1		0.047	0.03	0.133	0.103	15.2	L	1		2.4	1.67	20.4	16.587	476	4.7	262.004	1.87
2000PN040315	116.171	0	21	L	0.01	0.027	1.357	1.33	10.1		0.003	0.007	0.024	0.017	9.98	L	1		1.7	0.41	14.8	19.992	282	3.2	153.744	1.36
2000PN040316	122.961	0	21.8	L	0.01	0.046	1.566	1.52	10.1		0.002	0.005	0.03	0.025	8.95	L	1		1.8	0.23	16.5	21.088	290	1.7	158.674	1.58
2000PN040317	130.207	0	16.1	L	0.01	0.149	1.919	1.77	7.8		0.002	0.018	0.05	0.032	10.2		2.8		5.4	1.24	31.4	32.302	398	1.8	206.034	3.4
2000PN040318	252.292	0	22.1	L	0.01	0.036	2.606	2.57	7.82		0.053	0.061	0.172	0.111	14.8		1.2		3.6	12.3	18.6	12.989	547	2.5	312.924	8.3
2000PN040319	260.838	0	28.3	L	0.01	0.104	2.834	2.73	7.58		0.096	0.076	0.241	0.165	15.9		4		5.2	14	24.9	16.162	584	2.9	333.684	6.4
2000PN040320	222.62	0	28.6	L	0.01	0.046	2.236	2.19	8.11		0.125	0.054	0.266	0.212	20.3	L	1		3	1.2	20.4	15.157	520	2.3	284.584	2.1
2000PN040321	224.83	0	16.4	L	0.01	0.295	0.989	0.694	8.35		0.004	0.066	0.079	0.013	4.6		34		39.6	0.15	79.9	42.983	800	106	448.744	36

Appendix C *Distribution and number per sample of* Caenestheriella belfragei *in Mamawi Lake (June, 1994).*



Appendix C (cont'd) *Distribution and number per sample of* Caenestheriella belfragei *in Mamawi Lake (June, 1999).*



Appendix C (cont'd) *Distribution and number per sample of* *Caenestheriella belfragei* *in Mamawi Lake (June, 2002).*