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OIL SANDS REGIONAL AQUATICS MONITORING PROGRAM (RAMP)

FIVE YEAR REPORT

Submitted to:

RAMP Steering Committee

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The binder cover page and spine artwork was designed and drawn by artist Robert F. McDonald.

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ACKNOWLEDGEMENTS

This report summarizes the results of the first five years of the Oil Sands Regional Aquatics Monitoring Program (RAMP). RAMP is a multi-stakeholder program composed of representatives from industry, provincial and federal governments, local aboriginal groups and environmental organizations. Funding for this five year review was provided by Albian Sands Energy Inc. (Albian), Canadian Natural Resources Limited (CNRL), ExxonMobil Canada Ltd. (ExxonMobil), Devon Canada Corporation (Devon), OPTI Canada Inc./Nexen Canada Ltd. (OPTI/Nexen), Petro-Canada Oil and Gas (Petro-Canada), Shell Canada Limited (Shell), Suncor Energy Inc. (Suncor), Syncrude Canada Ltd. (Syncrude) and TrueNorth Energy L.P (TrueNorth).

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1 RAMP HISTORY

1.1 INTRODUCTION

This section introduces the evolution of the Regional Aquatics Monitoring Program (RAMP) from 1997 to 2001. It describes why RAMP was formed and what it is trying to achieve. It also discusses how the program structure has changed and how new members have influenced the study area and the study design.

Environmental Impact Assessments (EIAs) in the Oil Sands Region study the baseline environmental conditions and predict effects from proposed developments. The EIA predictions are conservative to ensure that future impacts will not be greater than predicted. The expectation is that impacts will be less than predicted. However, the conservative nature of the EIA predictions needs to be verified as it is recognized that the Oil Sands Region covers a large, complex area in which the natural variability and trends are poorly understood.

The natural variability of the aquatic environment is influenced by climate, landforms and terrain features. Relative to other regions in Alberta, the Oil Sands Region experiences a short growing season that is susceptible to cycles of drought and flooding, as well as extreme winter temperatures. The large land base encompasses many landforms ranging from varying depths of limestone, sand and oil deposits to the following features:

- wetlands;
- lakes, rivers, ephemeral creeks, springs and seeps;
- muskeg areas;
- uplands; and
- glacial, fluvial and aeolian terrains.

Understanding the long-term natural variability in the Oil Sands Region is an essential first step in determining if changes to the aquatic environment over time are due to cumulative effects of developments, natural extremes or both.

Considerable growth has occurred in the Oil Sands Region. In addition to the oil sands projects listed by year in the following sections, the following examples of other activities have the potential to affect the aquatic environment in the Oil Sands Region:

- municipal infrastructure;
- aggregate operations;
- fishing and recreational activities;
- oil and gas activities; and
- forestry operations.

Of these activities, some involve direct withdrawal of water for industrial or urban services. Fort McMurray, Fort McKay and Fort Chipewyan operate intakes from the Athabasca River system for municipal water supplies. Gravel pits, such as that at Susan Lake, run dewatering activities and subsequently discharge excess water. Golf courses may obtain permits to withdraw water for irrigation. Conventional oil and gas development may also involve water withdrawal within the Athabasca River watershed. Alternately, some development activities may not require water directly, but may affect the way that water moves through the watershed. For example, forestry may affect the speed of runoff into watercourses and may lead to changes in siltation, while road development can affect drainage patterns. Urban pesticide or herbicide use and other runoff from urban areas may also contribute to changes in the aquatic environment.

RAMP was designed as a long-term monitoring program that incorporated both traditional and scientific knowledge. Specific programs in RAMP were established each year by committees and subcommittees after consultation with industrial, Aboriginal, environmental and regulatory stakeholders and expert independent consultants. Through the years, the program included the following environmental monitoring in the Oil Sands Region:

- water quality and sediment in rivers (1997 to 2001);
- fish in rivers (1997 to 2001);
- benthic invertebrates in rivers (1997, 1998, 2000 and 2001) and two lakes (1997 to 2001);
- water quality in wetlands (1998 to 2001) and acid sensitive lakes (1999 to 2001);
- aquatic vegetation (1999 to 2001); and
- hydrology and climate (monitoring began in 1995, but became a component of RAMP in 2000).

Funding for the program has increased from $178,340 in 1997 to $1,172,861 in 2001 as the program has expanded. Funding was provided by financial contributions from oil sands producers and fluctuated from year to year, in accordance with changes in the planned monitoring program and budgetary constraints. Industrial facilities adjacent to heavily monitored waterbodies were expected to pay more than facilities that had little monitoring nearby. The 20-year bitumen production rates of oil sands facilities were considered a reasonable basis to determine funding obligations. The distribution of RAMP's budget was prorated against those 20-year production rates.

As RAMP is a multi-stakeholder initiative, non-funding members included regulators, Aboriginal groups, environmental non-governmental organizations (ENGOs) and other stakeholders (e.g., local communities). Benefits to non-funding members include the following:

- receiving information relevant to their concerns or issues related to aquatic environments;
- increasing confidence in the information that was collected;
- communication of the state of the aquatic environment; and
- ensuring that sharing of information and addressing of issues continue beyond oil sands developments until closure.

As the Oil Sands Region experienced rapid growth from 1997 to 2001, changes to RAMP were made annually. These changes not only affected RAMP's objectives, and organizational structure, but the study area and study design as well. Potential sampling methods, sentinel species and reference lakes and streams were also evaluated during this period. Some methods were adopted and then abandoned the following year. The following sections will summarize the changes to RAMP from 1997 to 2001.

1.2 RAMP IN 1997

Conditions in the Environmental Protection and Enhancement Act (EPEA) amending approval of Suncor Energy Inc., Oil Sands (Suncor) Lease 86/17 mine, as well as conditions in their amending approval for the Steepbank Mine, prompted the creation of RAMP. In the spring of 1997, Suncor and its neighbour, Syncrude Canada Ltd. (Syncrude), proposed the concept of RAMP to Alberta Environmental Protection (AEP) as a joint initiative (Golder 1997a). With the Muskeg River Mine Application submitted, Shell Canada Limited (Shell) also joined in the initiative in 1997. Suncor, Syncrude and Shell proceeded to implement the RAMP program design as outlined in the proposal, to meet their approval conditions. The Oil Sands Regional Aquatics Monitoring Program (RAMP) 1997 report (Golder 1998) provided a detailed assessment of the data.

1.2.1 Program Objectives

To follow its mandate to monitor, evaluate, compare, review and communicate the state of the aquatic environment in the Athabasca Oil Sands Region, RAMP had developed Program Objectives, which were reviewed and adjusted annually to consider new developments in the Oil Sands Region. There were three main objectives of RAMP in 1997:

- to monitor aquatic environments in the Oil Sands Region to allow assessment of regional trends and cumulative effects;
- to provide baseline data against which impact predictions of recent EIAs for oil sands developments will be verified; and
- to design and execute a program that addresses the anticipated aquatic monitoring requirements of oil sands operators' environmental approvals.

1.2.2 Membership and Development

In 1997, existing developments with some type of disturbance included Suncor's Lease 86/17 and Steepbank mines, as well as Syncrude's Mildred Lake, North and Aurora North mines. Shell's Muskeg River Mine application was in the regulatory approval process in 1997. Thus, the first members of RAMP were Suncor, Syncrude and Shell (Table 1.1 and Figure 1.1).

Table 1.1 Oil Sands Developments in 1997

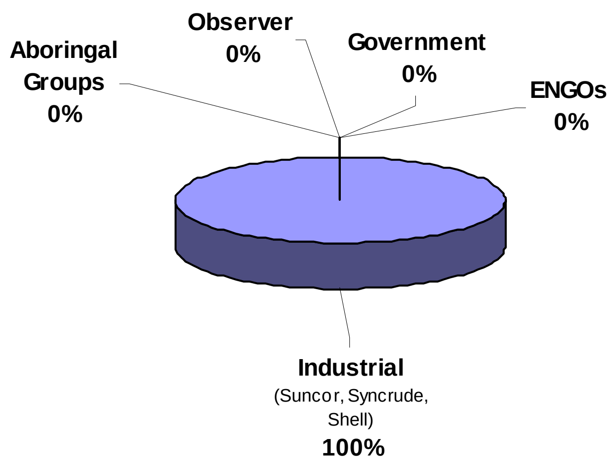
Oil Sands Development	Date of Application	Capacity (bpd)[a]	Development Area (ha)[b]	Type of Operation	Existing Disturbance in 1997
Suncor Energy Inc.					
Fixed Plant Expansion/ Lease 86/17/Steepbank	1996/1964/ 1996	450,000 S	18,298	processing/ open-pit	✔
Syncrude Canada Ltd.					
Mildred Lake Upgrader/ North Mine	1973/1995	480,000 S/ 160,000 B	21,100	processing/ open-pit	✔
Aurora North	1996	200,000 B	7,700	open-pit	✔
Aurora South	1996	200,000 B	7,300	open-pit	
Shell Canada Limited					
Muskeg River Mine	1997	155,000 B	4,343	open-pit	

Note: nyd = Not yet developed.

[a] Barrels per day (bpd) of B = Bitumen; S = Synthetic Crude or pipelineable crude; bpd values are rounded off.

[b] Development areas are those that will result from the existing approved and planned operations. Areas represent the maximum disturbance footprint for terrestrial resources.

Figure 1.1 Membership Distribution in 1997



In addition to effects resulting from dewatering and closed-circuiting of water systems at oil sands developments, surface diversions affecting water flow in 1997 included the Beaver River diversion at Syncrude Base Mine. Other developments in 1997 included urban growth in Fort McMurray (i.e., expansion of residential areas with 300 new home starts, new golf course development at Quarry Ridge and increasing water withdrawal requirements) and forestry activities by Alberta-Pacific Forest Industries Ltd. (Al-Pac) in the watershed of the Pierre River (Al-Pac 1999). Although the regional harvests by Al-Pac remained relatively consistent between 1997 and 2001, the locations of harvests relative to the Athabasca River system changed each year.

1.2.3 Organizational Structure

Although three meetings were held to discuss the organization of RAMP in 1997, no decision was made to establish the structure. It was expected that the program would be frequently adjusted to meet its objectives by considering monitoring results, technological advances and community concerns, and that the organizational structure would be adjusted accordingly.

The extent of stakeholder involvement and the method of involving stakeholders in RAMP was not determined in 1997; however, initial stakeholders were identified as follows:

- Fort Chipewyan;

- Fort McKay;
- Regional Municipality of Wood Buffalo (RMWB);
- Oil Sands Environmental Coalition (OSEC);
- Fort McMurray Naturalist Society; and
- Fish and Game Association.

1.2.4 Study Area

The 1997 RAMP study area was similar to study areas used for the EIAs submitted at that time (e.g., Suncor's Project Millennium and Shell's Muskeg River Mine); however, RAMP extended the study area farther downstream to include the Athabasca delta. It encompassed a reach of the Athabasca River, from upstream of Fort McMurray to the Athabasca River delta, including the watersheds of the Muskeg, Steepbank, MacKay and Firebag rivers (Figure 1.2).

1.2.5 Study Design

The study design during the first year of RAMP stemmed from the initial proposal developed by Golder in 1997 (Golder 1997a) as well as from initial meetings between Suncor, Syncrude, Shell and Golder. The initial design stressed establishing baseline conditions and temporal trends in the Oil Sands Region. In addition to traditional, chemistry-based monitoring, sensitive biological indicators were chosen to allow for early detection of potential effects related to oil sands developments. To provide supporting data for the biological surveys, including benthic invertebrates, fish and aquatic plants (in wetlands), RAMP also monitored water and sediment chemistry.

In addition to monitoring surveys, RAMP reviewed data from previous studies in the study area to provide a basis for future comparisons. These studies included the baseline studies conducted in 1995 and 1996 for the Steepbank and Aurora mines (Golder 1996a).

The 1997 RAMP study design is summarized below and described in further detail in the individual component sections.

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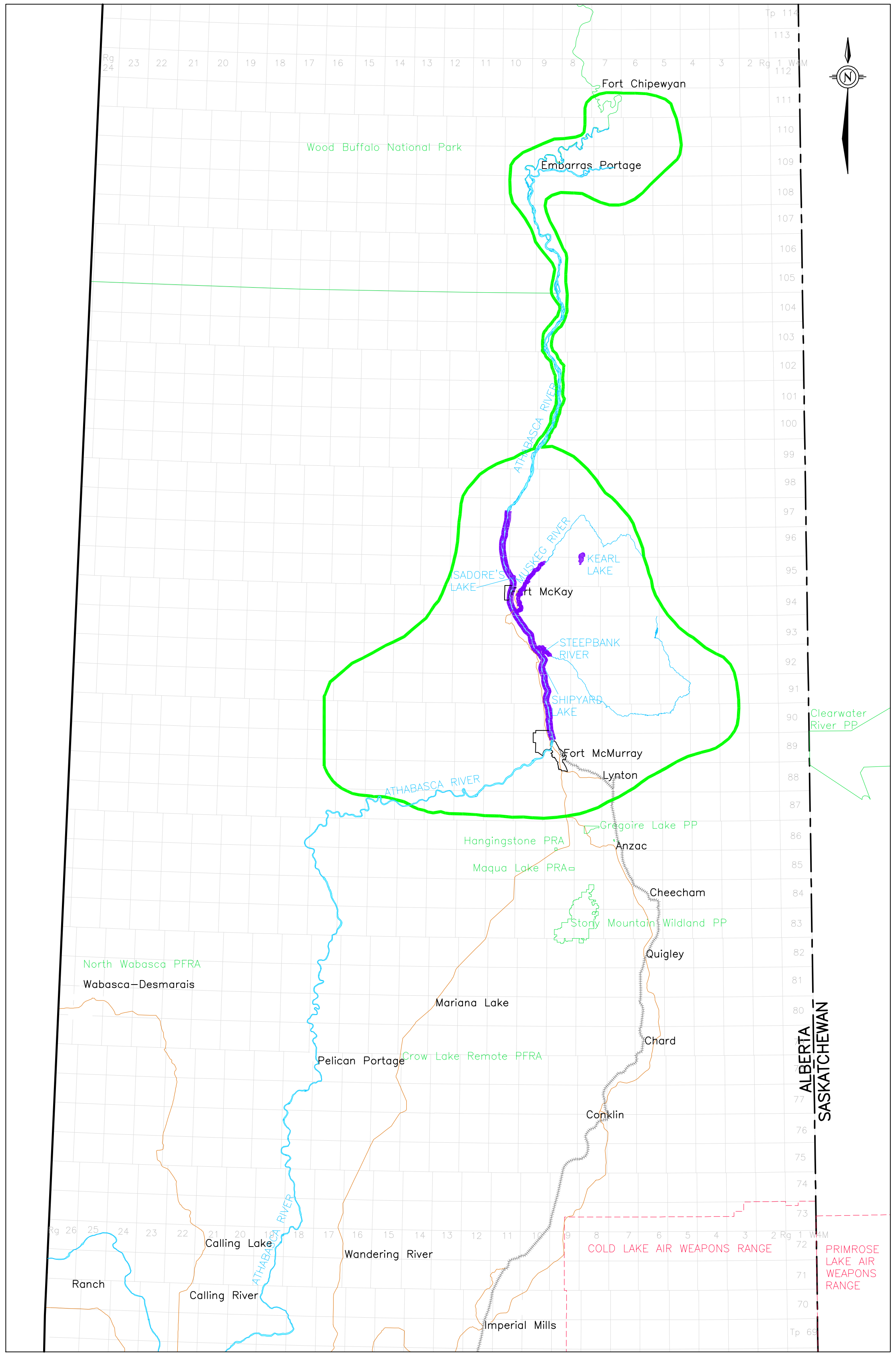
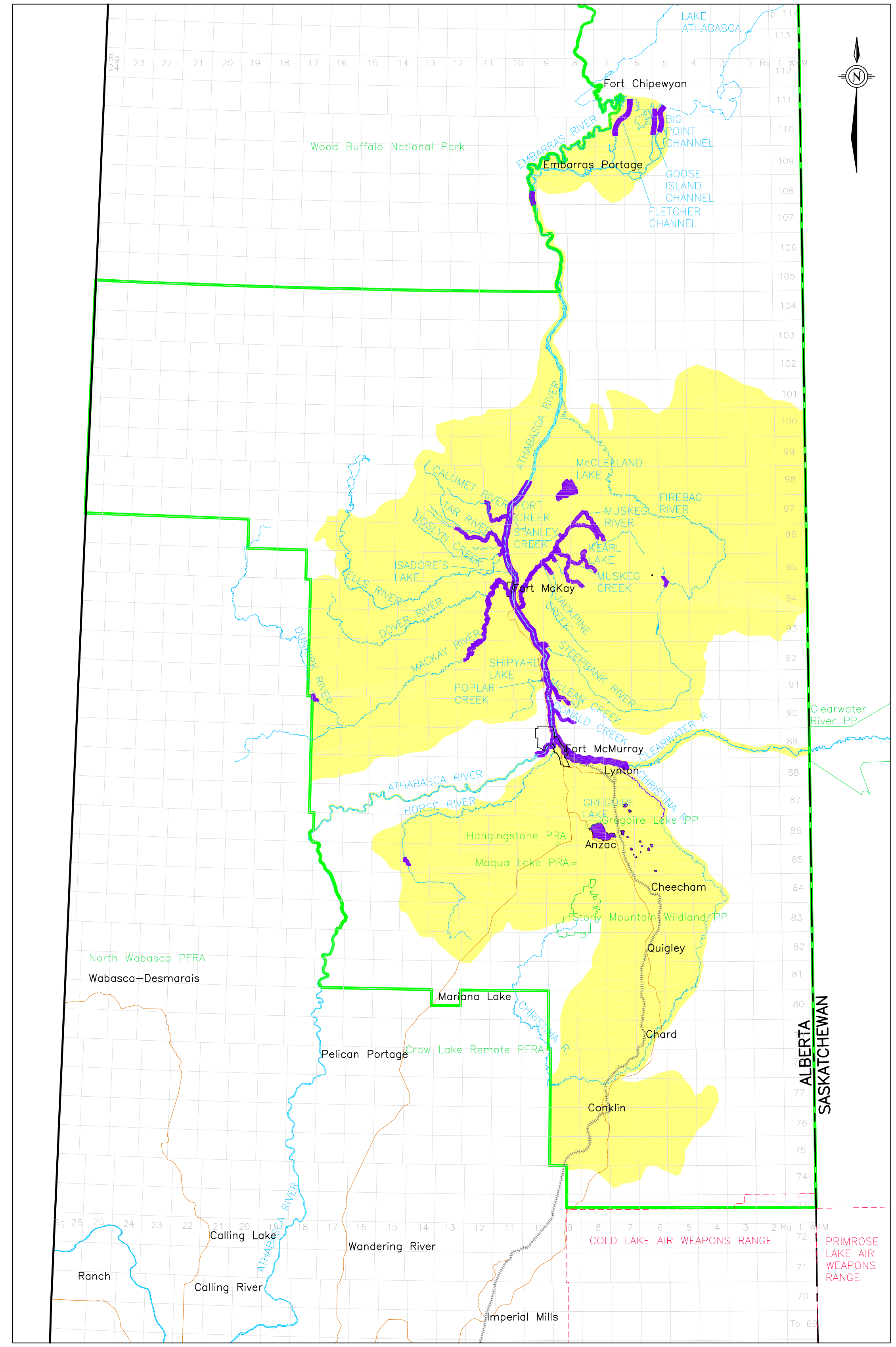


RAMP STUDY AREA 1997



RAMP STUDY AREA 2001

LEGEND

- RAMP REGIONAL STUDY AREA
- RAMP FOCUS STUDY AREA
- WATERBODIES MONITORED
- RIVERS AND STREAMS
- ROADS

REFERENCE

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SCALE KILOMETRES

PROJECT

RAMP FIVE YEAR REPORT

TITLE

RAMP STUDY AREAS IN 1997 AND 2001

Golder Associates
Calgary, Alberta

PROJECT No. 022-2301.5400			FILE No.	ramp study areas
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CADD	AS	11/12/02		
CHECK	TD	03/01/03		
REVIEW				

FIGURE: 1.2

1.2.5.1 Water and Sediment Quality

In 1997, RAMP monitored water quality in the Athabasca, Steepbank and Muskeg rivers during spring, summer and fall surveys. The goals were as follows:

- to expand the available baseline data for dissolved metals and trace organic compounds;
- to determine seasonal variation in water quality; and
- to determine spatial variation in water quality in the oil sands area on a regional scale.

During the fall of 1997, RAMP monitored sediment quality in the Athabasca, Muskeg, Steepbank and MacKay rivers and Poplar and Jackpine creeks for the following reasons:

- to provide baseline data on natural variability in concentrations of metals and trace organic compounds in sediments in the oil sands area; and
- to compare sediment quality the Athabasca River above and below the oil sands area.

The rationale for the water and sediment quality program was as follows:

- to provide regulatory requirements;
- to measure suitability of a waterbody to support aquatic life;
- to determine potential chemical inputs from point and non-point sources;
- to compare measured chemical concentrations with guidelines and objectives designed to protect aquatic life; and
- to provide supporting data for biological surveys.

1.2.5.2 Benthic Invertebrate Community

In 1997, RAMP conducted an initial benthic invertebrate survey in the Athabasca River with a plan to sample every two years. The goals of the benthic invertebrate program were:

- to select regional monitoring sites in the Athabasca, Steepbank and Muskeg rivers;

- to conduct an initial survey of the Athabasca River, comparing benthic communities above and below the oil sands area; and
- to build on the available baseline information to allow proper design of subsequent surveys.

The rationale for the benthic invertebrate monitoring program was as follows:

- to form an essential component of the aquatic monitoring program;
- to provide a regulatory requirement for industries that discharge water to rivers and lakes; and
- to complement fisheries, water and sediment quality surveys by indicating availability of invertebrate food for fish and environmental quality of a waterbody.

1.2.5.3 Fish Populations

In 1997, RAMP monitored fish populations in four reaches (or areas) of the Athabasca River (i.e., Poplar, Steepbank, Muskeg and Tar-Ells areas). The purpose of this monitoring was as follows:

- to examine year-to-year variability in fish population indicators (e.g., length-at-age, size distribution) and species composition;
- to document fish habitat associations by species and life stage to allow consideration of the effects of natural variation in habitat availability, when examining potential changes in fish populations;
- to identify and evaluate potential reference areas for fish population monitoring;
- to conduct a radiotelemetry study of two species in the Athabasca River in order to address data gaps regarding fish spawning and overwintering areas and residence time in the Oil Sands Region; and
- to build on available baseline information to allow appropriate design of subsequent monitoring.

Monitoring fish populations is an integral part of RAMP because fish are key components of aquatic food webs and an important recreational and subsistence resource for the public.

1.2.5.4 Wetlands Vegetation

In 1997, RAMP surveyed aquatic vegetation at four wetlands in the study area to provide a description of wetlands types and vegetation health as a baseline for future monitoring. Those monitored in 1997 included Kearl, Shipyard and Isadore's lakes (location shown on Figure 1.2) and Lease 25 wetlands (reference area).

Wetlands vegetation was selected as a RAMP component because changes in the abundance and distribution of aquatic plants in wetlands may:

- indicate changes in water level, circulation patterns and clarity caused by oil sands developments or water releases; and
- influence the use of wetlands by invertebrates, fish, waterfowl and wildlife.

1.2.5.5 1997 Recommendations

As a result of the 1997 program, the following recommendations were noted for future monitoring by RAMP:

- to expand the sediment program to sample chemistry and toxicity of sediments in benthic invertebrate sampling areas;
- to conduct field surveys to determine the feasibility of fisheries reference sites identified in 1997;
- a need for a more uniform and consistent sampling program within RAMP; and
- to conduct winter radiotelemetry tracking flights to determine overwintering of fish in Athabasca River.

1.3 RAMP IN 1998

In 1998, RAMP established an organizational structure, mandate, defined objectives and Terms of Reference. With this focused direction and the fundamentals of RAMP in place, the importance of program flexibility was recognized. The 1998 annual report (Golder 1999) incorporated the new mandate, objectives and Terms of Reference, and was submitted to the members of RAMP.

1.3.1 Program Objectives

The three 1997 Program Objectives were modified and increased to seven in the draft Terms of Reference completed in 1998. The objective to design and execute a program that addressed the anticipated aquatic monitoring requirements of oil sands operators' environmental approvals was modified to be more specific. The 1998 program also included the following additional objectives:

- to collect baseline and historical data to characterize variability in the oil sands area;
- to recognize and incorporate traditional knowledge into the monitoring and assessment activities;
- to communicate monitoring and assessment activities and results to communities in the RMWB, regulatory agencies and other interested parties; and
- to review and adjust the program to reflect monitoring results, technological advances and community concerns.

1.3.2 Membership and Development

Applications for two in-situ projects and one open-pit mine were submitted in 1998 (i.e., EnCana Christina Lake, Petro-Canada MacKay River Project and Suncor Project Millennium) (Table 1.2). Syncrude submitted its Application for the Mildred Lake Upgrader Expansion Project. However, Mobil Oil Canada Properties (Mobil) was the only additional funding member that joined RAMP. Also in this year, AEP (now Alberta Environment or AENV) assigned Syncrude similar conditions to Suncor's Steepbank Mine in their EPEA approval for the Aurora North Mine. Regulators and traditional landowners who participated in RAMP as non-funding members are shown in Figure 1.3 and are as follows:

- Environment Canada;
- AENV;
- Fort McKay Industry Relations Corporation (representing Fort McKay First Nations and Fort McKay Métis Local); and
- Athabasca Chipewyan First Nation.

Table 1.2 Oil Sands Developments in 1998

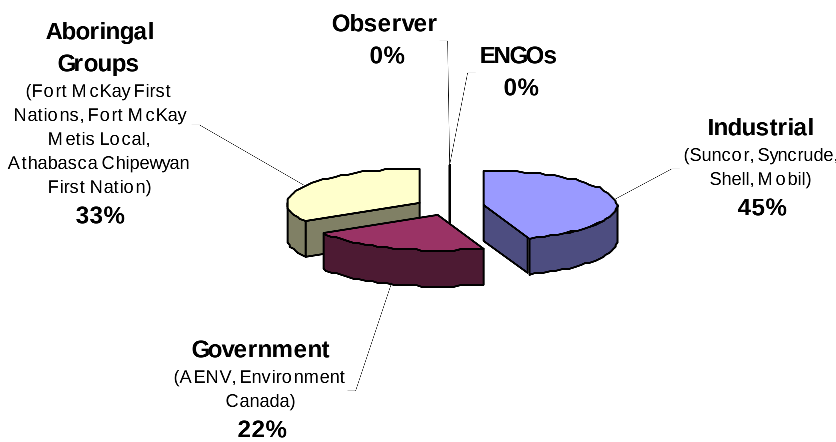
Oil Sands Development	Date of Application	Capacity (bpd)[a]	Development Area (ha)[b]	Type of Operation	Existing Disturbance in 1998
Suncor Energy Inc.					
Fixed Plant Expansion, Lease 86/17, Steepbank and Millennium Mines	1996, 1964, 1996, 1998	450,000 S	18,298	processing/ open-pit	✔ (except Millennium)
Syncrude Canada Ltd.					
Mildred Lake Upgrader/Expansion/North Mine	1973, 1998, 1995	480,000 S/ 160,000 B	21,100	processing/ open-pit	✔
Aurora North	1996	200,000 B	7,700	open-pit	✔
Aurora South	1996	200,000 B	7,300	open-pit	✔
Shell Canada Limited					
Muskeg River Mine	1997	155,000 B	4,343	open-pit	
Conoco (formerly Gulf)					
Surmont Pilot	1996	2,000	7	in-situ	✔
Northstar Energy Dover					
Old UTF	1987	2,000 B	22	in-situ	✔
EnCana					
Christina Lake	1998	85,000 B	527	in-situ	
JACOS					
Hangingstone Pilot	1997	10,000 B	420	in-situ	✔
Petro-Canada Oil and Gas					
MacKay River	1998	30,000 B	170	in-situ	

Note: nyd = Not yet determined.

(a) Barrels per day (bpd) of B = bitumen; S = synthetic crude or pipelineable crude; bpd values are rounded off.

(b) Development areas are those that will result from the existing approved and planned operations. Areas represent the maximum disturbance footprint for terrestrial resources.

Figure 1.3 Membership Distribution in 1998



In addition to oil sands developments, other development in 1998 included urban growth in Fort McMurray and development of the Aggregates Management Inc. Susan Lake Gravel Pit. Dewatering and subsequent discharge of water occurred from this gravel pit.

1.3.3 Organizational Structure

During 1998, the organizational structure of RAMP continued to develop. RAMP was composed of a Steering Committee with a Chairperson and Program Manager, a Program Review Committee, a Science Advisory Committee (proposed), a Secretariat and Investigators. Finance and Technical Subcommittees were also formed. A Terms of Reference Subcommittee was created, but disbanded upon completing its objectives in this year.

1.3.3.1 Steering Committee

The 1998 Steering Committee, was the decision-making body for RAMP and established Committees or Subcommittees, as required. Steering Committee members included representatives from industry, regulators and stakeholders who provided resources, such as in-kind contributions, technical advice or funding. The mandate of the 1998 Steering Committee was as follows:

- to prioritize monitoring (data collection) projects within the program objectives to optimize the use of available resources and to address regional aquatic environmental issues;
- to ensure that traditional knowledge is incorporated into monitoring program planning;
- to review the results of projects for relevance to Program Objectives;
- to communicate results and solicit input on regional aquatic issues from interested parties;
- to review the progress of projects against RAMP objectives, budgets and schedules; and
- to decide on the acceptability of membership.

1.3.3.2 Program Review Committee

The Program Review Committee consisted of Steering Committee representatives and other parties with industry, traditional, recreational or regulatory interest in the study area. The objectives of the Program Review Committee were to evaluate the program for technical merit and for relevance to the needs of the members as well as to facilitate communication and linkage with other regional environmental initiatives.

1.3.3.3 Science Advisory Committee

Academics, regulators and consultants that were well regarded in aquatic research made up the membership in the Science Advisory Committee. This Committee evaluated and reviewed project proposals and results for scientific validity and program relevance against RAMP's Program Objectives.

1.3.3.4 Finance Subcommittee

The annual budget and funding formula was developed in 1998 by the Finance Subcommittee, which consisted of all funding participants and other interested members of the Steering Committee. The annual budget and funding formula required approval from the Steering Committee. Prior to the establishment of a funding formula in 1998, the cost of the RAMP program was divided equally between Suncor, Syncrude and Shell and took into account their in-kind contributions.

1.3.3.5 Technical Subcommittee

The 1998 Technical Subcommittee was comprised of RAMP members with scientific expertise in the monitoring of aquatic environments or traditional knowledge of the regional aquatic environment. Any other interested stakeholder or member of the Steering Committee could also participate in the technical subcommittee. This subcommittee was accountable for the development and review of the RAMP technical program. This subcommittee's function was to do the following:

- to prepare an annual monitoring program for review and approval by the Steering Committee;
- to evaluate the program for technical merit and for relevance to the needs of the members;
- to coordinate the technical review of the RAMP program; and
- to facilitate communication and linkage with other regional environmental initiatives.

1.3.3.6 Secretariat

It was the Secretariat's duty to attend all meetings of the Steering Committee and to ensure that accurate minutes of those meetings were maintained. RAMP's

Secretariat was also accountable for keeping records of all RAMP members of and their addresses and distributing notices of the various meetings among members.

1.3.3.7 Investigators

Investigators consisted of consultants, Aboriginal community representatives, AENV and Al-Pac. Investigators were responsible for proposing and conducting projects within RAMP's Terms of Reference. Consultants such as Golder Associates Ltd. were primarily responsible for carrying out the field work and analysis as defined in the annual monitoring program that had been established by the committees mentioned previously.

1.3.4 Study Area

In 1998, the RAMP study area was the same as the 1997 study area. In addition to continuing with the monitoring plan initiated in 1997, the 1998 program evaluated potential reference areas, including: the Athabasca River, about 200 km upstream of the oil sands developments (in the vicinity of Duncan Creek); the lower reaches of the Ells, Tar and MacKay rivers; and the Spruce Pond wetlands.

1.3.5 Study Design

The development of a core monitoring program for RAMP was initiated in 1998 by the RAMP Steering Committee. The objectives of the core monitoring program were as follows:

- to outline the main components of the program for each waterbody to provide consistency to the monitoring;
- to define sampling locations and frequencies; and
- to allow for modifications of sampling as issues arise.

The 1998 RAMP study design is outlined in the following sections.

1.3.5.1 Water and Sediment Quality

The water and sediment quality program was expanded in 1998 to sample both the east and west sides of the Athabasca River sites, including a new site upstream of the Muskeg River. Water toxicity testing in the tributaries was initiated to determine if baseline toxicity conditions existed. Monitoring began at new water quality sites in the tributaries to the Athabasca River including the upper Muskeg River, Ells, Tar and MacKay rivers, and Wapasu and Muskeg creeks. New sediment quality monitoring sites at the mouths of the Ells and Tar rivers were also initiated.

1.3.5.2 Benthic Invertebrate Community

The benthic invertebrate community in the Athabasca River was not sampled in 1998; however, this year marked the first year of a long-term tributary benthic invertebrate monitoring program. Three sampling sites were established in the lower 1 km of the Muskeg and Steepbank rivers. Two reference tributaries (Tar and Ells rivers) were dropped in 1998 due to low flow discharge levels and replaced with three sampling sites within the lower 1 km of the MacKay River.

1.3.5.3 Fish Populations and Habitat

In 1998, RAMP continued to build on the available baseline information of Athabasca River fish populations and fish habitat. In 1998, RAMP conducted the following additional monitoring:

- potential reference areas for fish population monitoring were evaluated;
- sentinel species monitoring in the Athabasca River was initiated;
- Athabasca River fish tissue was collected for analyses of polycyclic aromatic hydrocarbons (PAHs), mercury and other trace metals;
- the radiotelemetry study initiated in 1997 was completed; and
- the occurrence and movement of fish species in and out of the Muskeg and Steepbank rivers and reference tributaries were documented.

1.3.5.4 Wetlands Vegetation

The 1998 program abandoned the Lease 25 wetlands as a potential reference wetlands due to its close proximity to prospective oil sands developments. In 1998, Spruce Pond wetlands was evaluated as a potential reference wetlands for RAMP. Water quality was added to the wetlands monitoring program in 1998 and included the following:

- summer sampling for RAMP standard parameters and Microtox® toxicity analysis at Kearl, Shipyard and Isadore’s lakes; and
- winter dissolved oxygen (DO) profiles at Kearl Lake.

1.4 RAMP IN 1999

In 1999, RAMP witnessed a large influx of members and further identified and defined its organizational structure of committee and subcommittees. Also in 1999, the first RAMP Newsletter was issued and two community meetings (i.e., one in Fort Chipewyan and one in Fort McKay) were held to help RAMP achieve its objective to communicate information to the communities. The results of the 1999 monitoring program were included in the annual report (Golder 2000a).

1.4.1 Program Objectives

As in the two previous years, RAMP modified its Program Objectives to further meet the needs of the members. The refined wording of the Program Objectives was as follows:

- to monitor aquatic environments in the oil sands area to detect and assess cumulative effects and regional trends;
- to collect baseline and historical data to characterize variability in the oil sands area;
- to collect data to verify predictions contained in EIAs;
- to collect data that satisfies the monitoring required by regulatory approvals of oil sands developments;
- to recognize and incorporate traditional knowledge into the monitoring and assessment activities;
- to communicate monitoring activities, results and recommendations to communities in the RMWB, regulatory agencies, environmental committees/organizations and other interested parties; and
- to review and adjust the program to reflect monitoring results, technological advances and community concerns.

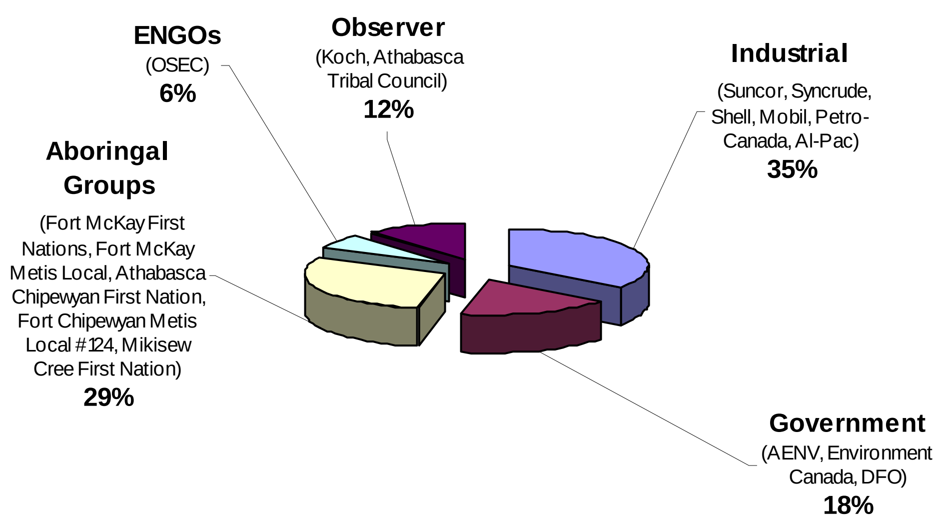
1.4.2 Membership and Development

No new applications for oil sands approvals were submitted to AENV or the Alberta Energy and Utilities Board (EUB) in 1999; however, Petro-Canada Oil and Gas (Petro-Canada) joined RAMP as a funding member (Figure 1.4). Interest in the program from regulators, traditional landowners and potential developers was growing. This was reflected in the following increase of memberships in the non-funding category:

- Department of Fisheries and Oceans (DFO);
- Athabasca Tribal Council (observer);
- Fort Chipewyan Metis Local #124;
- Koch Canada Ltd (observer);
- Mikisew Cree First Nation; and
- OSEC.

As effects to aquatic environments in the Oil Sands Region are not limited to oil sands operations, Al-Pac, the first non-oil sands related industry, joined RAMP and contributed to the program with in-kind support.

Figure 1.4 Membership Distribution in 1999



In addition to oil sands developments, other developments in 1999 included urban growth in Fort McMurray, with 566 new home starts (RMWB 2000) and Al-Pac forestry activities in the watersheds of Poplar and Parsons creeks and the upper Steepbank River (Al-Pac 1999).

1.4.3 Organizational Structure

RAMP's Terms of Reference Subcommittee met their objective by finalizing the Terms of Reference and the subcommittee was then disbanded.

Representatives from industry, communities and regulators as well as the RAMP Secretariat were participants in the Communication Subcommittee, which was initiated in 1999. The objective of the Communication Subcommittee was to develop and complete an annual review of the communication plan. A draft plan to implement communication strategies was developed in this year.

In 1999, RAMP also launched a Logo Subcommittee for a one-year term. Membership included representatives from industry, communities and government.

The Science Advisory Committee was dissolved as the Program Review Committee and the Technical Subcommittee absorbed its accountabilities.

1.4.4 Study Area

In addition to the 1998 focus, monitoring in 1999 was expanded to include areas potentially affected by development activities such as the Athabasca River delta, tributaries to the Muskeg River (i.e., Jackpine, Muskeg and Stanley creeks) and McLean Creek. RAMP also expanded its study area to include acid sensitive lakes in areas that could be affected by acidifying air emissions as well as control lakes outside the depositional area.

1.4.5 Study Design

In 1999, RAMP consisted of the following three main components:

- water and sediment quality in rivers and wetlands;
- fish populations in rivers; and
- water quality in acid sensitive lakes.

This year, RAMP also made significant progress in designing the core monitoring program. The 1999 RAMP study design is outlined in the following sections.

1.4.5.1 Water and Sediment Quality

During 1999, RAMP increased the number of sampling sites for water and sediment quality. It also developed a Quality Assurance/Quality Control (QA/QC) sampling program for water and sediment in partnership with AENV. The QA/QC program focused on field programs in the Muskeg River and Shipyard Lake.

The scope of the water and sediment quality programs was also expanded to include the following:

- additional seasonal water sampling and toxicity testing in the Muskeg River and its tributaries;
- monitoring of seasonal water temperatures for Muskeg River, McLean Creek and the Alsands Drain;
- water and sediment sampling far downstream of oil sands developments and at the mouth of McLean Creek; and
- development of a sediment monitoring plan for the Athabasca, Muskeg and Steepbank rivers.

1.4.5.2 Water Quality in Acid Sensitive Lakes

In 1999, lakes representative of the wide range of water chemistry in northeastern Alberta were selected for a long-term acidification monitoring network under RAMP. This new RAMP component was designed as a partnership between RAMP, Al-Pac and AENV to monitor lake chemistry as an early warning indicator of excessive acidic deposition. During the 1999 field program, 32 lakes were sampled.

1.4.5.3 Benthic Invertebrate Community

RAMP intended to collect benthic invertebrates in McLean Creek; however, low flows in the fall prevented the sampling program from occurring in 1999. Instead, the RAMP Technical Subcommittee developed a benthic invertebrate study design for the Athabasca River and tributaries based on data from RAMP's 1997 and 1998 benthic surveys, previous surveys in the area, a literature review and consultation with scientific experts.

1.4.5.4 Fish Populations

On June 16, 1999, the Technical Subcommittee decided to initiate fisheries monitoring on the Muskeg and Steepbank rivers in addition to continuing studies of the mainstem Athabasca River. In these areas, monitoring small-bodied sentinel fish species was recommended by the RAMP Technical Subcommittee to assess potential effects of stressors (e.g., industrial development) on fish populations.

In addition to sentinel species monitoring, the yearly evaluation of occurrence and abundance of dominant fish species in the Athabasca River was continued during the spring of 1999. The program was reduced in scope due to budget restraints.

1.4.5.5 Non-Core Programs

In 1999, RAMP also completed the following non-core programs:

- assessing mussels as a potential monitoring tool; and
- addressing community concerns about external abnormalities (e.g., tumours) in fish.

1.5 RAMP IN 2000

With OPTI Canada Inc.'s (OPTI) participation in RAMP, a larger study area was introduced to include the Long Lake Project and associated waterbodies that could be affected south of Fort McMurray. As in 1999, the year 2000 also saw a RAMP newsletter and an annual report (Golder 2001a,b), which presented the year's findings. To communicate a concise summary of the key results to the communities in the Oil Sands Region, a 2000 summary report (Golder 2002a) was also published for distribution to the communities in the RMWB.

1.5.1 Program Objectives

No changes were made to RAMP's objectives in 2000.

1.5.2 Membership and Development

In 2000, AENV and EUB received four in-situ development applications seeking approval (Table 1.3). Subsequently, Fort McMurray and Chipewyan Prairie First

Nations and the following four new oil sands developers joined RAMP's membership (Figure 1.5):

- Northstar Energy Dover (Northstar);
- Rio Alto Exploration Ltd. (Rio Alto);
- OPTI; and
- TrueNorth Energy (TrueNorth).

Table 1.3 Oil Sands Developments in 2000

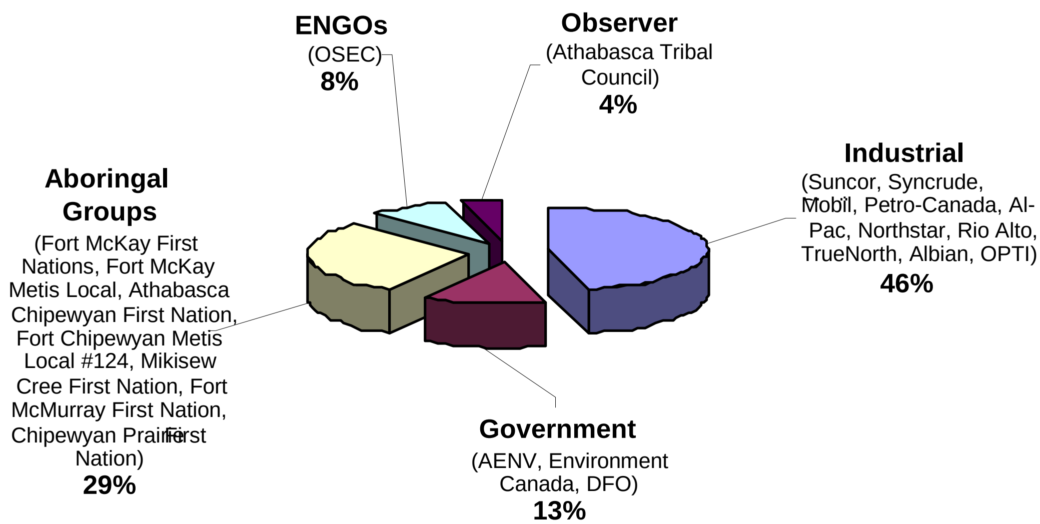
Oil Sands Development	Date of Application	Capacity (bpd)[a]	Development Area (ha)[b]	Type of Operation	Existing Disturbance in 2000
Suncor Energy Inc.					
Fixed Plant Expansion, Lease 86/17, Steepbank and Millennium Mines	1996, 1964, 1996, 1998	450,000 S	18,298	processing/ open-pit	✔ (except Millennium
Firebag Project	2000	140,000 B	1,105	in-situ	
Firebag Pilot Project	2000	1,200 B	369	in-situ	
Syncrude Canada Ltd.					
Mildred Lake Upgrader/Expansion, North Mine	1973, 1998, 1995	480,000 S/ 160,000 B	21,100	processing/ open-pit	✔
Aurora North	1996	200,000 B	7,700	open-pit	✔
Aurora South	1996	200,000 B	7,300	open-pit	
Shell Canada Limited					
Muskeg River Mine	1997	155,000 B	4,343	open-pit	✔
Conoco (formerly Gulf)					
Surmont Pilot	1996	2,000	7	in-situ	✔
Northstar Energy Dover					
Old UTF	1987	2,000 B	22	in-situ	✔
EnCana					
Christina Lake	1998	85,000 B	527	in-situ	✔
JACOS					
Hangingstone Pilot	1997	unknown	420	in-situ	✔
Petro-Canada Oil and Gas					
MacKay River	1998	30,000 B	170	in-situ	
OPTI					
Long Lake Project	2000	70,000 S 70,000 B	884	in-situ	
Rio Alto					
Kirby Pilot	2000	1,600 B	3	in-situ	✔

nyd = Not yet determined.

(a) Barrels per day (bpd) of B = Bitumen; S = Synthetic Crude or pipelineable crude; bpd values are rounded off.

(b) Development areas are those that will result from the existing approved and planned operations. Areas represent the maximum disturbance footprint for terrestrial resources.

Figure 1.5 Membership Distribution in 2000



In addition to the new oil sands development in 2000, other development included urban growth in Fort McMurray and forestry by Al-Pac in the Athabasca River watershed upstream of Fort McMurray, in the watersheds of the Pierre River and Asphalt Creek, and in the Muskeg River watershed as part of the Albian Sands Energy Inc. (Albian) Industrial Harvest Plan (Al-Pac 1999).

1.5.3 Organizational Structure

By 2000, RAMP had defined its organizational structure. RAMP was made up of one primary committee, the Steering Committee and a number of subcommittees. The Steering Committee is the decision-making body for RAMP and consists of funding and non-funding members. Membership typically consisted of industry, regulators and community representatives. The Steering Committee has two officers, a Chairperson and Vice-chairperson. Any member of the Steering Committee is eligible for these positions. The Chairperson is elected for a minimum of two years. The Chairperson is a member of all Committees and Subcommittees. The Chairperson, when present, presides at all meetings of the Steering Committee. The Vice-chairperson, is elected for a minimum of two years. The Vice-chairperson, in the absence or disability of the Chairperson, performs the duties and exercises the powers of the Chairperson.

The Steering Committee appoints a Secretary who provides a coordination and logistical function. The Secretary is appointed annually. The duties of the Secretary are to attend all meetings of the Steering Committee and to ensure that accurate minutes of these meetings, and other records, are kept.

The Program Manager coordinates and attends the Steering Committee and Technical Finance subcommittee meetings and provides support to the Chairpersons of those committees. The Program Manager acts as the Secretariat to the Technical Subcommittee. The Program Manager is also responsible for managing the overall RAMP program.

Since 2000, the organizational structure has remained relatively unchanged, except for the disbanding of the Program Review Committee. The Program Review Committee was incorporated into the Technical Subcommittee. That committee divided the RAMP program into specialties and then required the specialty areas to involve external experts in review and development of their area of the overall program. The result of this decision was that the Program Review Committee was in-effect disbursed among the Technical Subcommittee's Subgroups (i.e., Water, Benthics, Sediments, Acid Sensitive Lakes, Hydrology/Climate, Vegetation and Fish). Investigators primarily carry out the field work, analysis and reporting, as defined by the program. Therefore, the 2000 organizational structure included the following:

- Steering Committee (industry, regulators, stakeholders and Secretariat);
- Finance Subcommittee (all funding participants and any interested Steering Committee Members);
- Technical Subcommittee (representatives from industry, communities, government and investigators);
- Communications Subcommittee (representatives from industry, communities and regulators); and
- Investigators (consultants, Aboriginal community representatives, AENV and Al-Pac).

1.5.4 Study Area

In 2000, RAMP adopted a regional study area boundary to correspond with that of Cumulative Environmental Management Association (CEMA). The new study area followed the RMWB periphery. The 2000 focus study area expanded to include rivers and lakes located south of Fort McMurray. This was due to increasing oil sands activities in the OPTI Long Lake Project local study area near Anzac, Alberta.

1.5.5 Study Design

This year, the RAMP Technical Subcommittee finalized the core monitoring program in the form of a living document, the RAMP Program Design and Rationale, Version I (Golder 2000b).

The 2000 RAMP study design is outlined in the following sections.

1.5.5.1 Climatic and Hydrologic Monitoring

A climatic and hydrologic monitoring program in the Muskeg River basin and surrounding areas was integrated into RAMP in 2000. The objectives of this program were as follows:

- to undertake baseline hydrologic monitoring for the TrueNorth Fort Hills Project;
- to undertake climatic and hydrologic monitoring required by AENV in the regulatory approvals for the Syncrude Aurora and Shell Muskeg River Mine projects;
- to undertake climatic and hydrologic monitoring recommended in the EIAs for the Syncrude Aurora and Shell Muskeg River Mine projects; and
- to expand the climatic and hydrologic database required for operational and reclamation water management planning and design of the existing and future oil sands developments in the region by Syncrude, Albian, Mobil, Suncor, TrueNorth and Petro-Canada.

Climatic and hydrologic monitoring in the Muskeg River basin was the focus of the 2000 program; however, it also included hydrologic monitoring for Mills, Fort and Poplar creeks, and McClelland and Isadore's lakes, all of which are located outside the Muskeg River basin. The 2000 program design was based on the following:

- current regulatory monitoring requirements;
- long-term need for expanding the regional climatic and hydrologic database; and
- thorough understanding of the historic database developed to date.

Monitoring was conducted at sites such as the Aurora Climate Station, McClelland Lake outlet, Alsands Drain, Muskeg River Aurora, Muskeg River, Poplar, Fort, Jackpine, Mills and Stanley creeks, Albian Pond #3, and Kearl and Isadore's lakes.

1.5.5.2 Water and Sediment Quality

In 2000, RAMP continued to monitor the same set of water quality parameters analyzed in 1999. Additional water quality monitoring sites added to the 2000 program included the following:

- Poplar, Fort and Unnamed creeks and the MacKay River; and
- three cross-channel sample points in the Athabasca River upstream of Donald Creek, the Steepbank River, Muskeg River and Fort Creek.

The sediment quality monitoring program was expanded to include the following:

- Jackpine, Fort and Muskeg creeks;
- five additional sites in the Muskeg River; and
- the Athabasca River along east and west banks upstream of Donald Creek, the Steepbank River, Muskeg River and Fort Creek, as well as cross-channel composite upstream of the Embarras River.

1.5.5.3 Acid Sensitive Lakes

During this second year of acid sensitive lakes monitoring, lakes monitored, sampling and analytical methods were similar to the program in 1999 with the following few exceptions:

- the addition of one new lake;
- the replacement of two lakes showing low acid sensitivity with more sensitive lakes;
- the addition of Gran alkalinity to the parameter list to obtain a more reliable indication of acid neutralizing capacity (ANC); and
- the omission of three lakes due to weather-related and logistical difficulties in the field.

1.5.5.4 Benthic Invertebrate Community

The RAMP benthic invertebrate component in 2000 included sampling of selected tributaries (MacKay, Muskeg and Steepbank rivers) and Shipyard Lake.

Also in 2000, the Benthic Invertebrate Technical Subgroup undertook a review of all existing benthic invertebrate data in the RAMP study area to strengthen the baseline database for the region.

1.5.5.5 Fish Populations

In 2000, RAMP monitored fish populations in the Oil Sands Region to investigate the following:

- potential changes in spawning habitat quality, quantity and utilization in the Muskeg River system over time;
- additional reference sites for sentinel species (slimy sculpin) monitoring on the Muskeg and Steepbank rivers; and
- mobility and overwintering habitat for longnose sucker in the Athabasca River, and northern pike and Arctic grayling in the Muskeg River system and the Athabasca River.

1.5.5.6 Wetlands Vegetation

Air photo interpretation was conducted this year for RAMP as per the core monitoring program developed in 1999. In 2000, air photos were only available for Shipyard Lake. These were mapped and compared to previous years' air photos. Wetlands water quality was monitored in 2000.

1.6 RAMP IN 2001

In 2001, the Fish Tag Return and Fish Abnormalities programs and the River Response Network were implemented. These programs, along with the publishing of two newsletters in 2001, assisted RAMP in achieving its mandate and objective of communicating and incorporating traditional knowledge.

During this year, RAMP had expanded many of its programs such as climate monitoring, snow surveys, stream flow monitoring and included an additional 14 waterbodies south of Fort McMurray. A second annual summary (Golder 2002b) as well as a two volume report (Golder 2002c,d) provided the results of the 2001 program.

1.6.1 Program Objectives

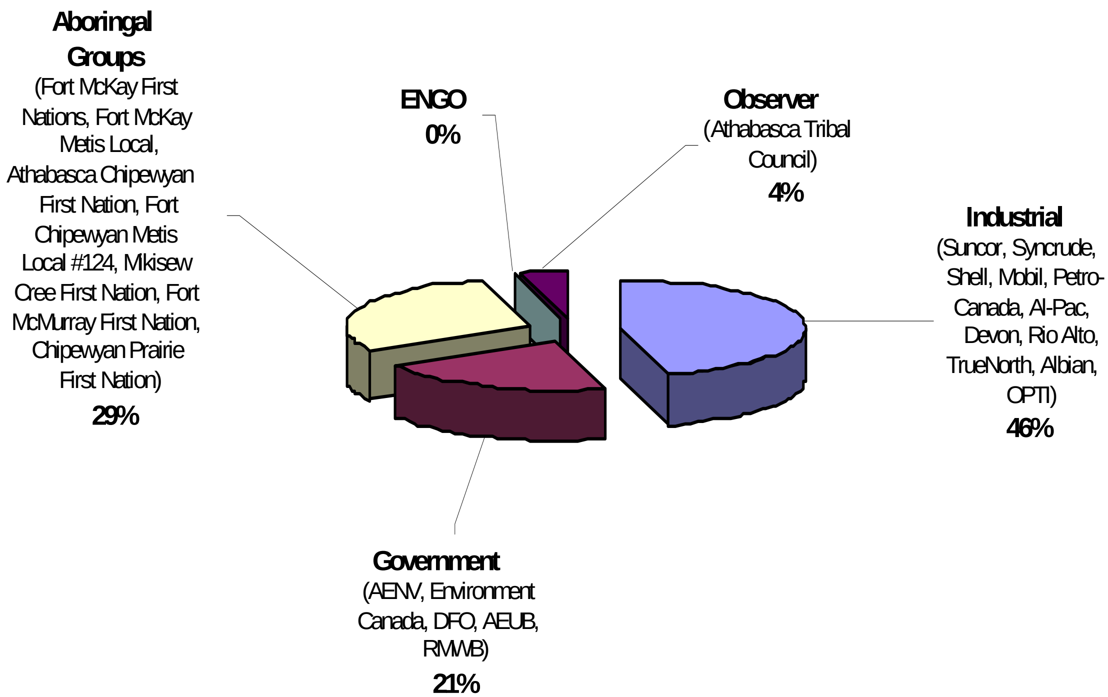
Revisions to the Program Objectives in 2001 focused on "scientifically defensible" data collection, incorporating flexibility and technological advances into monitoring activities and to work with other relevant, current and historical research and monitoring programs. This evolution of RAMP has resulted in the current Program Objectives as follows:

- to monitor aquatic environments in the oil sands area to detect and assess cumulative effects and regional trends;
- to collect scientifically defensible baseline and historical data to characterize variability in the oil sands area;
- to collect data against which predictions contained in EIAs can be verified;
- to collect data that may be used to satisfy the monitoring required by regulatory approvals of developments in the oil sands area;
- to recognize and incorporate traditional knowledge (including Traditional Ecological Knowledge and Traditional Land Use studies) into the monitoring and assessment activities;
- to communicate monitoring and assessment activities, results and recommendations to communities in the RMWB, regulatory agencies, environmental committees/organizations and other interested parties;
- to design and conduct various RAMP activities such that they have the flexibility to be adjusted, on review, to reflect monitoring results, technological advances and community concerns; and
- to seek cooperation with other relevant research and monitoring programs where practical, and generate interpretable results which can build on their findings and on those of historical programs.

1.6.2 Membership and Development

In 2001, representatives from the EUB and RMWB joined RAMP (Figure 1.6). By this time, 14 projects had received approval for their project applications. Petro-Canada had submitted Applications for Approval for their Meadow Creek project. TrueNorth and Conoco Canada Resources Limited (Conoco) also sought approval for their in-situ projects. At this time, however, Conoco (formerly Gulf Canada) has not participated in RAMP. The oil sands developments for 2001 are shown in the next section.

Figure 1.6 Membership Distribution in 2001



Development activities in 2001 also included ice bridge and gravel development along the Athabasca River, as well as changes in urban water use. An ice bridge was installed near Peden's Point, to assist in gravel extraction at the Peden's Point site by TBG Contracting Ltd. (Fort McMurray Today 2001a). Fort MacKay community amended their waterworks approval to add a MicroFloc treatment unit to their water treatment process. This was a temporary interim measure prior to the construction of a new water treatment plant (Fort McMurray Today 2001b). Water use in Fort McMurray increased to 3,000 ML in the first six months of 2001, an increase of 4% from 2000 (Fort McMurray Today 2001c). However, water rationing occurred during the summer of 2001, due to low water levels. The water intake in Lake Athabasca for Fort Chipewyan was also upgraded in the spring of 2001 (Larry Wright, pers. comm. 2002).

1.6.3 Organizational Structure

No changes occurred to the organizational structure in 2001.

1.6.4 Study Area

RAMP had a Regional Study Area (RSA) and a Focus Study Area in 2001 (Figure 1.2). (Note: climate and hydrologic stations, radiotelemetry extents and the locations of the acid sensitive lakes are not shown in this figure due to the small scale of the figure). As in 2000, the RSA covered a large portion of northeastern Alberta and was consistent with the CEMA Water Working Group study area (i.e., the RMWB). The focus study area identified for 2001, located within the regional study area boundary, included watersheds where oil sands development was occurring or planned as well as areas downstream of those developments. The RAMP Terms of Reference in 2001 identified that the focus study area included in each year's RAMP monitoring program would be defined by the Technical Subcommittee as part of setting the annual scope of activities.

1.6.5 Study Design

The 2001 RAMP monitoring program consisted of the following four main components:

- water and sediment quality in rivers and some wetlands (both assessed by chemical analyses and toxicity bioassays);
- benthic invertebrate communities in tributaries and wetlands;
- fish populations in rivers, particularly regional fish resources and sentinel species; and
- water quality in acid sensitive lakes.

The 2001 RAMP study design is outlined in the following sections.

1.6.5.1 Climatic and Hydrologic Monitoring

RAMP developed a regional climatic and hydrologic database in 2001, and installed and monitored twelve new water level stations. Also in 2001, there were additions to the RAMP climate monitoring program. These additions are as follows:

- climate monitoring to Calumet River and Iyinimin Creek together with existing Aurora Climate Station; and
- snow surveys to include the Birch Mountains East Slopes for the CNRL Horizon Project.

1.6.5.2 Water and Sediment Quality

Expansions of the 2001 RAMP water and sediment quality monitoring program are as follows:

- water and sediment sampling and seasonal temperature monitoring to include the Clearwater River at locations upstream of Fort McMurray and the Christina River;
- water quality sampling at selected lakes in and around the OPTI Long Lake project area;
- water quality sampling to include baseline data collection in the headwaters of the Firebag River.
- sediment quality sampling to include the Big Point, Goose Island and Fletcher channels in the Athabasca delta;
- sediment quality sampling at two locations on the MacKay River; and
- sediment quality sampling at Kearl, Isadore's and Shipyard lakes.

1.6.5.3 Acid Sensitive Lakes

In 2001, two new lakes were added to replace lakes that were difficult to access during the acid sensitive lakes field surveys of 2000. A total of 32 lakes were monitored in 2001.

1.6.5.4 Fish Populations

The 2001 RAMP fisheries program included fish tissue collection, fish health and populations, and fish radiotelemetry studies.

Fish tissue was collected and analyzed from the Athabasca and Muskeg rivers. This is the second time that RAMP has analyzed fish tissue in the Oil Sands Region in its five-year history, the first program having occurred in 1998.

In 2001, RAMP monitored health and population parameters of slimy sculpin in the Muskeg and Steepbank rivers, as well as the reference sites on the Steepbank, Dunkirk and Horse rivers, chosen in 2000. A two-way fish counting fence was installed and monitored on the Muskeg River during the spring of 2001 to monitor the timing and size of the spawning run. The fish counting fence was included as part of the RAMP core monitoring activities. The fish fence study was relatively unsuccessful due to high flow conditions. A general fish inventory for the Muskeg River and Jackpine Creek was conducted in the summer of 2001.

In June 2001, RAMP completed a one-year radiotelemetry study initiated in 2000 that focused on longnose sucker movements in the Athabasca River.

1.6.5.5 Benthic Invertebrate Community

The fall 2001 benthic invertebrate program sampled three additional sites: the Clearwater River; Fort Creek and Kearl Lake. The mainstem of the Athabasca River was not sampled.

1.6.5.6 Wetlands Vegetation

This year, the four wetlands were sampled for vegetation species composition and distribution in addition to water quality.

1.6.5.7 Non-Core Programs

Non-core programs conducted in 2001 included the following:

- water sampling at 13 lakes near the proposed OPTI/Nexen Project;
- baseline water quality sampling at Suncor Firebag;
- initiation of the Fish Abnormalities Program;
- initiation of the Fish Tag Return Program; and
- initiation of the River Response Network.

1.7 SUMMARY

This section introduces the evolution of the Regional Aquatics Monitoring Program (RAMP) from 1997 to 2001. It describes why RAMP was formed and what it is trying to achieve. It also discusses how the program structure has changed and how new members have influenced the study area and the study design.

Considerable growth has occurred in the Oil Sands Region. In addition to the oil sands projects shown in Table 1.4, the following examples of other activities have the potential to affect the aquatic environment in the Oil Sands Region:

- municipal infrastructure;
- aggregate operations;
- fishing and recreational activities;
- oil and gas activities; and
- forestry operations.

Table 1.4 Status of All Known Oil Sands Developments, 1997 to 2001

Oil Sands Development	Date of Application	Date of First Disturbance	Capacity (bpd)[a]	Development Area (ha)[b]	Type of Operation	Status
Suncor Energy Inc.						
Fixed Plant Expansion, Lease 86/17, Steepbank and Millennium Mines	1996, 1964, 1996, 1998	existing disturbance area, 1967, 1997, 2002	450,000 S	18,298	processing /open-pit	approved
Firebag Project	2000	2002	140,000 B	1,105	in-situ	planned
Firebag Pilot Project	2000	2000	1,200 B	369	in-situ	approved
Voyageur	unknown	n/a	550,000 B	nyd	processing	planned
Syncrude Canada Ltd.						
Mildred Lake Upgrader/Expansion, North Mine	1973, 1998, 1995	1973, existing disturbance area, 1996	480,000 S/ 160,000 B	21,100	processing /open-pit	approved
Aurora North	1996	1996	200,000 B	7,700	open-pit	approved
Aurora South	1995	n/a	200,000 B	nyd	open-pit	EUB approved
Albian Sands Energy Inc. (Operator)						
Muskeg River Mine	1997	2000	155,000 B	4,343	open-pit	approved
Shell Canada Limited						
Jackpine Mine (Phase 1)	2002	n/a	200,000 B	8,474	open-pit	planned
Lease 88 & 89 (Phase 2)	unknown	n/a	100,000 B	7,105	open-pit	planned
Conoco (formerly Gulf)						
Surmont Pilot	1996	1996	2,000 B	7	in-situ	approved
Surmont	2001	n/a	100,000 B	567	in-situ	planned
Northstar Energy Dover, (formerly Northstar Dover)						
Old UTF	1987	1987	2,000 B	22	in-situ	approved
EnCana						
Christina Lake	1998	2000	85,000 B	527	in-situ	approved
TrueNorth Energy L.P.						
Fort Hills	2001	n/a	190,000 B	12,000	open-pit	approved
JACOS						
Hangingstone Pilot	1997	1998	10,000 B	420	in-situ	approved
Hangingstone	unknown	n/a	50,000 B	nyd	in-situ	planned
Petro-Canada Oil and Gas						
MacKay River	1998	2002	30,000 B	170	in-situ	approved
Meadow Creek	2001	n/a	80,000 B	1,181	in-situ	planned
Lewis Project	unknown	n/a	50,000 B	nyd	in-situ	planned
OPTI/Nexen						
Long Lake Project	2000	n/a	140,000 S 70,000 B	884	in-situ	planned
ExxonMobil Canada Ltd.						
Kearl Mine	unknown	n/a	165,000 S	nyd	in-situ	planned
Upgrader	unknown	n/a	185,000 B		processing	planned
Canadian Natural Resources Limited						
Kirby Pilot	2000	2001	1,600 B	3	in-situ	approved
Kirby Project	2002	n/a	30,000 B	190	in-situ	planned
Horizon In-Situ	2002	n/a	270,000 B	15,000[c]	in-situ	planned
Horizon	2002	n/a	240,000 S	nyd	open pit, upgrader	planned
Deer Creek Energy						
Deer Creek Pilot	2000	n/a	30,000 B	nyd	in-situ	planned

(a) Barrels per day (bpd) of B = Bitumen; S = Synthetic Crude or pipelineable crude; bpd values are rounded off.
(b) Development areas are those that will result from the existing approved and planned operations. Areas represent the maximum disturbance footprint for terrestrial resources.
(c) Total hectares for SAGD and mining.
nyd = not yet determined.
n/a = not applicable

1.7.1 Membership

In 1997, the three original companies forming RAMP were Shell, Suncor and Syncrude. After that year, membership in RAMP steadily increased, seeing a rise in both funding and non-funding members.

In 1998, Mobil joined RAMP as a funding member, while Environment Canada, Alberta Environment, Fort McKay Industrial Relations Corporation and Athabasca First Nation all came on board as non-funding members.

1999 saw Petro-Canada and Al-Pac join RAMP as two funding members. This year also saw a large influx of non-funding members, including DFO, Athabasca Tribal Council, Fort Chipewyan Metis Local, Koch, Mikisew Cree First Nation and OSEC.

Four new oil sands developers joined RAMP in 2000, consisting of Northstar, CNRL, OPTI and TrueNorth. In 2000, Fort McMurray and Chipewyan first nations also joined as non-funding members.

In 2001, representatives from the EUB and RMWB joined RAMP, along with Albian and Devon.

Table 1.5 illustrates the changes to RAMP's membership over the five years.

Table 1.5 Changes in RAMP's Membership

Member	1997	1998	1999	2000	2001
Funding	Suncor Inc., Oil Sands Syncrude Canada Ltd. Shell Canada Limited	Suncor Inc., Oil Sands Syncrude Canada Ltd. Albian Sands (Shell Canada Limited) Mobil Oil Canada Properties	Suncor Energy Inc. Syncrude Canada Ltd. Albian Sands (Shell Canada Limited) Mobil Oil Canada Properties Petro-Canada Oil and Gas	Suncor Energy Inc. Syncrude Canada Ltd. Albian Sands (Shell Canada Limited) ExxonMobil Canada Ltd. Petro-Canada Oil and Gas Northstar Energy Dover Canadian Natural Resources Limited OPTI Canada Inc. TrueNorth Energy	Suncor Energy Inc. Syncrude Canada Ltd. Albian Sands (Shell Canada Limited) ExxonMobil Canada Ltd. Petro-Canada Oil and Gas Devon Energy Corporation Canadian Natural Resources Limited OPTI Canada Inc. TrueNorth Energy
Non-funding	.	Environment Canada Alberta Environmental Protection Fort McKay Industry Relations Corporation (represents Fort McKay First Nations and Fort McKay Metis Local) Athabasca Chipewyan First Nation	Environment Canada Alberta Environmental Protection Fort McKay Industry Relations Corporation (represents Fort McKay First Nations #468 and Fort McKay Metis Local #122) Athabasca Chipewyan First Nation Athabasca Tribal Council (observer) Fort Chipewyan Metis Local #124 Koch Canada Ltd (observer) Mikisew Cree First Nation Oil Sands Environmental Coalition Department of Fisheries and Oceans Alberta Pacific Forest Industries	Environment Canada Alberta Environment Fort McKay Industry Relations Corporation (represents Fort McKay First Nations #468 and Fort McKay Metis Local #122) Athabasca Chipewyan First Nation Athabasca Tribal Council (observer) Fort Chipewyan Metis Local #124 Mikisew Cree First Nation Oil Sands Environmental Coalition Department of Fisheries and Oceans Alberta Pacific Forest Industries Fort McMurray First Nation Chipeywan Prairie First Nation	Environment Canada Alberta Environment Fort McKay First Nations #468 and Fort McKay Metis Local #122) Athabasca Chipewyan First Nation Athabasca Tribal Council (observer) Fort Chipewyan Metis Local #124 Mikisew Cree First Nation Oil Sands Environmental Coalition Fisheries and Oceans Canada Fort McMurray First Nation Chipeywan Prairie First Nation Alberta Energy and Utilities Board Regional Municipality of Wood Buffalo Alberta Pacific Forest Industries

1.7.2 Structure

As membership in RAMP increased, the organizational structure went through a series of changes. This was due not only to the greater involvement, but also to the expanding program. Committees and subcommittees were formed and disbanded, as either their objective was achieved or other groups within RAMP absorbed their responsibilities. Table 1.6 illustrates the organizational changes over the past five years. As seen in the table, the Steering Committee, Finance and Technical subcommittees, the Secretariat and Investigators have been present since the organizational structure was established in 1998.

Table 1.6 Changes in RAMP's Organizational Structure

Committee	1997 Operation	1998	1999	2000	2001
Steering Committee		X	X	X	X
Finance Subcommittee		X	X	X	X
Technical Subcommittee		X	X	X	X
Secretariat		X	X	X	X
Investigators		X	X	X	X
Terms of Reference Subcommittee		X			
Communications Subcommittee			X	X	X
Science Advisory Committee		X			
Program Review Committee		X	X		
Logo Subcommittee			X	X	

1.7.3 Study Area

The RAMP study area slowly increased in size over the five years, corresponding with development activities in the area and increasing membership in the program. In 1997, the study area was similar to the study areas used in EIAs for Suncor's Project Millennium and Shell's Muskeg River Mine, but also expanded further downstream to include the Athabasca River delta.

Monitoring expanded again in 1999 to include areas potentially affected by development, including Muskeg River tributaries and McLean Creek. Acid sensitive lakes were also included this year.

In 2000, RAMP adopted a regional study area boundary similar to that of CEMA. This new study area followed the periphery of the RMWB. The focus study area was also expanded to include the rivers and lakes south of Fort McMurray. The 2001 study area was similar to that of 2000.

1.7.4 Study Design

As RAMP grew, the study design also expanded and became more comprehensive. This was due in part to increasing membership in RAMP, but also to expanding development in the Oil Sands Region. The increasing number of proposed, planned and approved projects in the Oil Sands Region, combined with growing membership, required RAMP to be flexible and adaptive in its study design. As new issues were raised, new methods were tried or new projects were introduced, RAMP's study design needed to respond accordingly in order to continue to ensure comprehensive and relevant data collection.

Although there were yearly changes to the study design, several types of monitoring programs remained constant during the entire five years. Water and sediment quality, benthic invertebrate communities and fish populations were examined every year. However, the locations and types of sampling in these programs have changed over the years.

In addition to these programs, wetlands vegetation monitoring was included every year except 1999. Monitoring of acid sensitive lakes was introduced into the study design in 1999, and was included in 2000 and 2001, as well. Non-core programs were also incorporated into the study design in 1999, and then again in 2001. In 1999, mussels were assessed as a potential monitoring tool, and community concerns regarding external abnormalities were addressed. In 2001, water sampling at 13 lakes near the proposed OPTI/Nexen project occurred, and baseline water quality sampling at Suncor Firebag was also conducted. In addition, the Fish Abnormalities Program, the Fish Tag Return Program and the River Response Network were initiated that year.

Details on specific locations and types of monitoring during the five years can be found in Table 1.7.

Table 1.7 Changes to Monitoring Locations

Waterbody	1997	1998	1999	2000	2001
Athabasca River Mainstem and Delta					
Athabasca River	WQ F S B	WQ F/Sen S	WQ F/Sen CH	WQ F S	WQ F S CH
Steepbank River	WQ F S	WQ S B	WQ F/Sen CH	WQ F/Sen S B	WQ F/Sen B
Delta			WQ M S	WQ S	WQ S
Flour Bay				S	
Big Point Channel				WQ S	WQ S
Fletcher Channel					WQ S
Goose Island Channel					WQ S
South of Fort McMurray					
Clearwater River					WQ B S CH
Gregoire Lake				WQ F	WQ
Gregoire River				WQ F	
Wapasu Creek			WQ S	WQ	
Hangingstone River				F	
Horse River				F	Sen
Canoe Lake				WQ F	WQ
Long Lake				WQ F	WQ
Pushup Lake				WQ F	WQ
Unnamed Lakes 1, 2 and 3				WQ F	WQ
Birch Lake				F	WQ
Sucker Lake				F	WQ
Caribou Horn Lake				WQ F	WQ
Frog Lake				F	WQ
Kiskatinaw Lake				WQ F	WQ
Poison Lake				F	

Table 1.7 Changes to Monitoring Locations (continued)

Waterbody	1997	1998	1999	2000	2001
Rat Lake				F	WQ
North of Fort McMurray					
McLean Creek			WQ S	WQ S CH	WQ S CH
MacKay River	S	WQ B S	CH	WQ B S	WQ B S
Ells River	F	WQ S		WQ F/Sen	CH
Firebag River			CH		WQ
Tar River	F	WQ S	Sen		CH
Poplar Creek				WQ	WQ
Fort Creek				WQ	WQ
Unnamed Creek				WQ	
Alsands Drain			WQ		WQ
Shelly Creek			WQ		CH
Dover River				F	
Dunkirk River				F	Sen
Mills Creek				CH	CH
Calumet River					CH
Upland Tar River					CH
Upland Calumet River					CH
Lowland Tar River					CH
Upper Muskeg River				CH	CH
Khahago Creek				CH	CH
Iyinimin Creek					CH
Muskeg River Watershed					
Muskeg River	WQ F S	WQ B S CH	WQ Sen S	WQ F/Sen S CH B	WQ F/Sen S CH B
Jackpine Creek	S		WQ S CH	WQ F S CH	WQ F/Sen

Table 1.7 Changes to Monitoring Locations (continued)

Waterbody	1997	1998	1999	2000	2001
Muskeg Creek		WQ S	WQ	WQ S	WQ CH
Stanley Creek			WQ	WQ S CH	WQ
Albian Pond #3				CH	
Wetlands					
Shipyard Lake	V	WQ V	WQ	WQ B	WQ B S
Isadore's Lake	V	WQ V		WQ CH	WQ S CH
Kearl Lake	V	WQ V	S	WQ CH	WQ B S CH
Lease 25	V				
Spruce Pond		WQ V			
McClelland Lake				WQ CH	WQ CH
Other					
Wabasca River		F			
Acid Sensitive Lakes			WQ	WQ	WQ

[(a)] WQ = water quality; F = includes either fish habitat, fish health or fish populations; F/Sen = includes either fish habitat, fish health or fish populations and sentinel survey; Sen = sentinel survey; M=mussel survey; B = benthic survey; S = sediment survey; CH = climate and/or hydrology sampling; V = vegetation survey.

2 FIVE YEAR REPORT APPROACH

2.1 OVERALL OBJECTIVES

The purpose of the Regional Aquatic Monitoring Program (RAMP) Five Year Report is to analyze the results of the initial five years of sampling data (from 1997 to 2001) to address the three fundamental program objectives that are most relevant to aquatic monitoring. The following three objectives are part of the eight objectives that guide the overall program (Chapter 1, Sections 1.2.1, 1.3.1 and 1.6.1):

- collecting scientifically defensible baseline and historical data to characterize variability in the oil sands area;
- monitoring aquatic environments in the oil sands area to detect and assess cumulative effects and regional trends; and
- collecting data against which predictions contained in Environmental Impact Assessments (EIAs) can be verified.

The first objective arises from the importance of sound scientific practices, such as consistency and adequacy of study design, study area, sampling methods and quality control measures, to produce field and laboratory data of known and defensible quality. Baseline field and laboratory data are used with historical data as "building blocks" in further assessments to help describe aquatic conditions (including natural variation) in the Oil Sands Region. Baseline data serve as a reference to compare aquatic conditions before, or upstream of, the occurrence of potential impacts to the environment. In addition, baseline data will also be used to meet the needs of the subsequent RAMP objectives.

The second objective states that RAMP data should be evaluated to identify changes to the aquatic environment in the Oil Sands Region due to cumulative effects or regional trends. Data collected during the RAMP program are evaluated using statistical or qualitative analysis to assess changes over time (e.g., before-after comparisons) or space (e.g., upstream-downstream comparisons). Spatial or temporal trends occur in the environment naturally; however, these trends may be influenced by man-made factors. For example, the sediment quality in a river may be different from one sample site to another because the geological material in the bedrock beneath the river is variable. The sediment quality in a river also may be affected by releases or seepage from a development. Thus, the water quality upstream of the development may be different from the water quality downstream for either or both of these reasons. In general, monitoring data can be used to identify a change (e.g., a change in the water quantity or quality) or an effect on the benthic invertebrate community or fish population. Monitoring alone may not be sufficient to determine the cause of an effect. The timing, location and magnitude of a change may provide useful information about possible causes; however, a separate study will, in most cases, be required to verify the source and pathway.

Temporal or time trends may be long-term or immediate, where changes in the aquatic environment are noticed gradually over a period of time or rapidly. For example, the structure of a benthic community may change gradually over time as the river or stream habitat changes (i.e., the habitat shifts from depositional to erosional). Benthic communities may also change rapidly if there is an addition of chemicals (e.g., nutrients) into the water.

Although the second objective identifies cumulative effects and regional trends separately, this report has combined these concepts because a regional trend, particularly a trend at a downstream location, incorporates the cumulative effect. The data collected at a given location in a given year represent the sum of all the effects on the aquatic environment (i.e., cumulative effects) at each sampling station. Cumulative effects on the aquatic environment are the result of both natural and man-made changes.

The third objective specifically addresses the adequacy of the RAMP study area and study design to confirm EIA predictions. Is RAMP collecting the right data in the right areas and at the appropriate frequency within the Oil Sands Region? Initial answers to these questions are provided in this Five Year Report, recognizing that the adequacy of the data depends on the future uses. Future modelling requirements may differ from the statistical applications considered in this report.

Due to the typically conservative (rather than realistic) nature of EIA predictions, impacts are expected to be less than predicted. Steady state models used in EIAs often generate point estimates for extreme or worst case conditions (e.g., maximum seepage concentrations occurring at 7Q10 low flows), which may never occur. When conservative steady-state predictions are far below effects thresholds, increased data collection and verification may not be warranted. Dynamic models, such as those that have recently been employed in the Muskeg River basin and the Tar – Calumet rivers, lend themselves more readily to model validation and re-calibration using RAMP data. This type of modelling could be used in the future to validate cause and effect predictions in EIAs. The amount and type of data needed would depend on the objective and type of modelling, as well as the accuracy required. Greater accuracy, and therefore more data, would be required if predictions are close to effects thresholds.

The other remaining five objectives of RAMP described below are not the focus of the Five Year Report:

- designing and executing a program that addresses the anticipated aquatic monitoring requirements of oil sands operators' environmental approvals.

  This is actively accomplished through the Technical Subcommittee. The program design is developed through a consensus process between members of technical subgroups representing all RAMP stakeholders. Most of the key funders look to RAMP for assistance with their environmental approval requirements. However, success in meeting this objective would be determined by the regulators and oil sands operators.

- recognizing and incorporating traditional knowledge into the monitoring and assessment activities.

  Representatives from most of the first nations in the Oil Sands Region are members of the Steering Committee, Technical Subcommittee and Subgroups. This objective is addressed through discussions at meetings and through community participation initiatives by RAMP.

- communicating monitoring and assessment activities and results to communities in the RMWB, regulatory agencies and other interested parties.

  This objective is accomplished through publications and community participation by RAMP members. The RAMP Secretary and the Communications Subgroup of the RAMP Steering Committee take an active role in planning and organizing events within local communities such as the Fort Chipewyan Dog Sled races, Fort McMurray Environmental Days and Fort McKay Open House. Information is also communicated to the public through media such as the RAMP website, newsletters, newspaper articles and an Annual Summary Report (2001, 2002) aimed at and written specifically for the communities in the Oil Sands Region.

- reviewing and adjust the program to reflect monitoring results, technological advances and community concerns.

  RAMP component methods are often modified by the various subgroups of the Technical Subcommittee, but not by means of a formal review system. The adjustments made to the program by the subgroups are reflected in the monitoring results available for analysis in the Five

Year Report; therefore, this report provides feedback to the subgroups of the Technical Subcommittee as they review the program. The recommendations in this report include recommendations for adjustments to the program for the subgroups' consideration. To meet Objective 7, the subgroups would also consider technological advances and community concerns.

- seeking cooperation with other relevant research and monitoring programs where practical and generating interpretable results which can build on their findings and on those of historical programs.

  This goal was incorporated into the RAMP Objectives in 2001, yet it has not been formally incorporated within the processes of design and implementation of RAMP. Sections of the Five Year Report include relevant historical data and more recent data from other sources (e.g., EIAs) in the analyses. This report contributes to Objective 8 where possible.

These five additional objectives deal with aspects of RAMP that do not focus on drawing scientific conclusions and determining variability and trends in aquatic monitoring data. These five objectives are addressed through processes outside of the Five Year Report. Therefore, they are not assessed here, although this report may contribute to some of the objectives, particularly the latter two objectives.

The Five Year Report is not a summary of the annual reports over the last five years. The overall objective of the Five Year Report is to determine if RAMP is meeting its three fundamental objectives.

2.2 SCOPE

The Five Year Report incorporates a greater scope than the annual RAMP reports. The annual monitoring reports describe the detailed monitoring activities and results for that particular year. In contrast, the Five Year Report includes the analysis of data over the last five years, where sufficient data are available. Components of the RAMP program that did not have sufficient data, such as the aquatic vegetation and acid sensitive lakes components were not included in the Five Year Report. Where possible, data were analyzed and assessed for variation, cumulative effects and regional trends in the Oil Sands Region. Since regional trends reflect the cumulative effects of natural and human influenced changes over space and time, cumulative effects are not addressed separately from regional trends.

The objectives and scope of each component are described in the component chapters. Brief summaries of the scope of each component included in the Five Year Report are provided below:

- **Climate and Hydrology**: The scope of the Climate and Hydrology component is based on the three broad objectives identified in Section 2.1 and input from the RAMP Climate and Hydrology Subgroup of the Technical Subcommittee. This component provides information on the climatic and hydrologic conditions in the RAMP focus study area. Long-term regional climatic and hydrologic data (archived by Environment Canada and supplemented by RAMP in cases where Environment Canada data are limited) were collected from the Athabasca and Muskeg rivers, and from corresponding tributaries. Precipitation, temperature, water yield, flood discharge and low flow discharge were described and evaluated to characterize existing variability and detect and assess regional trends in the Oil Sands Region. These analyses require long-term data because smaller data sets are unlikely to reflect the range and distribution of climatic and hydrologic conditions necessary to characterize long-term natural variation. Data from climate stations starting from 1944 and hydrologic stations starting from 1957 were used in this report.

  Short-term climatic and hydrologic data collected by RAMP were used to characterize the hydrologic conditions of smaller local areas monitored by RAMP and assess longer term conditions of these areas. Ten short-term RAMP stations from a three year period had appropriate data to use in the analyses. These data are also used to assess whether EIA predictions can be evaluated at this time and whether the data collected by RAMP will be appropriate to do so in the future.

- **Water Quality:** The scope of the Water Quality component was to characterize the water quality in the RAMP focus study area by examining the three broad objectives of RAMP listed in Section 2.1 and the additional issues raised by the Water and Sediment Subgroup of the Technical Subcommittee. The water quality data set included points from the Athabasca River upstream and downstream of oil sands developments, tributaries of the Athabasca River, the Athabasca River Delta, the Muskeg River watershed and four wetlands east of the Athabasca River.

  The existing variability in water quality was determined from examining the water quality parameters that may be correlated to each other, (i.e., total metal and total suspended solids concentrations) whether these correlations are common to all waterbodies sampled by RAMP was also determined. The influence of water flow and season (winter vs. fall) on water quality sampling results was also examined. The investigation into spatial trends in the water quality data set included examining general patterns within the lower Athabasca River watershed as a whole, as well as potentially significant variations along the length of the Athabasca River and within the Muskeg River watershed.

Long-term data collected from the Athabasca River (i.e., 1976 to 2001) and short-term data collected from the Muskeg River (i.e., 1997 to 2001) were used to complete the temporal trend analyses. Water quality was compared upstream and downstream of existing oil sands development along both rivers.

The Five Year Report also addresses whether water quality information collected by RAMP can be used to verify EIA predictions, whether causal links can be established between on-site activities and instream observations, and how the water component of RAMP may be improved.

- **Sediment Quality**: Sediment quality data collected by RAMP up to and including 2001 were used in the analyses for the Five Year Report. Sediment quality sampling sites were located upstream, downstream or in the vicinity of oil sands developments within the Athabasca, Muskeg and Steepbank rivers. Historical sediment quality data were not available for the analyses in the Five Year Report.

  The scope of the Sediment Quality Chapter was to characterize the sediment quality in the RAMP focus study area by examining the three broad objectives of RAMP listed in Section 2.1 and the additional issues raised by the Water and Sediment Subgroup of the Technical Subcommittee. The existing variability in sediment quality was characterized by examining the correlation of monitored parameters within the sediment data set (e.g., total recoverable hydrocarbon and polycyclic aromatic hydrocarbon (PAH) levels; sediment composition and PAH content). Regional trends in the sediment quality data set were examined at sampling locations where more than four years of sediment data were available. Therefore, data from five sampling locations were included in these analyses (i.e., Muskeg River mouth and sample sites in the upper and lower Athabasca River).

  The monitoring to verify EIA predictions discussed in Section 5.4 focused on whether the sediment quality information being collected by RAMP can be used to verify EIA predictions and establish causal links between on-site activities and instream observations and how the Sediment Quality component of RAMP may be improved.

- **Benthic Invertebrates:** The scope of the Benthic Invertebrates component is based on the three overall RAMP objectives and input from the RAMP Benthic Invertebrate Subgroup of the Technical

Subcommittee. Benthic invertebrate data used in analyses for this report are from the following lakes and tributaries of the Athabasca and Muskeg rivers sampled by RAMP, up to and including the 2001 program:

- Kearl Lake;
- Shipyard Lake;
- Clearwater River;
- MacKay River;
- Muskeg River;
- Steepbank River; and
- Fort Creek.

The Five Year Report also includes quantitative historical data available for each of the waterbodies sampled. Inclusion of the historical data was intended to facilitate examination of potential long-term trends, that may have begun before the period monitored by RAMP. Fall data were used in the analyses of the Five Year Report to simplify the interpretation of results, since all RAMP benthic sampling to date was done during the fall low-flow period.

The interpretation of results focused on defining baseline ranges for key benthic invertebrate community variables (i.e., total abundance, richness and abundances of dominant invertebrate groups) and characterizing spatial variation and regional trends in benthic community structure (i.e., abundances of benthic invertebrates converted to the family level or the "most common" level of identification) in the rivers and lakes monitored by RAMP. The analyses of the Five Year Report also compare benthic community structure between the two years that used consistent field methods (i.e., 2000 and 2001). Riverine benthic community structure was compared between reaches located upstream and downstream of oil sands developments, where possible.

An examination of RAMP sampling locations (past and future) relative to waterbodies that have been assessed in EIAs was completed to assess whether EIA predictions can be evaluated at this time and whether the benthic invertebrate data collected by RAMP will be appropriate to do so in the future.

- **Fish Populations:** The scope of the Fish Populations component is based on the three overall objectives of RAMP identified in Section 2.1.

Within these objectives, the general objectives of the fisheries program are to evaluate the health and sustainability of fish resources within the Oil Sands Region, with monitoring focused on the Athabasca River and tributaries potentially influenced by current or future oil sands development. Fish populations are monitored to provide a bioindicator of ecosystem integrity, with emphasis on regional fish resources and sentinel species. In addition, the RAMP Fish Subgroup of the Technical Subcommittee provided further guidance for the fisheries section of the Five Year Report (described in Section 7.1.2.). The scope of the Fish Populations Chapter of the Five Year Report includes individual components of the fisheries program that were conducted in more than one year and which provide data suitable for assessing regional variability and trends (i.e., general inventory, fish tissue, sentinel species, counting fence). Restricting the scope to the selected components was done to focus the analysis on the objectives of characterizing variability and evaluating regional trends. Data associated with non-selected components were used, where appropriate, to provide additional information for the components selected for inclusion in the analysis.

The components of the fisheries program addressed in this report currently have only two or three years of data collected under RAMP. Therefore, historical and recent data collected outside of RAMP were included with RAMP data, where appropriate, to assess the following specific objectives of the RAMP fisheries program:

- to characterize variability in the fish population data relative to species composition, relative abundance, population structure, growth, health, reproduction and suitability for human consumption;
- to evaluate whether the present study design is suitable for characterizing variability;
- to identify any regional trends indicated by the data relative to the health and sustainability of regional fish resources;
- to evaluate the ability of the present study design to detect regional trends;
- to evaluate whether the information being collected by RAMP could be used to verify EIA predictions regarding fish populations; and
- to evaluate if and how the RAMP fisheries program may be improved.

Water chemistry data collected during the first five years of RAMP by the Acid Sensitive Lakes component were not reanalyzed for trends, because such an analysis would not generate any more information than already provided in the 2002 annual RAMP report (Golder 2003a). As part of routine reporting, the entire available data set is analyzed for trends each year to evaluate whether emissions in the Oil Sands Region have affected water quality in sensitive lakes monitored by RAMP. The most recent summary of the available four years of data has shown that there have been no changes in indicators of acidity in these lakes (Golder 2003a).

2.3 REPORT STRUCTURE

The structure of the Five Year Report is divided by the five major components of the aquatic ecosystem monitored by RAMP. Therefore, the Five Year Report is organized in chapters by component to follow a logical sequence from physical and chemical changes to effects on biota:

- Chapter 3 – Climate and Hydrology
- Chapter 4 – Water Quality
- Chapter 5 – Sediment Quality
- Chapter 6 – Benthic Invertebrates
- Chapter 7 – Fish Populations

The three main RAMP objectives, as well as the specific objectives of the Technical Subcommittee subgroups, are addressed within each chapter. The methods, results and discussion for each objective are discussed. A summary of the findings are provided at the end of each chapter. Conclusions and recommendations are found in Chapter 8. References to the report are provided in Chapter 9.

3 CLIMATE AND HYDROLOGY

3.1 INTRODUCTION

3.1.1 Program Overview

The 2001 climate and hydrology component of RAMP evolved on a path convergent to the chemical and biological components of the program, according to the following timeline:

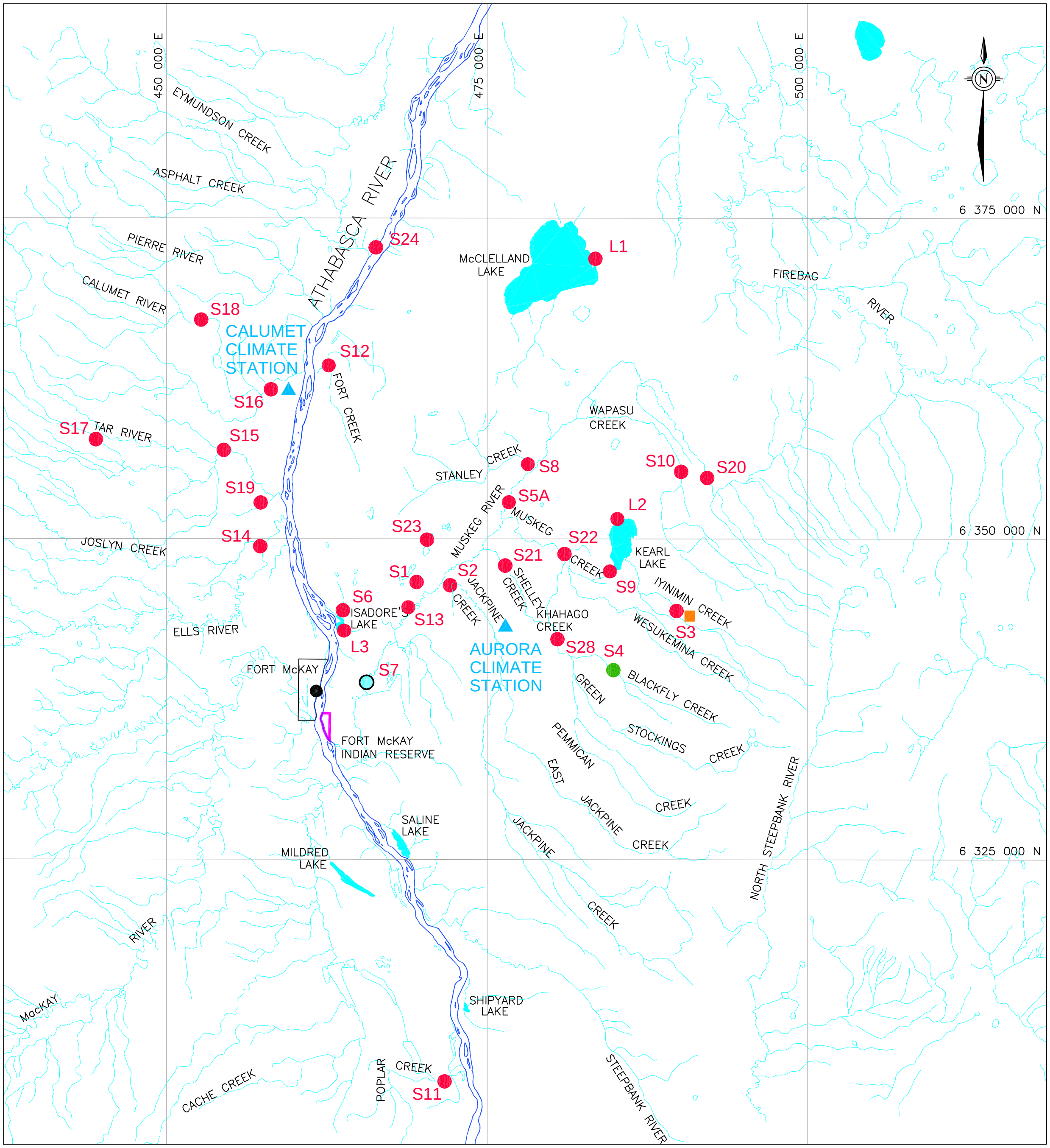
- 1995: Syncrude Canada Ltd. (Syncrude) commissions Agra Earth and Environmental to collect climate and hydrology data in support of the Aurora mine Environmental Impact Assessment (EIA). Five hydrology stations (Alsands Drain, Jackpine Creek, Iyinimin Creek, Blackfly Creek and Muskeg River Aurora) and one climate station are installed in the Muskeg River basin. A hydrology station is installed on Poplar Creek to monitor discharges from the Syncrude spillway.
- 1997: Shell Canada Limited (Shell), in support of the Lease 13 EIA, joins with Syncrude to form a funding group. Golder Associates Ltd. (Golder) takes over data collection responsibilities. New stations are installed on Mills Creek and McClelland Lake.
- 1998: Suncor Energy Inc., Oil Sands (Suncor) and Mobil Oil Properties, currently ExxonMobil Canada Ltd. (ExxonMobil) Canada join the funding group, in support of the Suncor Firebag and Mobil Kearl projects. New stations are installed on Kearl Lake Outlet and Wapasu Creek.
- 1999: Albian Sands Energy Inc. (Albian Sands) is recognized as a separate entity and is joined in the funding group by Petro-Canada Oil and Gas (Petro-Canada) and Koch Canada Ltd. (now TrueNorth Energy). Winter monitoring is initiated at the Environment Canada Muskeg River station and water level monitoring is initiated on Stanley Creek and Kearl Lake. A rain gauge is added to the Iyinimin Creek station and the Blackfly Creek station is discontinued.
- 2000: The integration of the climate and hydrology component into RAMP is driven by similarities in funding group membership and geographic scope. New stations are installed on Fort Creek, Albian Sands Pond #3 Outlet and Isadore’s Lake. Stations at Iyinimin Creek, Kearl Lake Outlet and Wapasu Creek are discontinued.
- 2001: Canadian Natural Resources Limited (CNRL) joins the funding group. Stations are installed on the Ells River, Tar River, Calumet River and three smaller tributaries in support of the CNRL Horizon EIA. The Calumet River station includes sensors to measure air temperature,

rainfall and snowfall. In support of the Shell Jackpine EIA, stations on Iyinimin Creek, Kearl Lake Outlet and Wapasu Creek are reactivated and stations are installed on the upper Muskeg River, Shelley Creek, Muskeg Creek and Khahago Creek. Syncrude adds the Aurora Boundary Weir to the program and a station on the Athabasca River, downstream of development, is supported by all funders.

In addition to the operation of climatic and hydrologic monitoring stations, additional data collection activities included in this program were snowcourse surveys undertaken in the Muskeg River basin from 1997 to 2001, in the Fort Creek basin in 2000 and in the Birch Mountains east slopes in 2001. High water mark measurements were collected at selected locations on the Muskeg River in 1997, 1999, 2000 and 2001 and on Jackpine Creek in 1997 and 2001.

From 1995 to 1999, program activities and budget allocations were reviewed annually by the funding group. When the program was integrated with RAMP in 2000, activities became subject to the direction and approval of the RAMP Climate and Hydrology Subgroup of the Technical Subcommittee and Finance Subcommittee. The locations of all RAMP climate and hydrology stations active between 1995 and 2001 are shown in Figure 3.1. Details of periods of operation, data collected and funding support for each station are provided in Table 3.1.

Data archived by Environment Canada are also purchased and compiled in the RAMP climate and hydrology database. This includes data from Oil Sands Region climate stations starting from 1944 and hydrologic stations starting from 1957. Locations of the 18 active and three inactive Environment Canada climate monitoring stations located in the Oil Sands Region north of Fort McMurray are shown in Figure 3.2 and station details are provided in Table 3.2. Of the 18 active stations, 16 are located at forestry lookouts and operate during summer only. Locations of the six active and 17 inactive Environment Canada hydrology monitoring stations located in the Oil Sands Region north of Fort McMurray are shown in Figure 3.3 and station details are provided in Table 3.3.



LEGEND

- ACTIVE HYDROLOGIC STATION (SUMMER OR YEAR–ROUND MONITORING BY RAMP)
- ACTIVE HYDROLOGIC STATION (WINTER MONIOTORING BY RAMP; SUMMER MONITORING BY ENVIRONMENT CANADA)
- INACTIVE HYDROLOGIC STATION
- RAMP CLIMATE STATION
- RAMP RAIN GAUGE

10 0 10

SCALE KILOMETRES

NOTE

STATION S4 WAS NOT OPERATIONAL IN 2001

REFERENCE

DIGITAL DATA 74D, 74E, 74I, 84A, AND 84H FROM RESOURCE DATA DIVISION ALBERTA ENVIRONMENT PROTECTION, 1997.

PROJECT

RAMP FIVE YEAR REPORT

TITLE

LOCATIONS OF RAMP CLIMATIC AND HYDROLOGIC MONITORING STATIONS ACTIVE BETWEEN 1995 AND 2001

Golder Associates
Calgary, Alberta

PROJECT	No. 022–2301.7250		FILE No. climatic–hydro1995&	
DESIGN	NS	27/11/02	SCALE AS SHOWN	REV. 0
CADD	AS	06/03/03		
CHECK	NS	03/01/03	FIGURE: 3.1	
REVIEW				

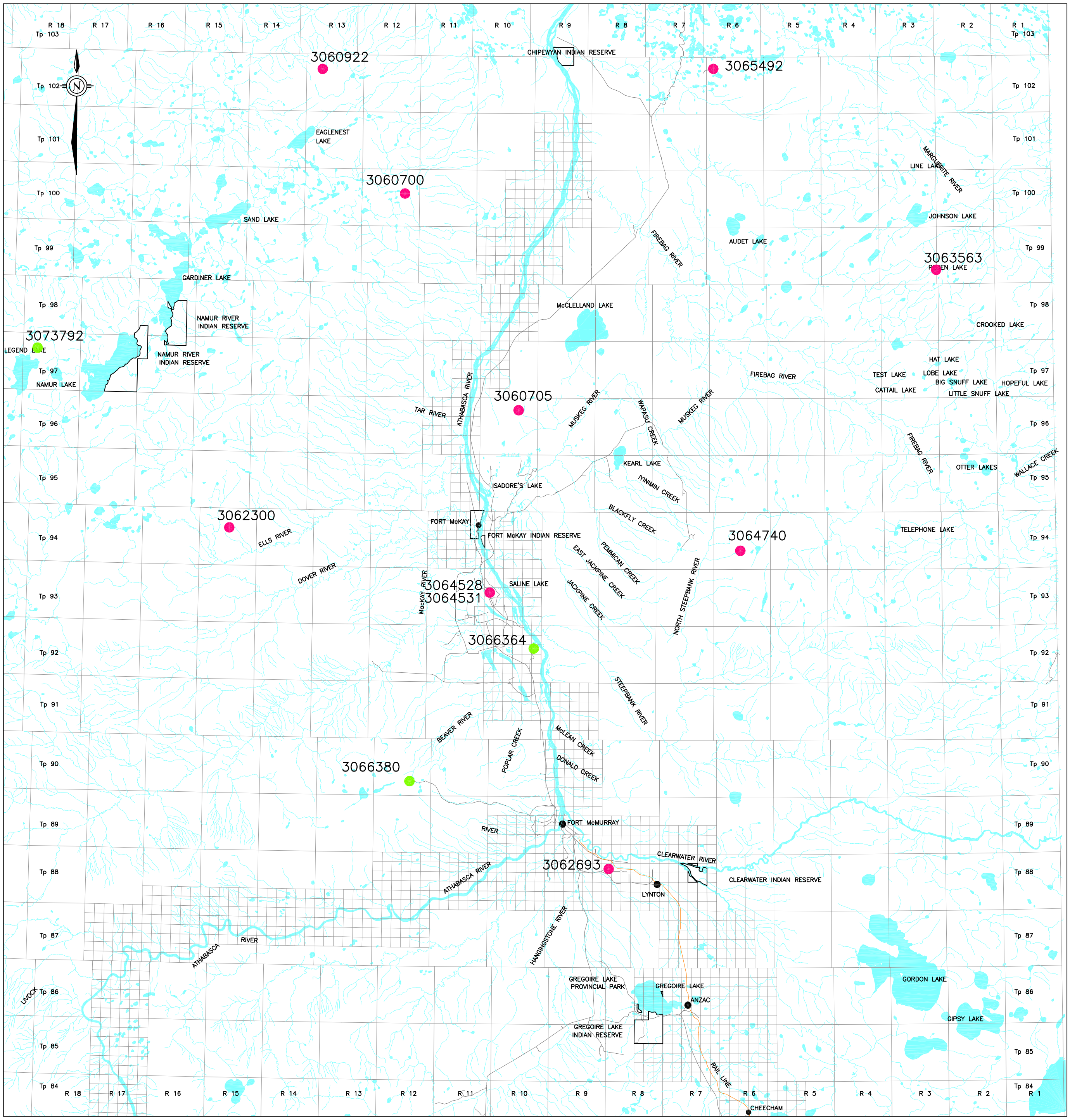
R:\CAD\2300\022–2301\7000\7250\ Drawing file: Climatic and Hydrologic1995&2001.dwg Mar 06, 2003 – 2:29pm

Table 3.1 Overview of Climatic and Hydrologic Data Collected for RAMP from 1995 to 2001

Station	1995	1996	1997	1998	1999	2000	2001	Installed By[(a)]	Currently Funded By[(a)]
S1 – Alsands Drain	Q_O	Q_O	Q_O	Q_O	Q_O	Q_O	Q_O	SYN	SYN, AS
S2 – Jackpine Creek	Q_O	Q_O	Q_O	Q_O	Q_O	Q_O	Q_O	SYN	SYN, SHE
S3 – Iyinimin Creek	Q_O	Q_O	Q_O	Q_O	Q_O, R	-	Q_O, R	SYN	SYN, SHE, MOB
S4 – Blackfly Creek	Q_O	Q_O	Q_O	Q_O	-	-	-	SYN	-
S5A – Muskeg River Aurora	Q_O	Q_O	Q_O	Q_A	Q_A	Q_A	Q_A	SYN	SYN, SHE, AS
S6 – Mills Creek	-	-	Q_O	Q_O	Q_O	Q_O	Q_O	SHE	SYN, AS
S7 – Muskeg River	-	-	-	-	Q_I	Q_I	Q_I	SYN, SHE, SUN	SYN, SHE, AS, SUN
S8 – Stanley Creek	-	-	-	-	WL_O	WL_O	WL_O	SYN	SYN
S9 – Kearl Lake Outlet	-	-	-	Q_O	Q_O	-	Q_O	SYN	SYN, SHE, MOB
S10 – Wapasu Creek	-	-	-	Q_O	Q_O	-	Q_O	MOB	MOB, AS
S11 – Poplar Creek	Q_O	Q_O	Q_O	Q_O	Q_O	Q_O	Q_O	SYN	SYN, SUN
S12 – Fort Creek	-	-	-	-	-	Q_O	Q_O	TNE	TNE
S13 – Albian Pond #3	-	-	-	-	-	Q_O	Q_O	SHE	SHE
S14 – Ells River	-	-	-	-	-	-	Q_O	CNR	CNRL
S15 – Tar River	-	-	-	-	-	-	Q_O	CNR	CNRL
S16 – Calumet River	-	-	-	-	-	-	Q_O, R, S, T	CNR	CNRL
S17 – Tar River Upland	-	-	-	-	-	-	Q_O	CNR	CNRL
S18 – Calumet River Upland	-	-	-	-	-	-	Q_O	CNR	CNRL
S19 – Tar River Lowland	-	-	-	-	-	-	Q_O	CNR	CNRL
S20 – Muskeg River Upland	-	-	-	-	-	-	Q_O	SHE	SHE, MOB, SYN
S21 – Shelley Creek	-	-	-	-	-	-	Q_O	SHE	SHE
S22 – Muskeg Creek	-	-	-	-	-	-	Q_O	SHE	SHE, SYN
S23 – Aurora Boundary Weir	-	-	-	-	-	-	Q_A	SYN	SYN
S24 – Athabasca River	-	-	-	-	-	-	Q_A	RAMP	SYN, SUN, SHE, AS, MOB, CNRL, TNE
S28 – Khahago Creek	-	-	-	-	-	-	Q_O	SHE	SYN, SHE
L1 – McClelland Lake	-	-	Q_O	Q_O	Q_O	Q_O	Q_O	SYN	SYN, TNE
L2 – Kearl Lake	-	-	-	-	WL_A	WL_A	WL_A	SYN	SYN, SHE, MOB
L3 – Isadore's Lake	-	-	-	-	-	WL_A	WL_A	SYN, ASE	SYN, AS
Muskeg River High Water	-	-	HWM	-	HWM	HWM	HWM	-	SYN, SHE
Jackpine Creek High Water	-	-	HWM	-	-	-	HWM	-	SYN, SHE
C1 – Aurora Climate Station	C_A	C_A	C_A	C_A	C_A	C_A	C_A	SYN	SYN, SUN, AS, MOB, CNRL, TNE
Muskeg River Snowcourse	-	-	SS	SS	SS	SS	SS	-	SYN, SUN, AS, MOB, CNRL, TNE
Fort Creek Snowcourse	-	-	-	-	-	SS	-	-	TNE
Birch Mountains Snowcourse	-	-	-	-	-	-	SS	-	CNRL

(a) SYN – Syncrude; SHE – Shell; SUN – Suncor; AS – Albian Sands; MOB – ExxonMobil; CNRL – Canadian Natural Resources Ltd.; TNE – TrueNorth Energy; RAMP – Regional Aquatics Monitoring Program Cooperative Station.

(b) Q_O – Open-water discharge; Q_I – Ice-covered discharge; Q_A – Annual discharge; WL_O – Open-water water level; WL_A – Annual water level; R – Rain gauge; S – Snow gauge; T – Temperature gauge; HWM – High water mark gauge; SS – Snowcourse survey; C_A – Annual gauging at comprehensive climate station.



LEGEND

- ROADWAYS
- RIVERS AND STREAMS
- ACTIVE CLIMATE MONITORING STATIONS
- DISCONTINUED CLIMATE MONITORING STATIONS

20 0 20
SCALE KILOMETRES

REFERENCE

DIGITAL DATA SETS 74D, 74E, 74I
84A AND 84H FROM RESOURCE DATA DIVISION
ALBERTA ENVIRONMENTAL PROTECTION, 1997.
DATUM: NAD83 PROJECTION: UTM ZONE 12

PROJECT

RAMP FIVE YEAR REPORT

TITLE

LOCATIONS OF ENVIRONMENT CANADA CLIMATE MONITORING STATIONS NORTH OF FORT McMURRAY

Golder Associates
Calgary, Alberta

PROJECT	No. 022-2301.7250		FILE No. Climate Monitoring St.	
DESIGN	NS	27/11/02	SCALE AS SHOWN	REV. 0
CADD	AS	06/03/03	**FIGURE: 3.2**	
CHECK	NS	03/01/03		
REVIEW				

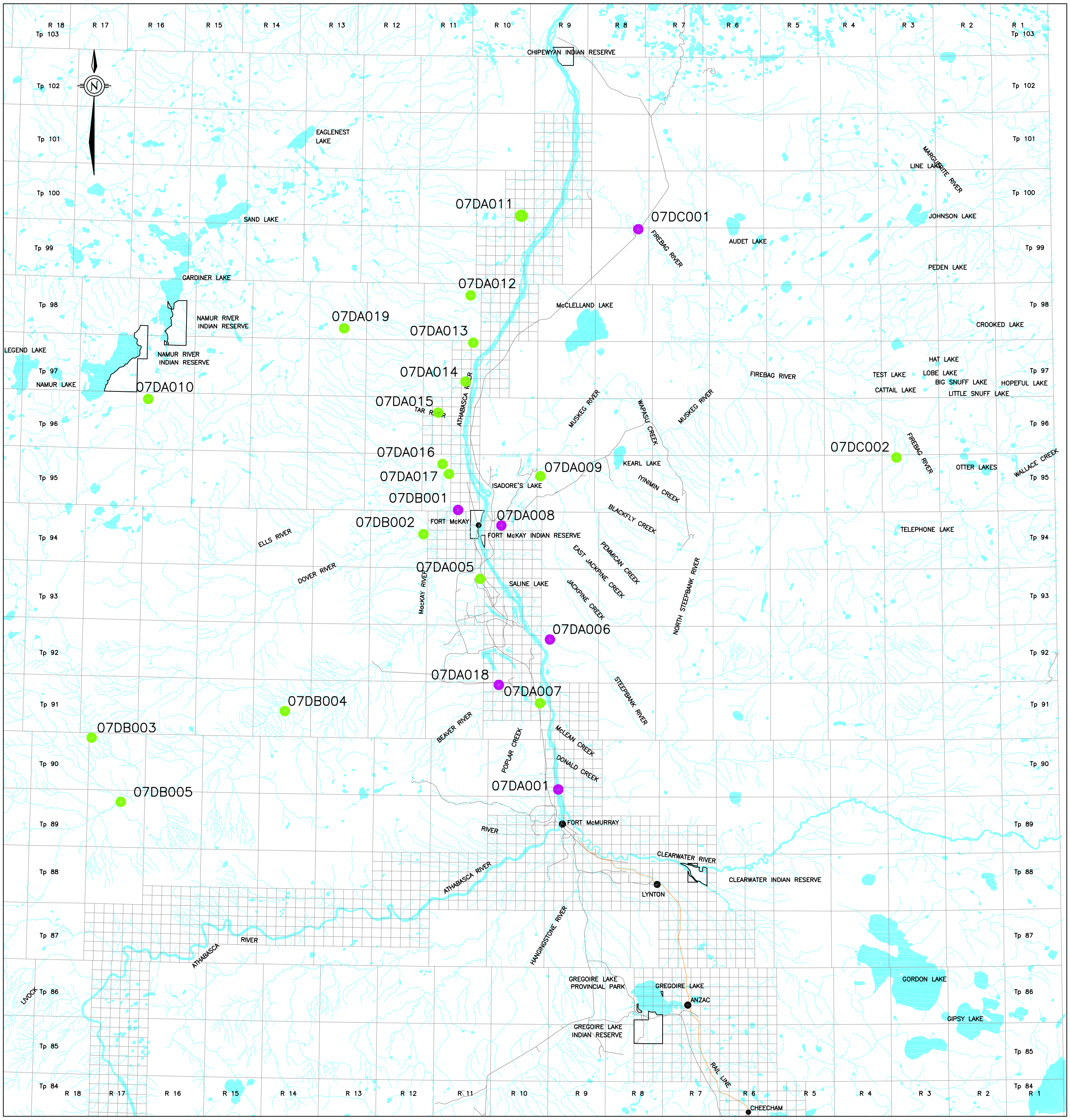
Table 3.2 Details of Environment Canada Climate Monitoring Stations North of Fort McMurray

Station	Location		Elevation (m)	Daily Mean Data	Hourly Data	Active?
	North	West				
Algar Lookout (Station 3060110)	56° 07'	111° 47'	780	rainfall 1957 – 2001[a] temperature 1965 – 2001[a]		✓
Birch Mountain Lookout (Station 3060700)	57° 43'	111° 51'	853	rainfall 1960 – 2001[a] temperature 1966 – 2001[a]		✓
Bitumont Lookout (Station 3060705)	57° 22'	111° 32'	349	rainfall 1962 – 2001[a] temperature 1962 – 2001[a]		✓
Buckton Lookout (Station 3060922)	57° 52'	112° 06'	793	rainfall 1965 – 2001[a] temperature 1965 – 2001[a]		✓
Christina Lookout (Station 3061580)	55° 35'	111° 51'	823	rainfall 1967 – 2001[a] temperature 1967 – 2001[a]		✓
Conklin Lookout (Station 3061800)	55° 37'	111° 11'	671	rainfall 1954 – 2001[a] temperature 1965 – 2001[a]		✓
Cowpar Lookout (Station 3061930)	55° 50'	110° 23'	563	rainfall 1957 – 2001[a] temperature 1965 – 2001[a]		✓
Ells Lookout (Station 3062300)	57° 11'	112° 20'	610	rainfall 1961 – 2001[a] temperature 1964 – 2001[a]		✓
Fort McMurray Airport (Station 3062693)	56° 39'	111° 13'	369	rainfall 1944 – 2001 snowfall 1944 – 2001 precipitation 1944 – 2001 temperature 1944 – 2001	atmospheric pressure 1953 – 2001 dew point temperature 1953 – 2001 dry bulb temperature 1953 – 2001 wind speed 1953 – 2001 wind direction 1959 – 2001	✓
Gordon Lake Lookout (Station 3062889)	55° 37'	110° 30'	488	rainfall 1964 – 2001[a] temperature 1964 – 2001[a]		✓
Heart Lake Lookout (Station 3063120)	55° 00'	111° 20'	887	rainfall 1947– 2001[a] temperature 1965 – 2001[a]		✓
Johnson Lake Lookout (Station 3063563)	57° 35'	110° 20'	549	rainfall 1965 – 2001[a] temperature 1965 – 2001[a]		✓
Legend Lookout (Station 3073792)	57° 27'	112° 53'	911	rainfall 1962 – 1995[a] temperature 1962 – 1995[a]		

Table 3.2 Details of Environment Canada Climate Monitoring Stations North of Fort McMurray (continued)

Station	Location		Elevation (m)	Daily Mean Data	Hourly Data	Active?
	North	West				
Mildred Lake (Station 3064531 and Station 3064528)	57° 05'	111° 36'	310	rainfall 1973 – 1982, 1993 – 2001 snowfall 1973 – 1982, 1993 – 2001 precipitation 1973 – 1982, 1993 – 2001 temperature 1973 – 1982, 1993 – 2001	temperature 1994 – 2001 dew point temperature 1994 – 2001 wind speed 1994 – 2001 rainfall 1995 – 1996 snow by weight 1995 – 1996 snow on ground 1995 – 1996	✓
Muskeg Lookout (Station 3064740)	57° 08'	110° 54'	652	rainfall 1965 – 2001[a] temperature 1965 – 2001[a]		✓
Richardson Lookout (Station 3065492)	57° 55'	110° 58'	305	rainfall 1960 – 2001[a] temperature 1964 – 2001[a]		✓
Round Hill Lookout (Station 3065560)	55° 18'	111° 59'	750	rainfall 1952 – 2001[a] temperature 1951 – 2001[a]		✓
Stoney Mountain Lookout (Station 3066160)	56° 23'	111° 14'	762	rainfall 1954 – 2001[a] temperature 1964 – 2001[a]		✓
Tar Island (Station 3066364)	56° 59'	111° 28'	240	rainfall 1970 – 1984[a]		
Thickwood Lookout (Station 3066380)	56° 53'	111° 39'	604	rainfall 1957 – 1994[a] snowfall 1957 – 1991[a] precipitation 1957 – 1991[a] temperature 1957 – 1992[a]		
Winefred Lookout (Station 3067590)	55° 20'	110° 12'	744	rainfall 1957 – 2001[a] temperature 1965 – 2001[a]		✓

Notes: [a] Seasonal values only.
Locations of these climatic monitoring sites are shown on Figure 3.2.



20 0 20

SCALE KILOMETRES

LEGEND

- ROADWAYS
- RIVERS AND STREAMS
- ACTIVE HYDROLOGY MONITORING STATIONS
- DISCONTINUED HYDROLOGY MONITORING STATIONS

REFERENCE

DIGITAL DATA SETS 74D, 74E, 74I
84A AND 84H FROM RESOURCE DATA DIVISION
ALBERTA ENVIRONMENTAL PROTECTION, 1997.
DATUM: NAD83 PROJECTION: UTM ZONE 12

PROJECT

RAMP FIVE YEAR REPORT

TITLE

LOCATIONS OF ENVIRONMENT CANADA HYDROLOGIC MONITORING STATIONS NORTH OF FORT McMURRAY

Golder Associates
Calgary, Alberta

PROJECT	No. 022-2301.7250		FILE No. Hydro Monitoring St.
DESIGN	NS	27/11/02	SCALE AS SHOWN REV. 0
CADD	AS	06/03/03	
CHECK	NS	03/01/03	FIGURE: 3.3
REVIEW			

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Table 3.3 Details of Environment Canada Hydrology Monitoring Stations North of Fort McMurray

Station	Location		Basin Characteristics		Period of Record	Active Station
	North	West	Drainage Area (km^2)	Elevation (m)		
Athabasca River (Station 07DA001)	56° 46’ 50”	111° 24’ 00”	133,000	240 – 1,490	1957 – 2001	✓
Beaver River (Station 07DA005)	57° 06’ 00”	111° 38’ 00”	454	270 – 530	1961 – 1966 1972 – 1975	
Steepbank River (Station 07DA006)	57° 00’ 14”	111° 24’ 53”	1,320	300 – 580	1972 – 2001	✓
Poplar Creek[a] (Station 07DA007)	56° 54’ 50”	111° 27’ 35”	151	270 – 460	1972 – 1986	
Muskeg River (Station 07DA008)	57° 11’ 30”	111° 34’ 05”	1,460	260 – 560	1974 – 2001	✓
Jackpine Creek[a] (Station 07DA009)	57° 15’ 34”	111° 27’ 53”	358	270 – 490	1975 – 1993	
Ells River (Station 07DA010)	57° 22’ 30”	112° 33’ 40”	1,380	640 – 730	1975 – 1979	
Unnamed Creek (Station 07DA011)	57° 39’ 41”	111° 31’ 11”	274	270 – 760	1975 – 1993	
Asphalt Creek (Station 07DA012)	57° 32’ 20”	111° 40’ 36”	148	290 – 850	1975 – 1977	
Pierre River (Station 07DA013)	57° 27’ 55”	111° 39’ 14”	123	270 – 820	1975 – 1977	
Calumet River[a] (Station 07DA014)	57° 24’ 12”	111° 40’ 57”	183	250 – 610	1975 – 1977	
Tar River[a] (Station 07DA015)	57° 21’ 14”	111° 45’ 29”	301	270 – 810	1975 – 1977	
Joslyn Creek (Station 07DA016)	57° 16’ 27”	111° 44’ 30”	257	270 – 760	1975 – 1993	
Ells River[a] (Station 07DA017)	57° 16’ 04”	111° 42’ 51”	2,450	270 – 730	1975 - 1986	
Beaver River (Station 07DA018)	56° 56’ 29”	111° 33’ 54”	165	320 – 530	1975 – 2001	✓
Tar River (Station 07DA019)	57° 29’ 05”	112° 01’ 10”	103	620 – 810	1976 – 1977	
MacKay River (Station 07DB001)	57° 12’ 38”	111° 41’ 36”	5,570	240 – 520	1972 – 2001	✓
Dover River (Station 07DB002)	57° 10’ 12”	111° 47’ 38”	963	290 – 580	1975 – 1977	
Dunkirk River (Station 07DB003)	56° 51’ 20”	112° 42’ 40”	1,570	490 – 820	1975 – 1979	
Thickwood Creek (Station 07DB004)	56° 53’ 55”	112° 10’ 15”	176	460 – 520	1976 – 1977	
MacKay River (Station 07DB005)	56° 45’ 35”	112 ° 36’ 50”	1,010	470 – 520	1983 – 1991	
Firebag River (Station 07DC001)	57° 38’ 30”	111° 10’ 30”	5,990	270 – 580	1971 – 2001	✓
Lost Creek (Station 07DC002)	57° 17’ 20”	110° 27’ 50”	418	470 – 640	1976 – 1977	

[a] Currently operated as RAMP hydrologic monitoring stations.

3.1.2 Objectives

Of the overall RAMP objectives listed in annual reports, the following three objectives are applicable to this report:

- collecting scientifically defensible baseline and historical data to characterize variability in the oil sands area;
- monitoring aquatic environments in the oil sands area in order to detect and assess cumulative effects and regional trends; and
- collecting data against which predictions contained in EIAs can be verified.

Based on these objectives and input from the RAMP Climate and Hydrology Subgroup of the Technical Subcommittee, the following specific objectives are addressed in this report, grouped by the three major objectives:

- Objective 1:
  - to characterize the natural variation in climatic and hydrologic parameters, including precipitation, temperature, water yield, flood peak discharges and low flows in the Oil Sands Region and identify linkages between climatic and hydrologic parameters; and
  - to define baseline ranges for climatic and hydrologic parameters for the area monitored by RAMP.
- Objective 2:
  - to investigate trends over time in precipitation, temperature, water yield, flood peak discharges and low flows, based on available long-term climatic and hydrologic data; and
  - to evaluate whether cumulative effects can be evaluated at this time and whether the data collected by RAMP will be appropriate to do so in the future.
- Objective 3:
  - to characterize the behaviour of the smaller local areas (streamflow and precipitation) monitored by RAMP and assess their likely behavior in the longer term; and
  - to evaluate whether EIA predictions can be evaluated at this time and whether the data collected by RAMP will be appropriate to do so in the future.

The cumulative hydrological effects of natural variation, oil sands development and other human activities ocurring in the watershed of each station are reflected in the results for each station. Cumulative effects are not treated separately in Section 3.4 of this report since they are inherently included in data used to assess trends in this Section.

One specific objective applies to all three major objectives. This objective is to evaluate the appropriateness of the current study design and recommend improvements, if applicable.

3.1.3 Scope

The objectives of this report are addressed by analyzing the following two sets of data:

- long-term regional climatic and hydrologic data, archived by Environment Canada and supplemented by RAMP data in cases where Environment Canada data are limited; and
- short-term climatic and hydrologic data collected by RAMP.

Long-term regional climatic and hydrologic data are used to characterize existing variability and to detect cumulative effects and regional trends. These analyses require long-term data because smaller data sets are unlikely to reflect the range and distribution of conditions necessary to characterize long-term natural variation. The natural variability of water-related parameters between extreme drought and extreme flood conditions can span orders of magnitude. Since the range of natural variation is large compared to mean values, a long period of record is necessary to identify cumulative effects or regional trends.

For instance, when undertaking a flood frequency analysis on a body of data, it has been calculated that 48 years of record would be required to provide a 100-year flood estimate accurate to within 25% of the expected population value at a 95% confidence limit, and that 115 years of record would be required to raise the accuracy to within 10% (Linsley et al. 1982). Gauging records for the Athabasca River mainstem are only available from the late 1950s and records for Athabasca River tributaries in the Oil Sands Region are only available from the early 1970s. The record of climatic data from Fort McMurray Airport begins in 1944. The scope of the analysis to characterize existing variability and to detect cumulative effects and regional trends will thus be limited to active stations with the longest available periods of record, as noted in Table 3.4.

Short-term climatic and hydrologic data collected by RAMP are used to characterize the hydrologic responses of the smaller local areas monitored by RAMP and assess their likely long-term regimes. They are used to assess whether EIA predictions can be evaluated at this time and whether the data collected by RAMP will be appropriate to do so in the future.

Results of the long-term data analysis are used to estimate long-term water yields for the RAMP stations. The similarities or differences in yields are discussed in terms of physical watershed parameters. The available short-term data are presented and compared to the long-term estimates. This allows recent measurements to be placed in historical context, in the absence of long-term data. Flood discharges and low flows are not analyzed for the short-term RAMP stations because comparisons between long- and short-term stations are likely to be less valid, for the following reasons:

- RAMP stations tend to have smaller watershed areas than the long-term, regional stations. Smaller watersheds tend to have flood responses that are more sensitive to intense, localized precipitation events and to variations in catchment physiography, such as slope, surficial geology, and lake and wetlands storage than flood responses from larger watersheds;
- winter low flows at RAMP stations are generally not continuously monitored. However, late-winter observations indicate that flows often cease at these stations as a result of small watershed areas and freezing conditions; and
- uncertainties associated with the predicted flood and low flow estimates are much higher from the short-term data sets and will complicate comparisons with estimates from the long-term data sets.

A brief, qualitative discussion of flood discharges and low flows at RAMP stations is presented.

Table 3.4 Long-Term Regional Climatic and Hydrologic Stations Selected for Analysis

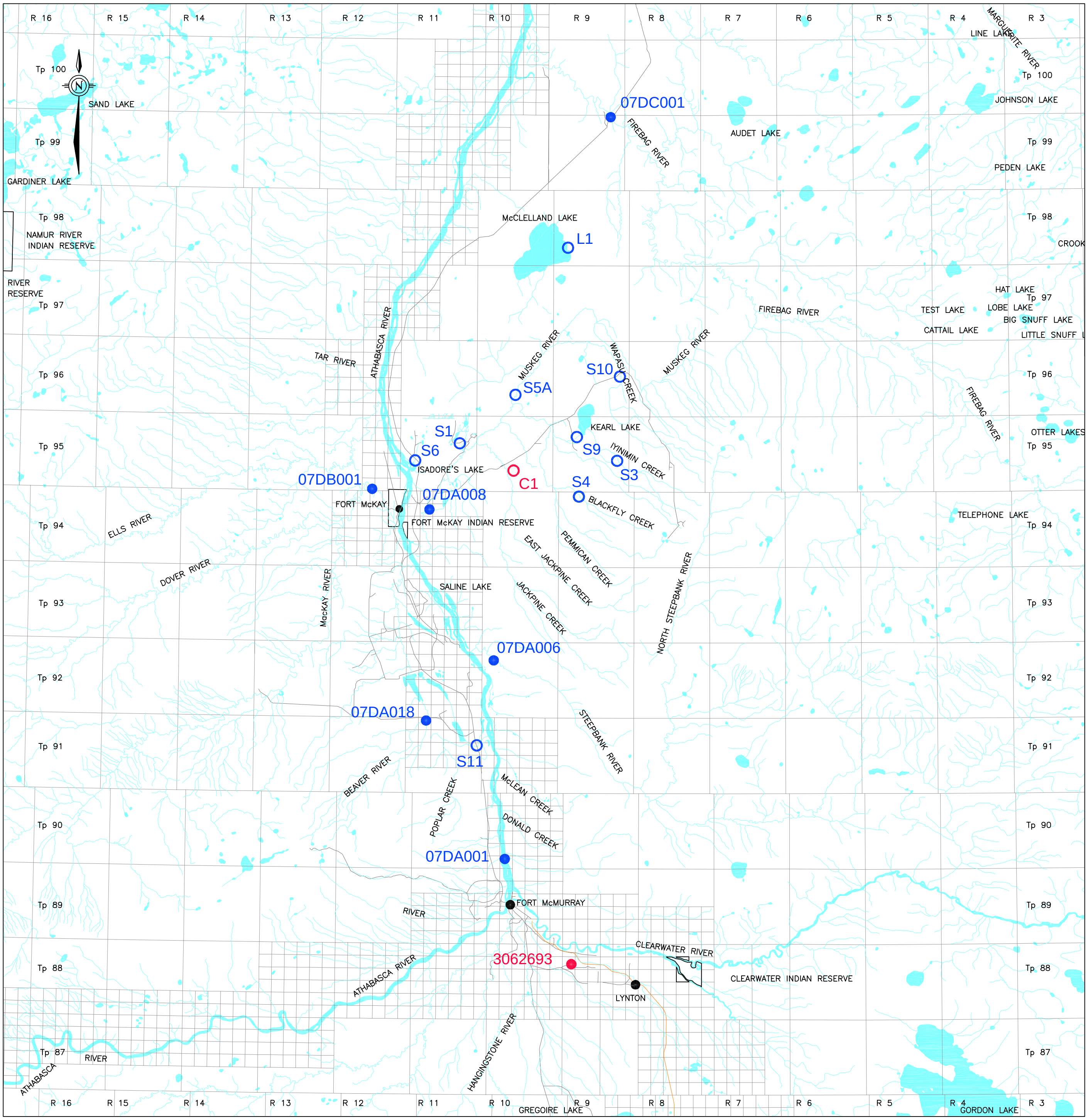
Station	Period of Record	Data Available
Environment Canada Station 07DA001 Athabasca River near Fort McMurray	1957 – 2001	12-month daily mean and extreme discharges.
Environment Canada Station 07DA006 Steepbank River near Fort McMurray	1972 – 2001	12-month daily mean and extreme discharges to mid-1987; 8-month (March to October) mean daily and extreme discharges to 2001.
Environment Canada Station 07DA008 Muskeg River near Fort MacKay	1974 – 2001	12-month daily mean and extreme discharges to mid-1987; 8-month (March to October) mean daily and extreme discharges to 2001; winter discharge data collected by RAMP since November 1999.
Environment Canada Station 07DA009 Jackpine Creek near Fort MacKay	1975 – 1993 1995 – 2001	12-month daily mean and extreme discharges to mid-1987; 8-month (March to October) mean daily and extreme discharges to 1993; open-water discharge data collected by RAMP since May 1995.
Environment Canada Station 07DA018 Beaver River above Syncrude	1975 – 2001	12-month daily mean and extreme discharges to mid-1987; 8-month (March to October) mean daily and extreme discharges to 2001.
Environment Canada Station 07DB001 MacKay River near Fort MacKay	1972 – 2001	12-month daily mean and extreme discharges to mid-1987; 8-month (March to October) mean daily and extreme discharges to 2001.
Environment Canada Station 07DC001 Firebag River near the Mouth	1971 - 2001	12-month daily mean and extreme discharges to mid-1987; 8-month (March to October) mean daily and extreme discharges to 2001.
Environment Canada Station 3062693 Fort McMurray Airport	1944 - 2001	12-month collection of temperature, precipitation and wind data; collection of solar radiation data discontinued in 1996.

The gradual expansion of the RAMP climate and hydrology component means that of the 29 stations for which data for the period 1995 to 2001 are available, only 14 have three or more years of record. A three-year period of record was selected as the lower threshold for analysis of short-term data. Of the 14 stations that met this criterion, those that measure water levels only are not considered, since these would require development of a detailed water balance model, including groundwater components, for which many inputs have not been measured. Those that are operated to supplement long-term stations are also not analyzed separately. This leaves 10 short-term RAMP stations for which detailed analyses are undertaken. A summary of short-term RAMP stations that are examined in this report is shown in Table 3.5.

Table 3.5 Short-Term RAMP Climate and Hydrology Station Selection Rationale

Station	Selected		Years	Rationale for Exclusion
	Yes	No	of Data	
S1 – Alsands Drain	✓		7	
S2 – Jackpine Creek		✓	7	supplements long-term station
S3 – Iyinimin Creek	✓		6	
S4 – Blackfly Creek	✓		4	
S5A – Muskeg River Aurora	✓		7	
S6 – Mills Creek	✓		5	
S7 – Muskeg River		✓	3	supplements long-term station
S8 – Stanley Creek		✓	3	water level data only
S9 – Kearl Lake Outlet	✓		3	
S10 – Wapasu Creek	✓		3	
S11 – Poplar Creek	✓		7	
S12 – Fort Creek		✓	2	<3 years period of record
S13 – Albian Sands Pond #3		✓	2	<3 years period of record
S14 – Ells River		✓	1	<3 years period of record
S15 – Tar River		✓	1	<3 years period of record
S16 – Calumet River		✓	1	<3 years period of record
S17 – Tar River Upland		✓	1	<3 years period of record
S18 – Calumet River Upland		✓	1	<3 years period of record
S19 – Tar River Lowland		✓	1	<3 years period of record
S20 – Muskeg River Upland		✓	1	<3 years period of record
S21 – Shelley Creek		✓	1	<3 years period of record
S22 – Muskeg Creek		✓	1	<3 years period of record
S23 – Aurora Boundary Weir		✓	1	<3 years period of record
S24 – Athabasca River		✓	1	<3 years period of record
S28 – Khahago Creek		✓	1	<3 years period of record
L1 – McClelland Lake	✓		5	
L2 – Kearl Lake		✓	3	water level data only
L3 – Isadore's Lake		✓	2	water level data only
C1 – Aurora Climate Station	✓		7	

The locations of long-term and short-term climatic and hydrologic monitoring stations examined in this report are shown on Figure 3.4.



LEGEND

ROADWAYS
RIVERS AND STREAMS
LONG–TERM HYDROLOGIC MONITORING STATION
LONG–TERM CLIMATIC MONITORING STATION
SHORT–TERM HYDROLOGIC MONITORING STATION
SHORT–TERM CLIMATIC MONITORING STATION

REFERENCE

DIGITAL DATA SETS 74D, 74E, 74I
84A AND 84H FROM RESOURCE DATA DIVISION
ALBERTA ENVIRONMENTAL PROTECTION, 1997.
DATUM: NAD83 PROJECTION: UTM ZONE 12

PROJECT
RAMP FIVE YEAR REPORT

TITLE
CLIMATIC AND HYDROLOGIC MONITORING STATIONS EXAMINED IN THE RAMP FIVE YEAR REPORT

Golder Associates
Calgary, Alberta

PROJECT	No. 022–2301.7250		FILE No. climat–hydrologic5yr	
DESIGN	NS	27/11/02	SCALE AS SHOWN	REV. 1
CADD	AS	06/03/03		
CHECK	NS	03/01/03	FIGURE: 3.4	
REVIEW				

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3.2 CHARACTERIZING EXISTING VARIABILITY

3.2.1 Precipitation

3.2.1.1 Methods

The Environment Canada Climate Station at Fort McMurray Airport (Station 3062693) provides precipitation data for the period of record 1944 to 2001. The available data include total daily rainfall, snowfall and precipitation.

Rainfall data were analyzed by determining the total rainfall measured in each calendar year, from 1944 to 2001. A frequency analysis was undertaken to determine the mean annual, as well as 100-year wet and dry rainfall depths.

Snowfall data were analyzed by determining the water equivalent depth of “snowfall-to-runoff”, for each year from 1945 to 2001. This was defined as the annual snowfall measured from October to May in each year, with the value assigned to the year in which snowmelt occurred. This period was selected to characterize the amount of snowfall that would contribute to spring runoff in that calendar year. The annual snowfall to May 1944 was not calculated because late-1943 data were unavailable. Snowfall data for the calendar years 1992 and 1993 are not reported by Environment Canada, so values were derived by subtracting the reported rainfall depths from the reported total precipitation depths. A frequency analysis was undertaken to determine the mean annual, as well as 10-year and 100-year wet and dry snowfall-to-runoff depths.

Precipitation-to-runoff values were determined by adding the annual rainfall and snowfall-to-runoff for each calendar year, from 1945 to 2001. A frequency analysis was undertaken to determine mean annual, as well as 10-year and 100-year wet and dry, precipitation-to-runoff depths.

The wet-year frequency analyses of annual rainfall, snowfall-to-runoff and precipitation-to-runoff were performed using the Log Pearson III distribution, which provided the best fit to the measured data. The dry-year frequency analyses of annual rainfall, snowfall-to-runoff and precipitation-to-runoff were performed using a Type III Extremal distribution, which provided the best fit to the measured data.

3.2.1.2 Results and Discussion

Annual precipitation data from the Environment Canada Climate Station at Fort McMurray Airport (Station 3062693), including rainfall, snowfall-to-runoff and precipitation-to-runoff, are provided in Table 3.6. Statistics of these data are provided in Table 3.7. Graphs of annual rainfall, snowfall-to-runoff and precipitation-to-runoff depths, including the results of the frequency analysis, are provided in Figures 3.5, 3.6 and 3.7, respectively.

Table 3.6 Annual Precipitation Data for Fort McMurray Airport

Year	Snowfall-to-Runoff (mm water)	Rainfall (mm water)	Precipitation-to-Runoff (mm water)
1944	-	361	-
1945	68	170	238
1946	92	271	363
1947	68	275	343
1948	63	205	267
1949	46	329	375
1950	143	210	353
1951	238	188	425
1952	139	273	412
1953	76	262	339
1954	137	346	483
1955	172	299	471
1956	168	410	578
1957	82	334	416
1958	187	257	444
1959	162	349	511
1960	177	407	584
1961	171	219	391
1962	213	279	491
1963	149	235	385
1964	126	281	407
1965	160	254	414
1966	136	359	494
1967	219	224	443
1968	109	337	446
1969	183	346	529
1970	209	449	657
1971	150	227	377

Table 3.6 Annual Precipitation Data for Fort McMurray Airport (continued)

Year	Snowfall-to-Runoff (mm water)	Rainfall (mm water)	Precipitation-to-Runoff (mm water)
1972	298	287	585
1973	280	533	813
1974	222	329	552
1975	131	506	637
1976	134	428	562
1977	151	285	436
1978	123	363	485
1979	173	350	522
1980	118	385	503
1981	112	267	378
1982	201	253	454
1983	174	298	471
1984	101	455	555
1985	186	285	471
1986	162	268	430
1987	177	280	457
1988	184	261	444
1989	194	387	580
1990	179	304	483
1991	150	477	627
1992	140	300	440
1993	93	224	317
1994	198	235	433
1995	107	402	509
1996	176	474	650
1997	94	378	472
1998	71	185	256
1999	98	234	332
2000	68	385	454
2001	85	254	339

Source: Environment Canada Climate Station 3062693.

Table 3.7 Statistics of Annual Precipitation Data for Fort McMurray Airport

Parameter	Annual Snowfall-to-Runoff	Annual Rainfall	Annual Precipitation-to-Runoff
length of record	57 years	58 years	57 years
high of record	298 mm (1972)	533 mm (1973)	813 mm (1973)
100-year wet	284 mm	574 mm	741 mm
10-year wet	220 mm	427 mm	601 mm
mean	148 mm	314 mm	461 mm
10-year dry	80 mm	211 mm	323 mm
100-year dry	46 mm	167 mm	233 mm
low of record	46 mm (1949)	170 mm (1945)	238 mm (1945)
standard deviation	54 mm	85 mm	107 mm
coefficient of variation	0.366	0.270	0.232

Source: Environment Canada Climate Station 3062693.

Figure 3.5 Annual Rainfall Data for Fort McMurray Airport

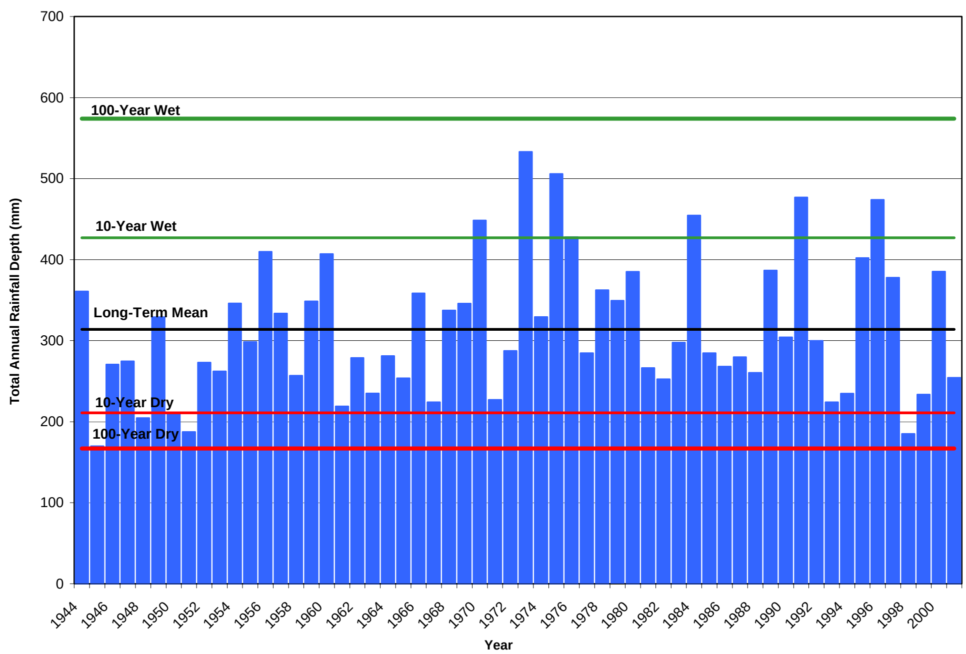


Figure 3.6 Annual Snowfall-to-Runoff Data for Fort McMurray Airport

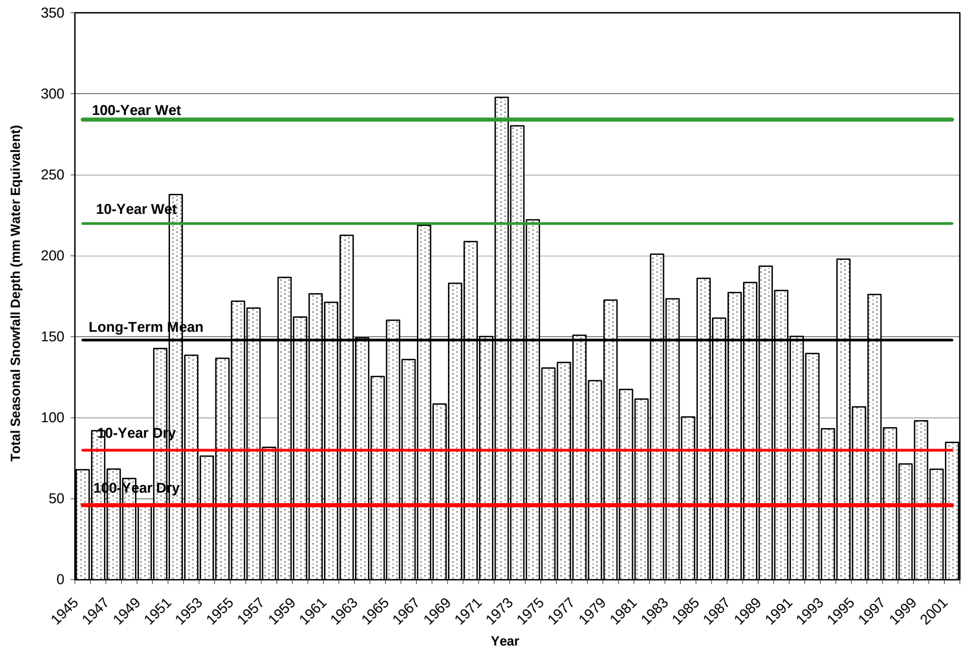
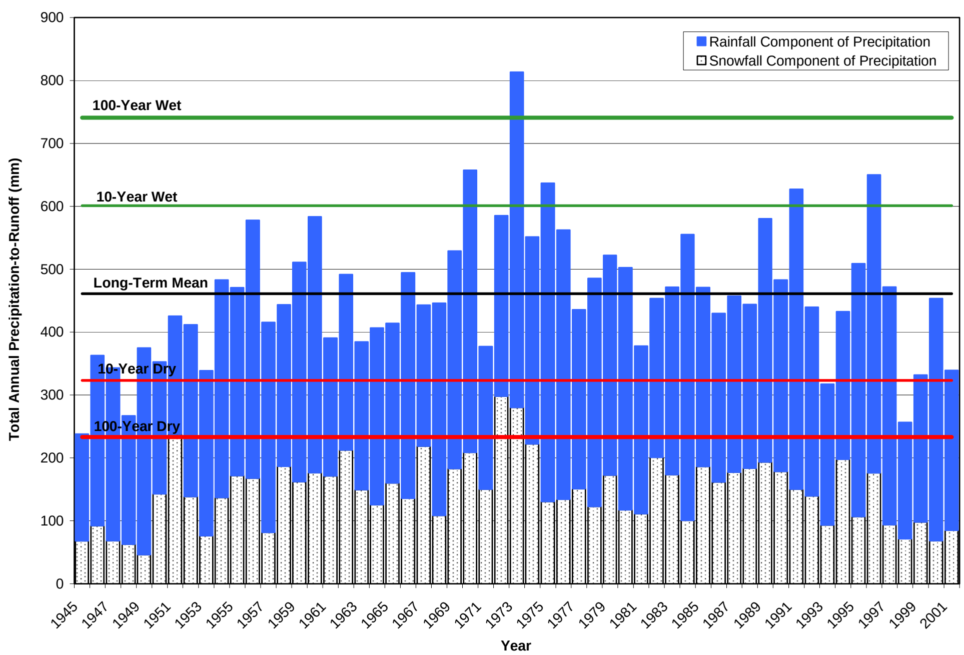


Figure 3.7 Annual Precipitation-to-Runoff Data for Fort McMurray Airport



The variability of the observed snowfall-to-runoff, rainfall and precipitation-to runoff at Fort McMurray Airport can be examined by calculating the coefficient of variation (standard deviation divided by the mean) of these data sets. A coefficient of variation of approximately 0.3 is normal for a data set consisting of natural annual hydrologic data. The calculated values of 0.37, 0.27 and 0.23 for the snowfall-to-runoff, rainfall and precipitation-to-runoff data, respectively, show that the observed variabilities are close to what might be expected. The data also show that snowfall is more variable than rainfall, and that total precipitation is less variable than rainfall. This indicates that the processes involved in generation of snow and factors governing the amount of snowfall are probably more variable than those for rainfall. Annual rainfall is not dependent on the antecedent snowfall-to-runoff, which is confirmed by the weak correlation (0.135) between the two data sets.

3.2.2 Temperature

3.2.2.1 Methods

The Environment Canada Climate Station at Fort McMurray Airport (Station 3062693) provides daily mean temperature data for the period of record from 1944 to 2001.

Temperature data were analyzed by calculating the mean annual temperature measured in each calendar year, from 1944 to 2001. A frequency analysis was undertaken to determine the mean annual, as well as 10-year and 100-year warm and cold, annual mean temperatures.

Winter and summer temperatures were also examined. The period from December to February was selected to represent winter temperatures, since this is the three-month period with the lowest mean temperature. The period from June to August was selected to represent summer temperatures, since this is the three-month period with the highest mean temperature. A frequency analysis was undertaken to determine the mean, as well as 10-year and 100-year warm and cold winter and summer temperatures.

The warm-year analysis for the mean annual, mean winter and mean summer temperatures was performed using the Log Pearson III distribution, which provided the best fit to the measured data. The cold-year analysis for mean annual, mean winter and mean summer temperatures was performed using a Type III Extremal distribution, which provided the best fit to the measured data.

3.2.2.2 Results and Discussion

Annual temperature data from the Environment Canada Climate Station at Fort McMurray Airport (Station 3062693), including mean annual temperatures, are provided in Table 3.8. Statistics of these data are provided in Table 3.9. Graphs of the annual mean temperature, winter mean temperature and summer mean temperature, including the results of the frequency analysis, are provided in Figures 3.8, 3.9 and 3.10, respectively.

Table 3.8 Annual Temperature Data for Fort McMurray Airport

Year	Winter (Dec-Feb) Mean Temperature (°C)[a]	Annual Mean Temperature (°C)	Summer (Jun-Aug) Mean Temperature (°C)
1944	-	1.8	14.3
1945	-14.9	-1.2	14.1
1946	-19.4	-0.9	14.3
1947	-21.8	-1.5	14.1
1948	-16.8	-0.8	15.2
1949	-21.1	-0.5	14.6
1950	-24.7	-2.6	14.1
1951	-18.9	-2.7	13.6
1952	-21.6	0.7	14.2
1953	-15.6	1.1	15.1
1954	-17.0	0.1	14.9
1955	-15.1	-1.6	15.7
1956	-20.6	-0.2	15.6
1957	-18.5	-0.3	14.3
1958	-15.8	0.6	14.5
1959	-19.2	-0.5	13.4
1960	-14.1	0.0	15.0
1961	-15.0	-0.5	16.8
1962	-21.8	-0.6	14.7
1963	-18.8	0.3	16.3
1964	-13.9	-0.2	15.9
1965	-23.7	-1.3	15.4
1966	-19.7	-1.6	14.8
1967	-18.1	-0.6	15.1
1968	-16.8	-0.1	13.7
1969	-22.6	-0.5	14.7
1970	-15.4	-0.5	16.2
1971	-20.5	0.0	16.3

Table 3.8 Annual Temperature Data for Fort McMurray Airport (continued)

Year	Winter (Dec-Feb) Mean Temperature (°C)[a]	Annual Mean Temperature (°C)	Summer (Jun-Aug) Mean Temperature (°C)
1972	-23.2	-1.9	15.4
1973	-17.7	0.6	15.5
1974	-19.8	-0.1	14.6
1975	-15.0	-0.1	15.1
1976	-16.1	1.5	15.7
1977	-13.3	1.3	13.6
1978	-19.1	0.0	14.5
1979	-21.3	-0.2	15.7
1980	-14.1	1.3	15.4
1981	-14.5	3.0	16.9
1982	-22.1	-1.7	14.8
1983	-15.5	0.7	16.3
1984	-15.2	0.9	16.6
1985	-18.7	0.0	14.5
1986	-13.1	1.8	15.3
1987	-8.4	3.2	15.2
1988	-15.1	1.3	16.1
1989	-15.1	-0.1	16.8
1990	-18.1	-0.1	16.4
1991	-16.8	1.3	17.0
1992	-12.6	1.3	14.5
1993	-16.9	1.6	14.3
1994	-19.1	0.7	16.3
1995	-14.1	0.7	14.9
1996	-18.6	-1.5	15.8
1997	-17.7	1.2	16.3
1998	-12.2	2.1	16.8
1999	-15.4	2.2	15.6
2000	-13.9	0.4	14.8
2001	-15.1	2.1	16.2

Source: Environment Canada Climate Station 3062693.

[a] Winter data include January-February of noted year and December of previous year.

Table 3.9 Statistics of Annual Temperature Data for Fort McMurray Airport

Parameter	Mean Winter (Dec-Feb) Temperature	Mean Annual Temperature	Mean Summer (Jun-Aug) Temperature
length of record	57 years	58 years	58 years
high of record	-8.4°C (1987)	3.2°C (1987)	17.0°C (1991)
100-year warm	-9.9°C	3.2°C	17.6°C
10-year warm	-13.1°C	1.8°C	16.5°C
mean	-17.4°C	0.2°C	15.2°C
10-year cold	-22.7°C	-1.5°C	14.0°C
100-year cold	-26.1°C	-2.8°C	13.4°C
low of record	-24.7°C (1950)	-2.7°C (1951)	13.4°C (1959)
standard deviation	3.3°C	1.3°C	0.9°C

Source: Environment Canada Climate Station 3062693.

Figure 3.8 Annual Mean Temperature Data for Fort McMurray Airport

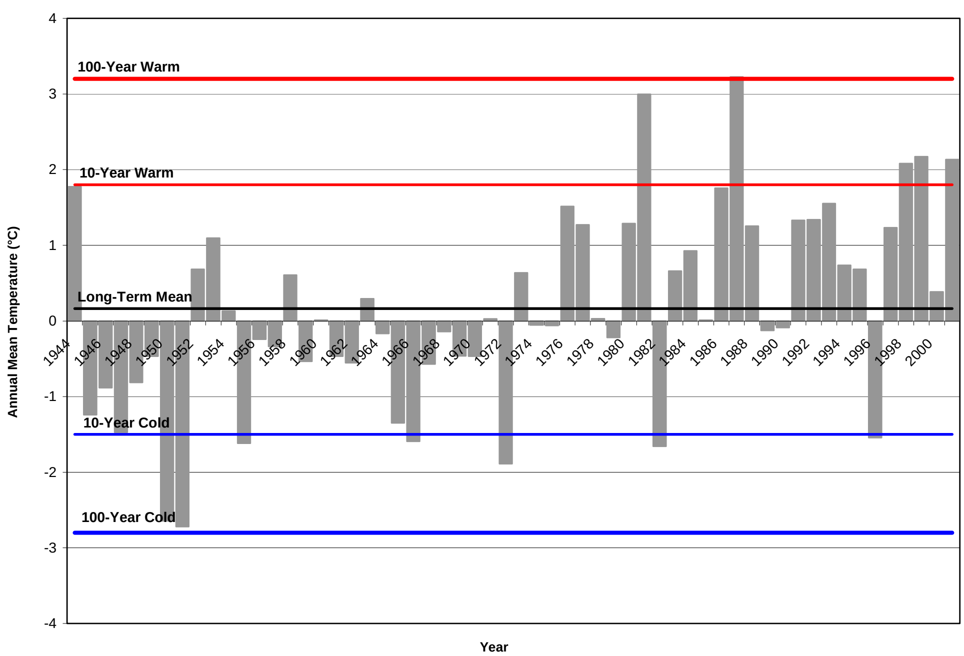


Figure 3.9 Winter Mean Temperature Data for Fort McMurray Airport

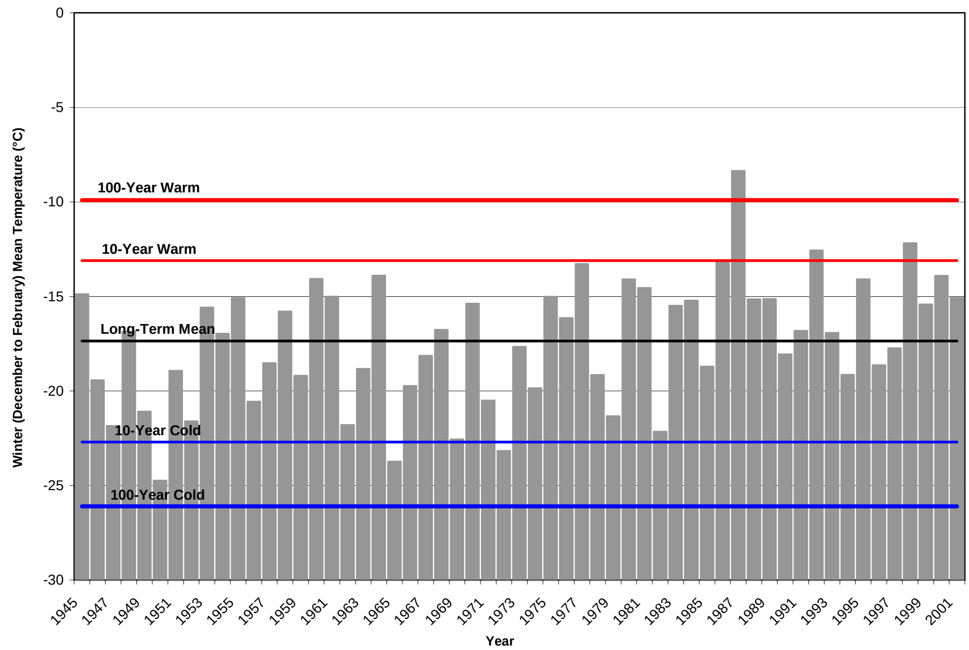
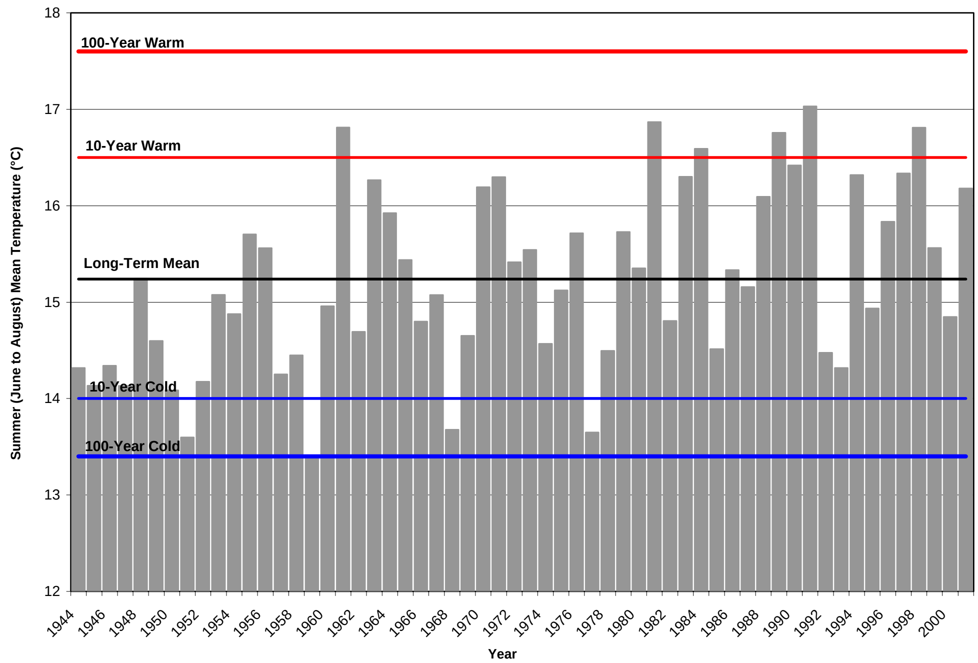


Figure 3.10 Summer Mean Temperature Data for Fort McMurray Airport



The variability of the observed annual mean, winter mean and summer mean temperatures at Fort McMurray Airport can best be examined by calculating the standard deviation of these data sets. The calculated values of 1.3°C, 3.3°C and 0.9°C for the annual mean, winter mean and summer mean data show that winter mean temperatures are more variable than annual mean temperatures, and that summer mean temperatures are less variable than annual mean temperatures. The observed data show that mean annual temperatures at Fort McMurray Airport are more likely to be influenced by the more variable winter temperatures than by less variable summer temperatures. The weak correlation (0.256) between the two data sets indicates that a cold winter is unlikely to cause a cold summer, or vice versa.

There appear to be cycles of warm and cold years and mean annual temperatures appear to be lower during the first half of the period of record than during the second half, with an abrupt change occurring after 1971. These observations are examined in more detail in Section 3.3.2, where data are analyzed for serial dependence and trend.

3.2.3 Water Yield

3.2.3.1 Methods

Annual water yield is defined as the mean depth equivalent of total runoff from a watershed over the course of the year. It is calculated by dividing the cumulative discharge volume measured over the year by the area of the watershed. Water yields are a function of climatic conditions and watershed characteristics. Very often, watershed characteristics and climatic regime are related to the climatic processes that formed the terrain. Steep, impermeable terrain is often associated with high elevations and high precipitation. For a given watershed, greater annual precipitation generally produces higher water yields, while greater evaporation generally produces lower water yields. Physical characteristics of the watershed that affect water yields include slope, surficial geology, and lake and wetlands storage. Steep, fast-draining watersheds tend to have higher water yields than flatter watersheds, which drain less rapidly and allow more water to be lost to deep percolation and evaporation. Surficial geology affects runoff quantities in a number of ways. Steep terrain tends to be associated with less erodible, and therefore less permeable, soil and also with higher elevations and therefore greater precipitation. The permeability of surficial material affects the rate of deep percolation, and the porosity of surficial material affects storage in the surficial aquifer. Drawdown of the surficial aquifer during a dry year may reduce water yields in the next year, as precipitation contributes to aquifer recharge instead of runoff. Surficial geology also correlates closely to vegetation type, which affects water losses to evapotranspiration. Lake and wetlands storage can have large effects on water yields, especially where open-water areas comprise a significant portion of the watershed. Evaporative losses from open water, including lakes, wetlands and beaver ponds, can significantly reduce water yields.

Water yields were analyzed by examining annual stream discharge data from the seven long-term hydrologic monitoring stations noted in Table 3.4:

- Station 07DA001 – Athabasca River below Fort McMurray;
- Station 07DA006 – Steepbank River near Fort McMurray;
- Station 07DA008 – Muskeg River near Fort MacKay;
- Station 07DA009 – Jackpine Creek near Fort MacKay;
- Station 07DA018 – Beaver River above Syncrude;
- Station 07DB001 – MacKay River near Fort MacKay; and
- Station 07DC001 – Firebag River near the Mouth.

Until mid-1987, most of the stations being examined have a continuous record of data, except for occasional gaps of varying duration. Calculation of annual water yields generally requires a complete January-to-December data set. Data gaps were filled based on best estimates of stream discharges during periods where records were unavailable. Data gaps were first examined by considering the duration and expected stream behaviour during the gap. Data gaps during the November to mid-March period, when base flows dominate and discharges are unaffected by snowmelt or rainfall, were filled by interpolating between measurements at the start and finish of the gap. This is justified by the existence of relatively steady flows during the winter season. Also, since discharges are at their lowest in the annual cycle, water yield calculations are less sensitive to possible inaccuracies than they would be to those applied to higher discharges. Data gaps during periods that could be affected by snowmelt or rainfall were also filled by interpolating between measurements at the start and finish of the gap. However, these gaps were filled by estimating variable discharges, based on data from adjacent stations, stations upstream or downstream on the same stream and/or local precipitation data.

After mid-1987, the flow record provided at Environment Canada hydrologic monitoring stations is limited to the period from March to October, except for the station on the Athabasca River. These long-duration data gaps over the winter months were filled based on the assumption that the missing data consisted of baseflows only, and that the shape of the recession curve was similar to that observed at the station for years where data were available. For stations with small watershed areas, such as the Beaver River and Jackpine Creek, flows frequently cease during midwinter. For the Muskeg River, winter data have been collected since late 1999 as part of RAMP.

Annual discharge volumes were divided by the tributary watershed area at the monitoring station to calculate a runoff depth for each year of available data. Frequency analyses of maximum and minimum events were undertaken to determine the mean annual water yield from the tributary watershed, as well as the 10-year and 100-year wet and dry water yields. The Consolidated Frequency Analysis (CFA) program, developed by Environment Canada, was used for the maximum event (high flow) frequency analysis. The frequency analysis program (FRQ), developed by G.W. Kite, was used for the minimum event (low flow) frequency analysis. Both programs allow the available data set to be analyzed using a variety of frequency distributions. The analysis involved selecting an appropriate distribution, based on the goodness-of-fit of the data.

The annual precipitation available for runoff, as measured at Fort McMurray and presented in Section 3.2.1, is also plotted on each water yield graph to compare the response of the watershed to precipitation. However, values measured at Fort McMurray may not be representative of precipitation on the local watershed, particularly for large watersheds such as the Athabasca River, or for localized storm events.

3.2.3.2 Results and Discussion

For watersheds of similar size, subject to similar precipitation inputs, annual water yields are larger for those that are steeper and have high drainage densities and a low proportion of open water. Conversely, watersheds that are flatter, with low drainage densities and a high proportion of open water, tend to have lower water yields. Water yields are reduced by losses to groundwater and may be increased by inflows of groundwater from adjacent watersheds or by significant releases from groundwater storage during baseflow. This behaviour should be considered when examining flood discharges for the long-term hydrologic monitoring stations in the Oil Sands Region.

Figures showing calculated annual water yields, derived water yield statistics and measured annual precipitation at Fort McMurray Airport for each station are provided in Figures 3.11 to 3.17. A summary of the water yield analysis for the Oil Sands Region long-term hydrologic monitoring stations is provided in Table 3.10.

Table 3.10 Statistics of Water Yields for Long-Term Hydrologic Monitoring Stations in the Oil Sands Region

Statistic	Athabasca River 07DA001	Steepbank River 07DA006	Muskeg River 07DA008	Jackpine Creek 07DA009	Beaver River 07DA018	MacKay River 07DB001	Firebag River 07DC001
drainage area	133,000 km^2	1,320 km^2	1,460 km^2	358 km^2	165 km^2	5,570 km^2	5,990 km^2
period of record	44 Years 1958-2001	28 Years 1974-2001	28 Years 1974-2001	26 Years 1975-93; 1995-2001	26 Years 1976-2001	29 Years 1973-2001	27 Years 1975-2001
mean annual discharge	638 m^3/s	4.99 m^3/s	4.06 m^3/s	1.07 m^3/s	0.539 m^3/s	14.9 m^3/s	25.0 m^3/s
frequency distribution (wet)	3-Parameter Lognormal	Generalized Extreme Value	Generalized Extreme Value	Generalized Extreme Value	Generalized Extreme Value	Generalized Extreme Value	Generalized Extreme Value
highest observed	240 mm (1997)	252 mm (1975)	172 mm (1997)	187 mm (1997)	214 mm (1996)	199 mm (1997)	188 mm (1997)
100-year wet return period	244 mm	269 mm	193 mm	223 mm	305 mm	263 mm	215 mm
10-year wet return period	193 mm	190 mm	143 mm	169 mm	179 mm	150 mm	177 mm
long-term average	151 mm	119 mm	89 mm	94 mm	103 mm	84 mm	132 mm
10-year dry return period	112 mm	56 mm	37 mm	27 mm	35 mm	28 mm	90 mm
100-year dry return period	94 mm	27 mm	7 mm	0 mm	7 mm	4 mm	63 mm
lowest observed	101 mm (2001)	33 mm (1999)	16 mm (1999)	3 mm (1999)	13 mm (1999)	6 mm (1999)	79 mm (1981)
frequency distribution (dry)	Type 3 Extremal	Type 3 Extremal	Type 3 Extremal	Type 3 Extremal	Type 3 Extremal	Type 3 Extremal	Type 3 Extremal
standard deviation of water yield	30.5 mm	51.9 mm	40.5 mm	50.7 mm	56.9 mm	49.4 mm	32.5 mm
coefficient of variation c_v	0.209	0.435	0.462	0.564	0.552	0.588	0.247
precipitation correlation coefficient	0.414	0.741	0.527	0.460	0.565	0.586	0.569

Figure 3.11 Annual Water Yields for Athabasca River Below Fort McMurray (Environment Canada Station 07DA001)

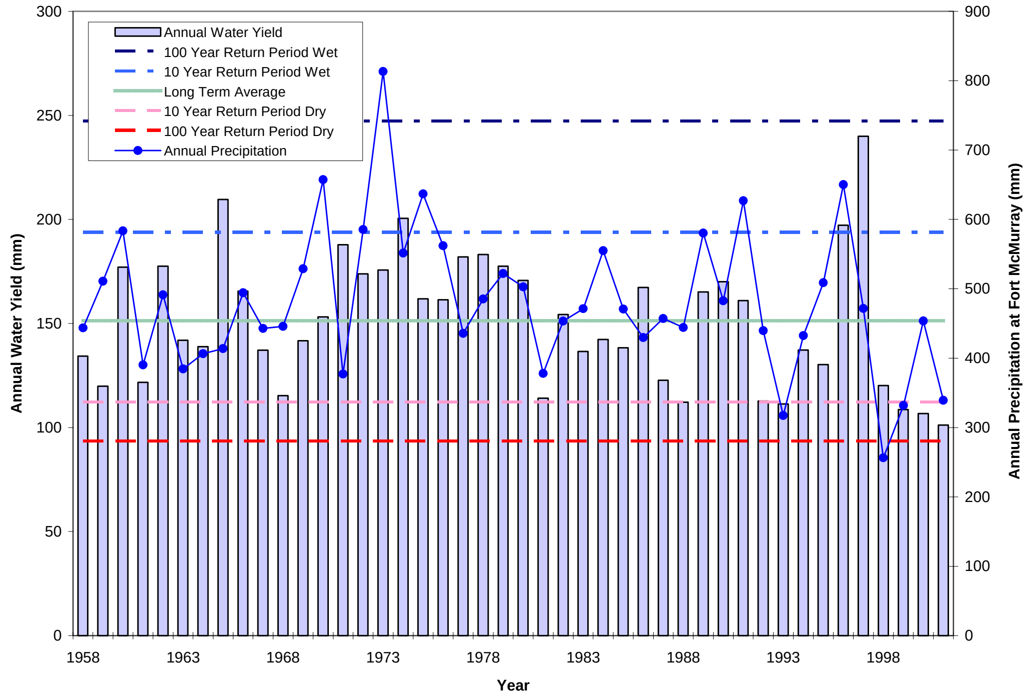


Figure 3.12 Annual Water Yields for Steepbank River Near Fort McMurray (Environment Canada Station 07DA006)

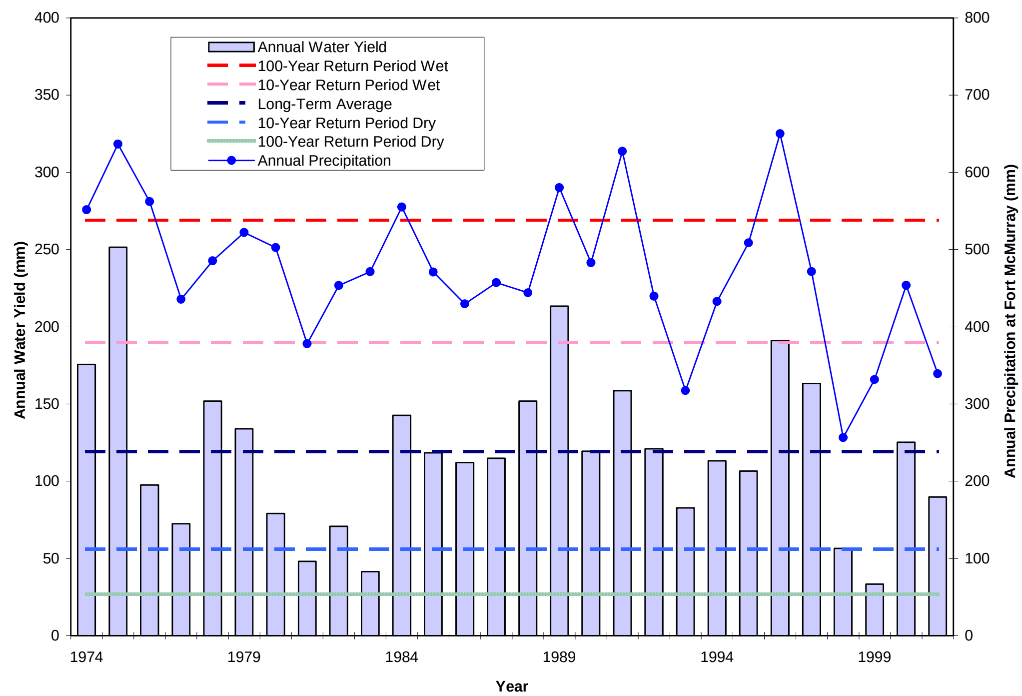


Figure 3.13 Annual Water Yields for Muskeg River Near Fort MacKay (Environment Canada Station 07DA008)

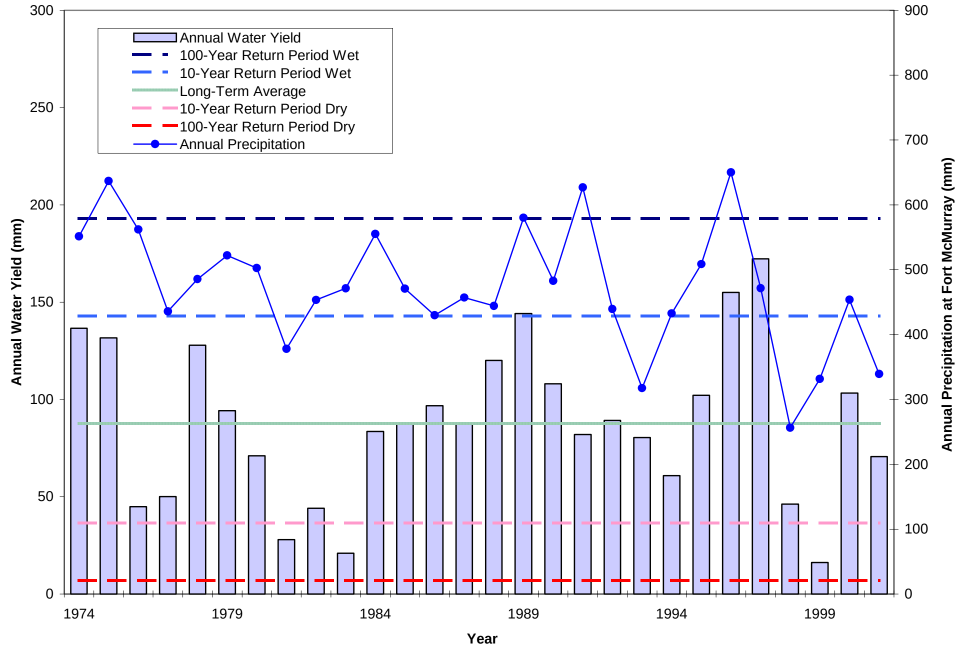


Figure 3.14 Annual Water Yields for Jackpine Creek Near Fort MacKay (Environment Canada Station 07DA009)

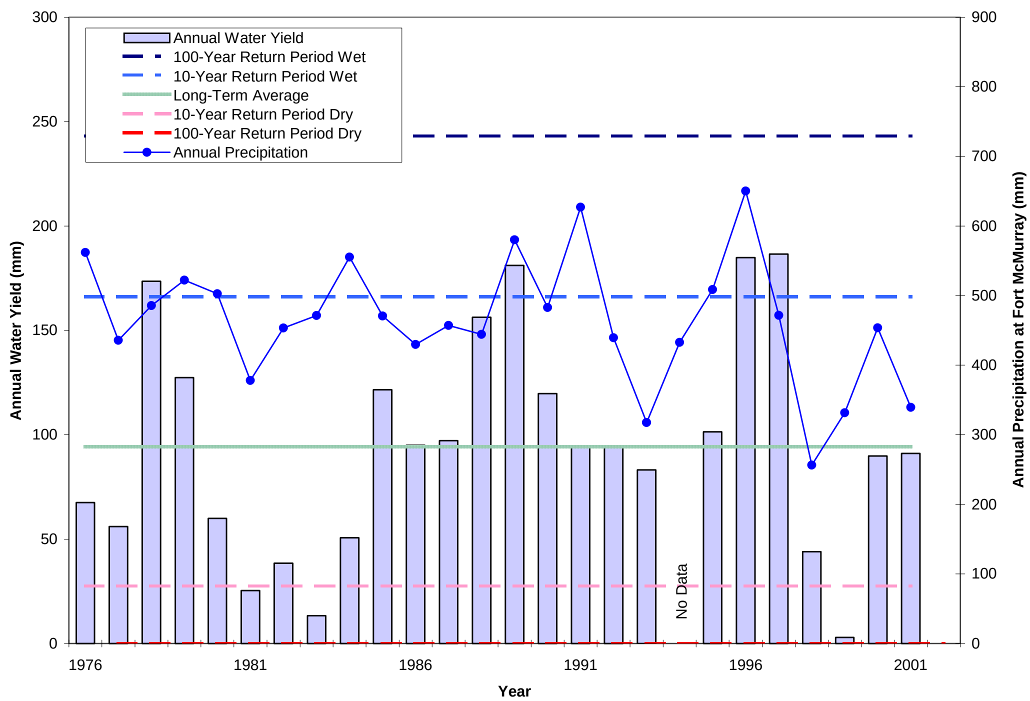


Figure 3.15 Annual Water Yields for Beaver River Above Syncrude (Environment Canada Station 07DA018)

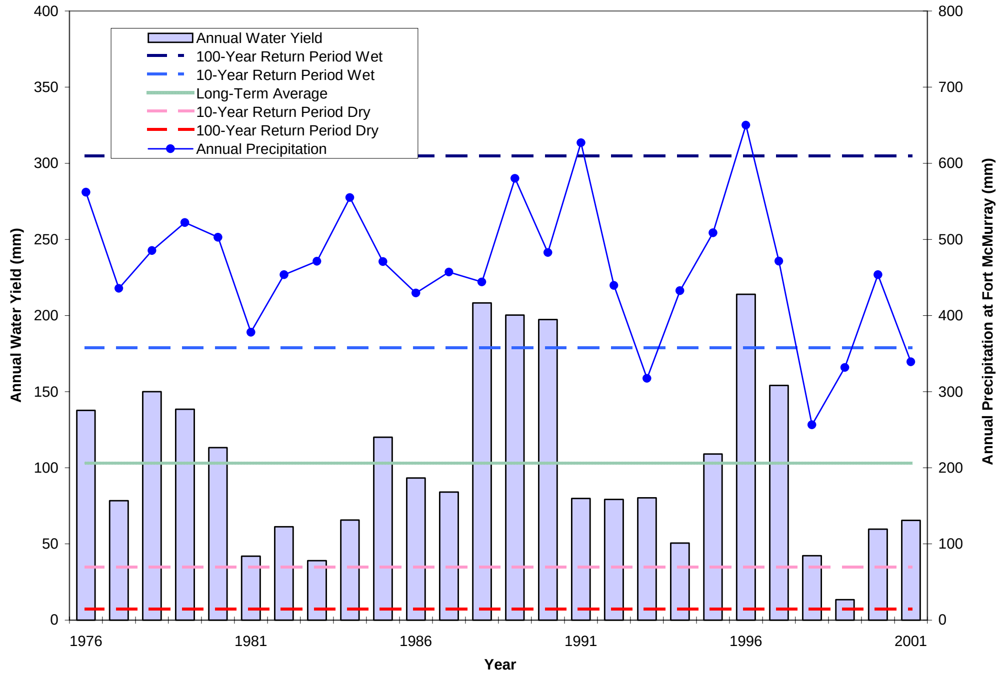


Figure 3.16 Annual Water Yields for MacKay River Near Fort MacKay (Environment Canada Station 07DB001)

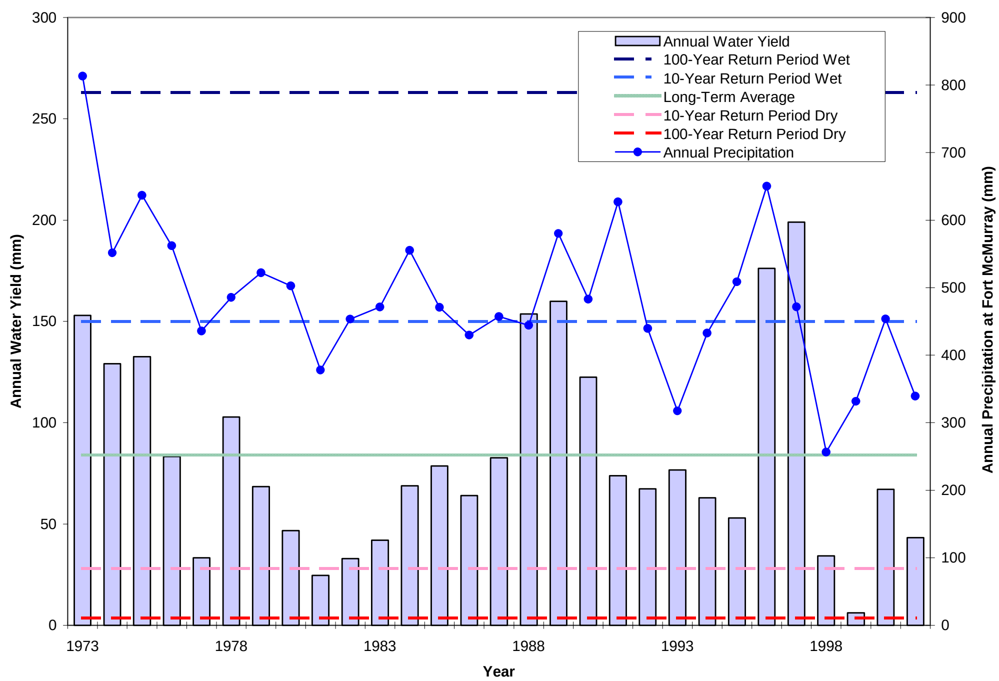
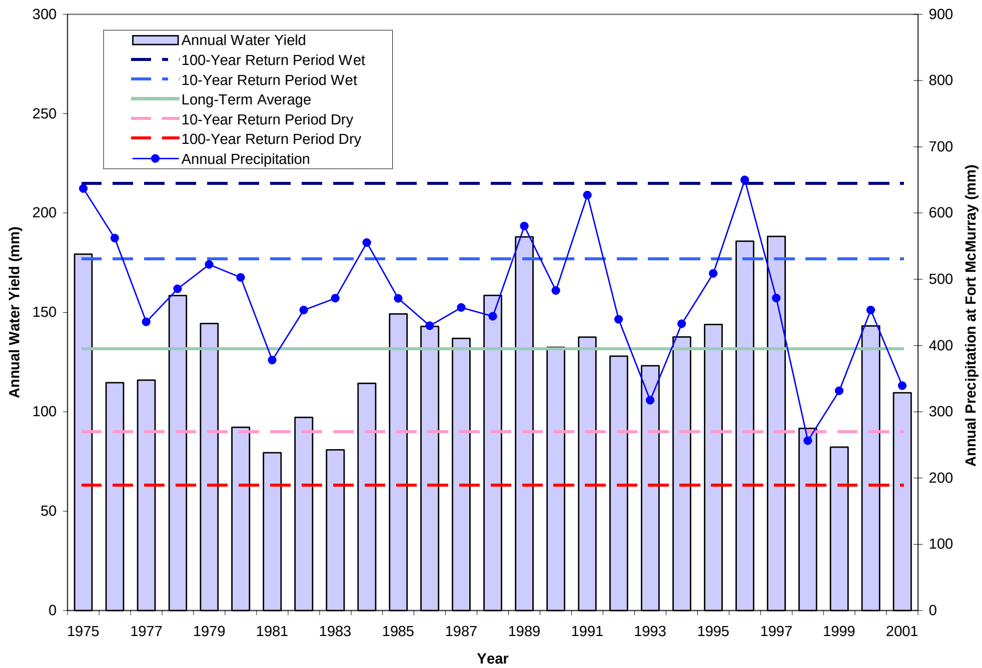


Figure 3.17 Annual Water Yields for Firebag River Near the Mouth (Environment Canada Station 07DC001)



Hydrologic Monitoring Station 07DA001 is located on the Athabasca River, below Fort McMurray and the confluence with the Clearwater River. It drains an area of 133,000 km^2 that extends from the Rocky Mountains in Jasper National Park to areas of northeast Saskatchewan. This watershed area includes regions with differing climatic and hydrologic characteristics and thus the Athabasca River is the river in the Oil Sands Region that is least affected by local conditions. However, a correlation coefficient of +0.41 indicates that annual precipitation at Fort McMurray is correlated to annual water yield at this station, as can be observed on Figure 3.11. This correlation is weaker than that for any of the other stations examined in this report, as would be expected, but may mean that conditions at Fort McMurray may be indicative of conditions across northern Alberta. That the long-term water yield of the Athabasca River at this station (151 mm) is the largest of any of the stations examined in this report is likely due to wetter conditions in the upper watershed. The calculated coefficient of variation (ratio of standard deviation to mean of the data set) of 0.209 is indicative of relatively low variability in water yield. The overall response of the watershed is probably dampened by the varying climate across the watershed area and the asynchronous responses of the individual sub-basins.

Hydrologic Monitoring Station 07DA006 is located on the Steepbank River, upstream of its confluence with the Athabasca River. It drains an area of 1,320 km^2 that includes much of the plateau and south slopes of Muskeg Mountain. This watershed comprises approximately 45% upland areas (slopes greater than 0.5%) and 55% lowland areas (slopes less than 0.5%). This station has a much smaller watershed area than the Athabasca River, which it is tributary to, and is thus more likely to be affected by local precipitation conditions. The correlation coefficient between annual precipitation at Fort McMurray Airport and water yield at this station is +0.74, which is significantly larger than that for the Athabasca River. The long-term water yield for the Steepbank River is 119 mm, which is less than that for the Athabasca River. The calculated coefficient of variation of 0.44 indicates that annual water yields are more variable than those of the Athabasca River, which would be expected for a smaller watershed.

Hydrologic Monitoring Station 07DA008 is located on the Muskeg River, upstream of its confluence with the Athabasca River. It drains an area of 1,460 km^2 that includes the south slopes of the Fort Hills, and the north and west slopes of Muskeg Mountain, including the Jackpine Creek watershed. This watershed comprises approximately 55% upland areas, 44% lowland areas and less than 1% lake area. This station has a tributary area similar to that of the Steepbank River watershed, which borders it to the south, and might be expected to have similar hydrologic characteristics. The correlation coefficient between annual precipitation at Fort McMurray Airport and water yield at this station is +0.53, which is somewhat less than that for the Steepbank River. Differences in water yield might be explained by differences in watershed evapotranspiration, storage capacity and losses to groundwater. The long-term water yield for the Muskeg River is 89 mm, which is less than that for the Steepbank River. The calculated coefficient of variation of 0.46 indicates that annual water yield variability is similar to that at the Steepbank River station.

Hydrologic Monitoring Station 07DA009 is located on Jackpine Creek, formerly known as Hartley Creek. It drains an area of 358 km^2 that includes the west slopes of Muskeg Mountain and contributes approximately 25% of the watershed area of the Muskeg River. This watershed comprises approximately 62% upland areas and 38% lowland areas. This station has a much smaller watershed area than the Steepbank or Muskeg rivers. The long-term water yield for Jackpine Creek is 94 mm, which is similar to that of the Muskeg River. The slightly higher water yield may be due to a higher mean elevation and higher proportion of upland area than for the Muskeg River. The correlation coefficient between annual precipitation at Fort McMurray Airport and water yield at this station is +0.46, and the calculated coefficient of variation of 0.56 indicates that water yields are more variable than those of the Steepbank and Muskeg rivers. This would be expected for a smaller watershed, where the water yield is more likely to be affected by local variations in precipitation.

Hydrologic Monitoring Station 07DA018 is located on the Beaver River, above the disturbed Syncrude base mine. It has a watershed area of 165 km^2 that drains the northeast slopes of the Thickwood Hills. This watershed comprises 100% upland area. This station has the smallest watershed area of the Oil Sands Region long-term hydrologic monitoring stations. The long-term water yield for Jackpine Creek is 103 mm, which is somewhat greater than that of the Muskeg River and Jackpine Creek watersheds, but still lower than that of the Steepbank River watershed. The correlation coefficient between annual precipitation at Fort McMurray Airport and water yield at this station is +0.57. The calculated coefficient of variation of 0.55 indicates that water yields have a similar variability to those of Jackpine Creek, the next smallest watershed examined in this report.

Hydrologic Monitoring Station 07DB001 is located on the MacKay River, upstream of its confluence with the Athabasca River. It drains an area of 5,570 km^2 that includes the north slopes of the Thickwood Hills and some of the plateau and south slopes of the Birch Mountains. The watershed area at this station is approximately four times as large as that at the Muskeg River and Steepbank River stations. The long-term water yield for the MacKay River is 84 mm, which is similar to that of the Muskeg River. Extreme wet-year water yields on the MacKay River are similar to those of the Steepbank River, but extreme dry-year water yields are smaller. The correlation coefficient between annual precipitation at Fort McMurray Airport and water yield at this station is +0.59, which is similar to that for the adjacent Beaver River watershed. The calculated coefficient of variation of 0.59 is the highest observed for the stations examined in this report, and indicates that water yields have a similar variability to those of Jackpine Creek and the Beaver River.

Hydrologic Monitoring Station 07DC001 is located on the Firebag River, upstream of its confluence with the Athabasca River. It drains an area of 5,990 km^2 that extends into Saskatchewan and includes the north-east slopes of Muskeg Mountain and the Marguerite River watershed. The watershed area at this station is approximately the same as that of the MacKay River. However, the mean annual water yield of the Firebag River is significantly higher than that of the MacKay River (132 mm verses 84 mm). This is likely due to a greater rate and volume of groundwater storage and release in the Firebag River watershed. The correlation coefficient between annual precipitation at Fort McMurray Airport and water yield at this station is +0.57, which is similar to that for the MacKay and Beaver river watersheds. The calculated coefficient of variation of 0.25 is, with the exception of the Athabasca River, the lowest observed for the stations examined in this report. This indicates a significantly lower water yield variability than for the Muskeg, Steepbank, Beaver and MacKay rivers and Jackpine Creek, which can again be attributed to the significant storage in this watershed.

3.2.4 Flood Discharge

3.2.4.1 Methods

Annual flood peak discharges may be characterized by the maximum daily mean discharge or by the maximum instantaneous discharge measured at a point. The set of maximum daily mean discharges is generally more complete than that of maximum instantaneous discharges, and hence is used in the following analysis. The use of maximum daily means requires careful interpretation of unit flood flows from large and small watersheds. Maximum instantaneous flows from smaller basins can be significantly larger than maximum daily flows and the differences would, in general, be larger for smaller watersheds than for larger watersheds. However, the long-term stations examined in this report tend to have a relatively large amount of watershed storage and measured maximum instantaneous discharges are typically not much larger than maximum daily discharges.

The annual maximum daily mean discharge is defined as the largest daily mean discharge measured at a hydrologic monitoring station over the course of a calendar year. It is calculated by averaging readings taken at a constant interval over a day (midnight to midnight).

Flood discharges are a function of climatic conditions and watershed characteristics. For a given watershed, larger precipitation events (storms or spring snowpack available for melt) generally produce higher flood discharges. Flood events are relatively short in duration and are therefore not significantly affected by evaporation. However, for snowmelt events, higher temperatures or rain-on-snow generally produce higher flood discharges. Physical characteristics of the watershed that affect flood discharges include slope, surficial geology, and lake and wetlands storage. Steep, fast-draining watersheds tend to have higher flood discharges than flatter watersheds, which drain less rapidly. Surficial geology affects flood discharges in a number of ways. The permeability of surficial material affects the rate of deep percolation, and the porosity of surficial material affects storage in the surficial aquifer. Drawdown of the surficial aquifer during a dry year may reduce flood discharges for a given precipitation event, as precipitation contributes to aquifer recharge instead of to runoff. Surficial geology also correlates closely to vegetation type, which can affect the initial abstraction of water from a precipitation event and affect runoff characteristics. Lakes, wetlands and beaver activity can have large effects on flood discharges, as floods are attenuated by storage in these waterbodies. For watersheds with large drainage areas or significant storage, maximum daily mean discharges are often only slightly lower than maximum instantaneous discharges.

Annual flood discharges were analyzed by examining annual stream discharge data from the seven long-term hydrologic monitoring stations noted in Table 3.4:

- Station 07DA001 – Athabasca River below Fort McMurray;
- Station 07DA006 – Steepbank River near Fort McMurray;
- Station 07DA008 – Muskeg River near Fort MacKay;
- Station 07DA009 – Jackpine Creek near Fort MacKay;
- Station 07DA018 – Beaver River above Syncrude;
- Station 07DB001 – MacKay River near Fort MacKay; and
- Station 07DC001 – Firebag River near the Mouth.

Since complete open-water season flow records are available for these stations, there were no data gaps to be filled. Reported maximum daily mean discharges were compiled for each station's period of record. A frequency analysis of maximum events was undertaken to determine the 2-year, 10-year and 100-year flood discharges at each station. The CFA program, developed by Environment Canada, was used for the maximum event frequency analysis. This program allowed the available data set to be analyzed using a variety of frequency distributions, and the analysis involved selecting an appropriate distribution, based on the goodness-of-fit of the data. Separate analyses of floods due to snowmelt and rainfall events were not undertaken.

3.2.4.2 Results and Discussion

For watersheds of similar size, subject to similar precipitation inputs, flood response is quicker and flood magnitude is larger for those that are steeper and have high drainage densities and low storage capacities. Conversely, watersheds that are flatter, with low drainage densities and high storage capacities, tend to have slower flood responses and lower peaks. As for water yields, it is again a combination of climate and watershed characteristics that governs flood magnitudes. For watersheds with similar topography, subject to similar precipitation inputs, the flood magnitude is larger for larger watersheds. However, smaller watersheds have a quicker flood response and a higher unit flood magnitude (discharge divided by watershed area). A watershed with a fast response to precipitation will generally have a peak flow data set with a higher skewness than that with a slow response. This behaviour should be considered when examining flood discharges for the long-term hydrologic monitoring stations in the Oil Sands Region.

Figures showing measured annual flood discharges and derived flood statistics for each station are provided in Figures 3.18 to 3.24. A summary of the flood discharge analysis for Oil Sands Region long-term hydrologic monitoring stations is provided in Table 3.11.

The Athabasca River at Hydrologic Monitoring Station 07DA001 has a mean annual discharge of 638 m^3/s and the observed maximum daily mean discharge of 4,700 m^3/s occurred in 1971. The mean annual unit discharge at this station is larger than for any of the other long-term regional stations, likely due to wetter areas in the upper watershed. However, the 100-year flood unit discharge at this station is lower than for any of the other long-term regional stations. This is attributed to the large drainage area of the Athabasca River relative to those of the regional stations. In the absence of other factors, the unit flood discharge of a given return period is expected to decrease with increasing watershed area. The calculated coefficient of variation for the flood data is 0.34, which is the lowest for any of the stations examined in this report. The calculated coefficient of skewness is 0.73, which is similar to that for the Muskeg and Steepbank rivers.

Table 3.11 Statistics of Flood Discharges for Long-Term Hydrologic Monitoring Stations in the Oil Sands Region

Statistic	Athabasca River 07DA001	Steepbank River 07DA006	Muskeg River 07DA008	Jackpine Creek 07DA009	Beaver River 07DA018	MacKay River 07DB001	Firebag River 07DC001
shown on figure	3.17	3.18	3.19	3.20	3.21	3.22	3.23
drainage area (km^2)	133,000	1,320	1,460	358	165	5,570	5,990
period of record	44 Years 1958-2001	28 Years 1974-2001	28 Years 1974-2001	26 Years 1975-93; 1995-2001	26 Years 1976-2001	30 Years 1973-2001	27 Years 1975-2001
mean annual discharge (m^3/s)	638	4.99	4.06	1.07	0.539	14.9	25.0
frequency distribution	GEV	Log Pearson III	Log Pearson III	Log Pearson III	Log Pearson III	Log Pearson III	Log Pearson III
highest observed[a] (m^3/s)	4,700 (1971)	81.0 (1985)	66.1 (1985)	17.3 (1997)	33.0 (1988)	339 (1985)	236 (1985)
100-year return period[a] (m^3/s)	5,600	92.6	71.4	25.9	36.3	480	263
10-year return period[a] (m^3/s)	3,780	64.5	46.8	17.0	20.7	258	162
2-year return period[a] (m^3/s)	2,420	32.3	24.1	7.52	7.14	112	93.9
lowest observed[a] (m^3/s)	1,280 (1993)	5.62 (1999)	3.84 (1999)	0.178 (1999)	0.579 (1999)	6.28 (1999)	43.5 (1999)
mean annual unit discharge ($m^3/s/km^2$)	0.0048	0.0038	0.0028	0.0030	0.0033	0.0027	0.0042
highest observed[a] ($m^3/s/km^2$)	0.0353	0.0614	0.0453	0.0483	0.2000	0.0609	0.0394
100-year return period[a] ($m^3/s/km^2$)	0.0421	0.0705	0.0489	0.0723	0.2200	0.0862	0.0439
10-year return period[a] ($m^3/s/km^2$)	0.0284	0.0492	0.0321	0.0475	0.1255	0.0463	0.0270
2-year return period[a] ($m^3/s/km^2$)	0.0182	0.0242	0.0165	0.0210	0.0433	0.0201	0.0157
lowest observed[a] ($m^3/s/km^2$)	0.0096	0.0043	0.0026	0.0005	0.0035	0.0011	0.0073
standard deviation of flood discharge (m^3/s)	871	21.7	15.5	5.30	8.45	49.4	45.9
coefficient of variation (C_v)	0.337	0.611	0.586	0.600	0.889	0.707	0.442
coefficient of skewness (C_s)	0.726	0.754	0.784	0.187	1.169	0.946	1.272

[a] Based on data set of annual maximum daily mean discharges.

Figure 3.18 Annual Maximum Daily Mean Discharges for Athabasca River below Fort McMurray (Environment Canada Station 07DA001)

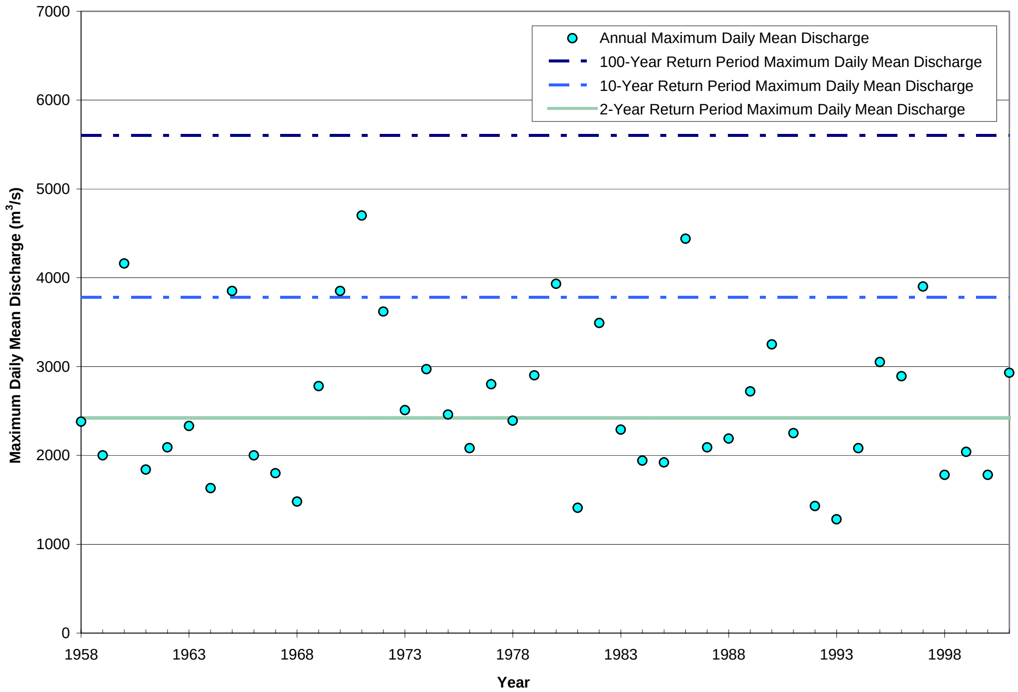


Figure 3.19 Annual Maximum Daily Mean Discharges for Steepbank River near Fort McMurray (Environment Canada Station 07DA006)

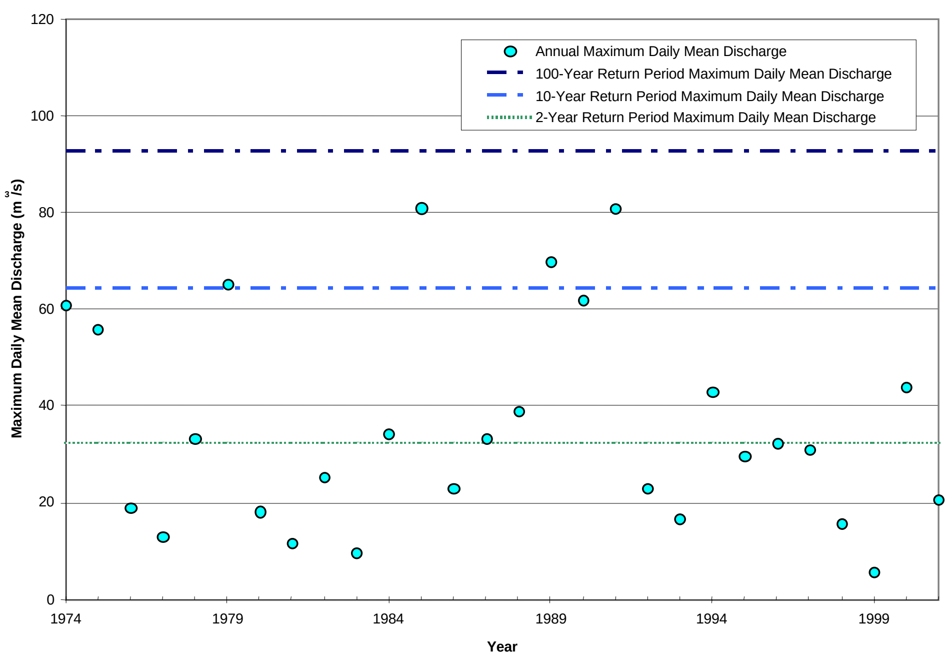


Figure 3.20 Annual Maximum Daily Mean Discharges for Muskeg River near Fort MacKay (Environment Canada Station 07DA008)

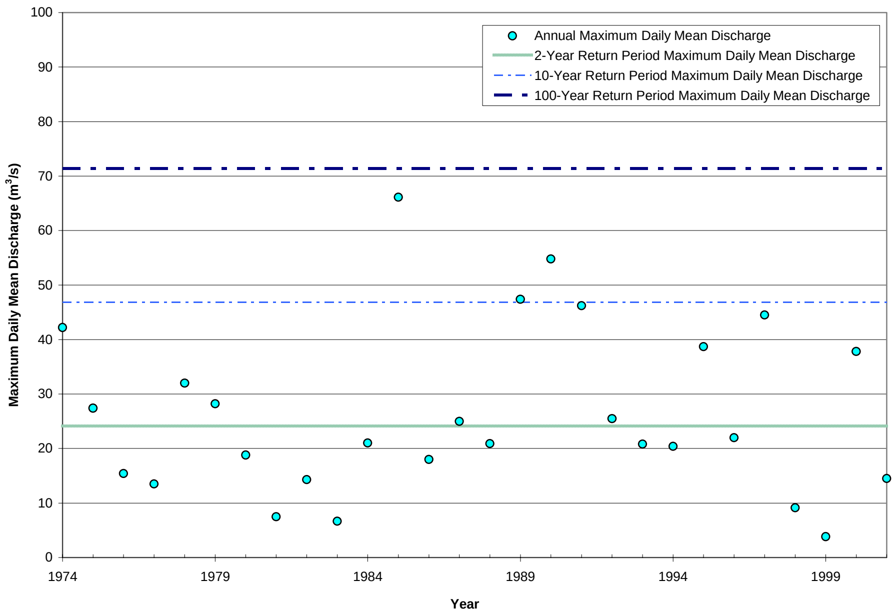


Figure 3.21 Annual Maximum Daily Mean Discharges for Jackpine Creek near Fort MacKay (Environment Canada Station 07DA009)

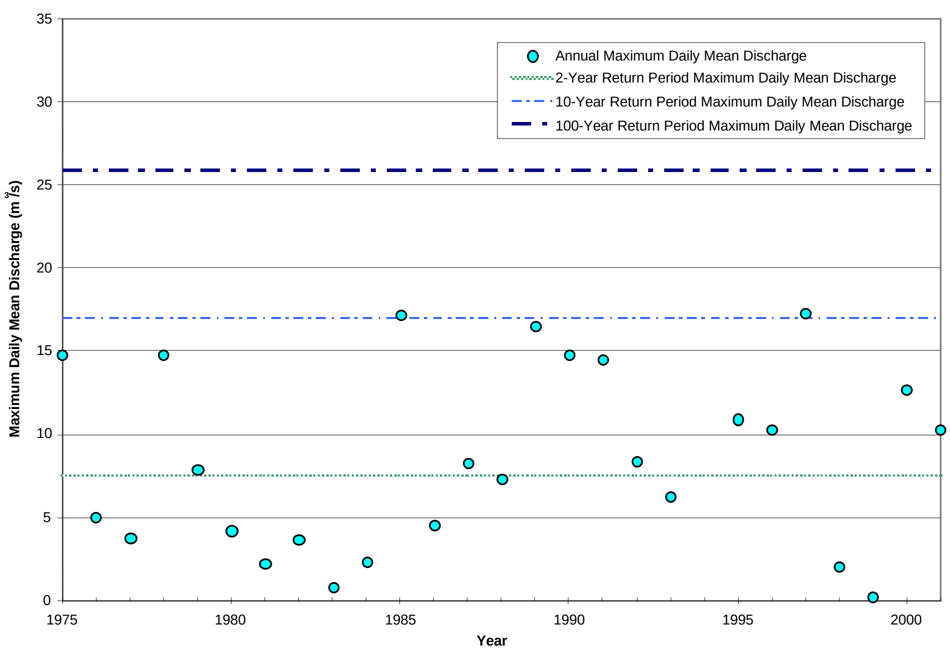


Figure 3.22 Annual Maximum Daily Mean Discharges for Beaver River above Syncrude (Environment Canada Station 07DA018)

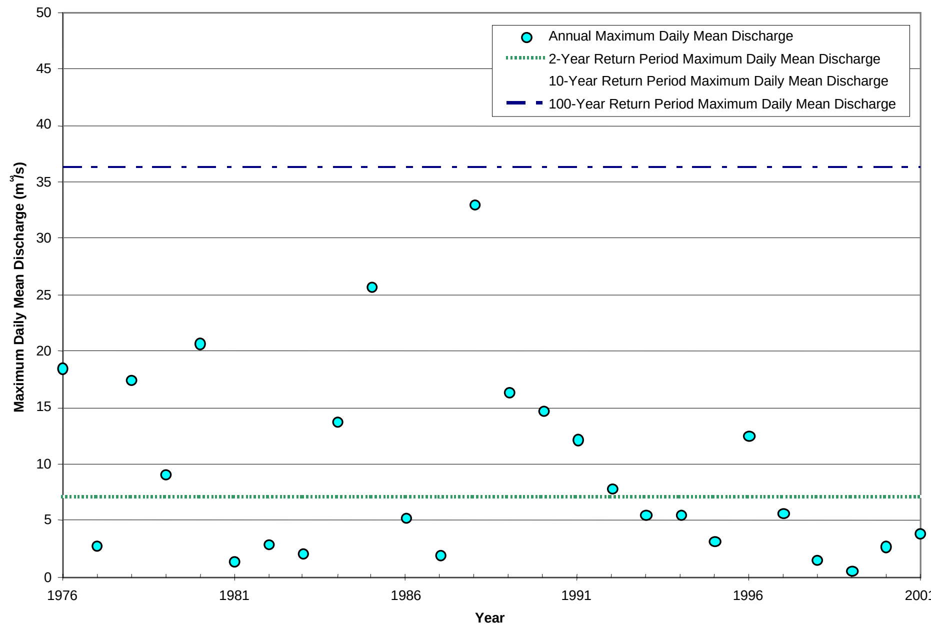


Figure 3.23 Annual Maximum Daily Mean Discharges for MacKay River near Fort MacKay (Environment Canada Station 07DB001)

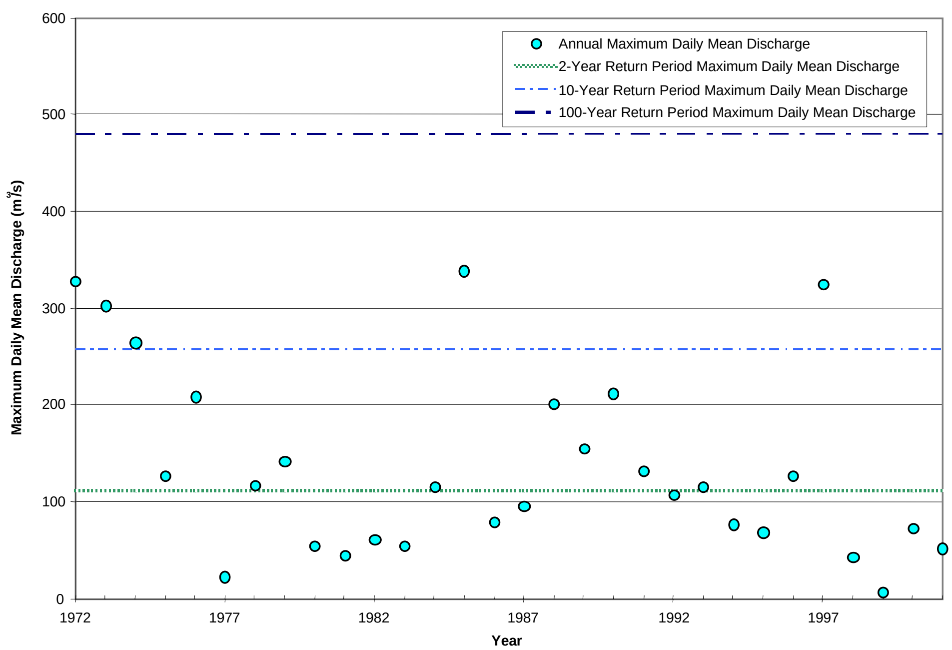
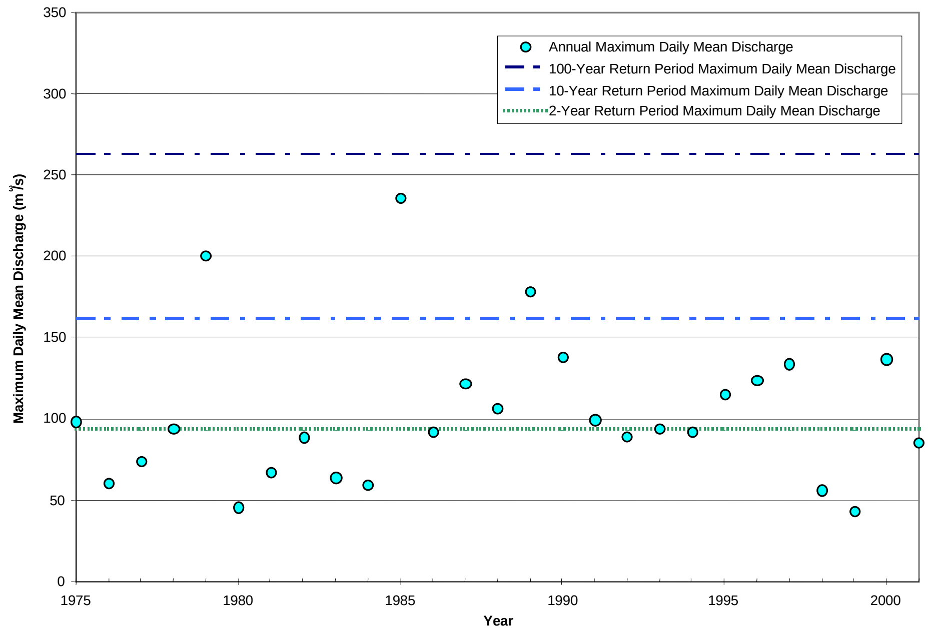


Figure 3.24 Annual Maximum Daily Mean Discharges for Firebag River near the Mouth (Environment Canada Station 07DC001)



The Steepbank River at Hydrologic Monitoring Station 07DA006 has a mean annual discharge of 4.99 m^3/s and the observed maximum daily mean discharge of 81.0 m^3/s occurred in 1985. The 100-year flood unit discharge at this station is almost twice that for the Athabasca River, but is similar to that of the MacKay River and slightly larger than those for the Muskeg River and Jackpine Creek. The calculated coefficient of variation for the flood data is 0.61, which indicates a higher range of variability than for the Athabasca River, but is similar to those for the MacKay River, Muskeg River and Jackpine Creek. The calculated coefficient of skewness is 0.75, which is similar to that for the Muskeg and Athabasca rivers.

The Muskeg River at Hydrologic Monitoring Station 07DA008 has a mean annual discharge of 4.06 m^3/s and the observed maximum daily mean discharge of 66.1 m^3/s occurred in 1985. The flood unit discharges at this station are lower than those for the Steepbank River, MacKay River and Jackpine Creek, likely because of greater storage in a broad, muskeg floodplain. The flood unit discharges are in fact similar to those for the Firebag River, which has a larger watershed and a large storage capacity. The calculated coefficient of variation for the flood data is 0.59, which indicates a higher range of variability than for the Athabasca River, but is similar to the coefficients of variation for the Steepbank River, MacKay River and Jackpine Creek. The calculated coefficient of skewness is 0.78, which is similar to that for the Steepbank and Athabasca rivers.

Jackpine Creek at Hydrologic Monitoring Station 07DA009 has a mean annual discharge of 1.07 m^3/s and the observed maximum daily mean discharge of 17.3 m^3/s occurred in 1997. The flood unit discharges at this station are similar to those for the Steepbank River watershed, which borders the Jackpine Creek watershed to the south. The calculated coefficient of variation for the flood data is 0.60, which indicates a higher range of variability than for the Athabasca River, but is similar to those for the Steepbank, Muskeg and MacKay rivers. The calculated coefficient of skewness is 0.19, which is the lowest observed at the long-term regional stations.

The Beaver River at Hydrologic Monitoring Station 07DA018 has a mean annual discharge of 0.539 m^3/s and the observed maximum daily mean discharge of 33.0 m^3/s occurred in 1988. The flood unit discharges at this station are the highest observed at long-term regional stations and are indicative of a small, steep watershed. The calculated coefficient of variation for the flood data is 0.89, which is again the highest observed at long-term regional stations. The calculated coefficient of skewness is 1.17. Among long-term regional stations, it is second only to the Firebag River. This suggests that the watershed occasionally generates extremely high floods, probably due to a rapid response to precipitation. This can be attributed to its high basin slope, since the watershed consists of 100% upland terrain. The highest flood recorded on the Beaver River is almost twice that on Jackpine Creek, which has a drainage area less than half that of the Beaver River.

The MacKay River at Hydrologic Monitoring Station 07DB001 has a mean annual discharge of 14.9 m^3/s and the observed maximum daily mean discharge of 339 m^3/s occurred in 1985. The flood unit discharges at this station are similar to those observed on the Steepbank River and Jackpine Creek and slightly larger than those observed on the Muskeg River. The calculated coefficient of variation for the flood data is 0.71, which is slightly larger than the coefficients of variation observed on the Steepbank River, Muskeg River and Jackpine Creek. The calculated coefficient of skewness is 0.95, which indicates a slightly more rapid response to precipitation than for the Muskeg or Steepbank rivers.

The Firebag River at Hydrologic Monitoring Station 07DC001 has a mean annual discharge of 25.0 m^3/s and the observed maximum daily mean discharge of 236 m^3/s occurred in 1985. The flood unit discharges at this station are similar to those observed on the Athabasca River, despite the Firebag River watershed having less than one-twentieth the area of the Athabasca River watershed. This is likely attributable to high storage capacity and flow attenuation within the Firebag River watershed. The calculated coefficient of variation for the flood data is 0.44, which is slightly larger than that of the Athabasca River data, but lower than those observed on the Steepbank River, Muskeg River and Jackpine

Creek. The calculated coefficient of skewness is 1.27, which indicates a relatively rapid response to precipitation. However, the high storage capacity of the Firebag River watershed probably attenuates the flood response, as illustrated by the fact that the Firebag and MacKay rivers have similar watershed areas and experienced their flood of record in the same year, yet the flood on the MacKay River was almost 50% larger.

3.2.5 Low Flow Discharge

3.2.5.1 Methods

Annual low flows may be characterized by the minimum daily mean discharge or by the minimum instantaneous discharge measured at a point. There is generally little difference between the two for low flows, because of the steady nature of low flows. The annual minimum daily mean discharge is defined as the lowest daily mean discharge measured at a hydrologic monitoring station over the course of a calendar year. It is calculated by averaging readings taken at a constant interval over a calendar day. Low flow discharges are a function of climatic conditions and watershed characteristics. For a given watershed, drier years generally produce lower low-flow discharges, and the water available for sustaining low flows can be reduced by greater evaporation. Air temperatures can also affect low flows, as small tributaries in the Oil Sands Region may freeze to the bottom during the winter months and contribute no flow. Physical characteristics of the watershed that affect low flows include slope, surficial geology, and lake and wetlands storage. Steep, fast-draining watersheds tend to have lower low flow discharges than flatter watersheds, which drain less rapidly. Surficial geology affects runoff quantities in a number of ways. The baseflow of a stream tends to comprise only seepages of groundwater and has little or no surface water runoff or interflow component. Thus, the permeability of surficial material affects the rate of release of water to the stream, and the porosity of surficial material affects the amount of storage in the surficial aquifer. Drawdown of the surficial aquifer during a dry year may reduce low flow discharges. Conversely, the presence of lakes, wetlands and beaver ponds can have large effects on low flows, as storage in these waterbodies is gradually released over the winter months.

Annual low flow discharges were analyzed by examining annual stream discharge data from the seven long-term hydrologic monitoring stations noted in Table 3.4:

- Station 07DA001 – Athabasca River below Fort McMurray;
- Station 07DA006 – Steepbank River near Fort McMurray;

- Station 07DA008 – Muskeg River near Fort MacKay;
- Station 07DA009 – Jackpine Creek near Fort MacKay;
- Station 07DA018 – Beaver River above Syncrude;
- Station 07DB001 – MacKay River near Fort MacKay; and
- Station 07DC001 – Firebag River near the Mouth.

Commencing in the fall of 1987, only March to October flow records are available for these stations, with the exception of the Athabasca River below Fort McMurray. An examination of the available complete annual flow records indicates that the annual low flow typically occurs prior to spring breakup in March or April. Nevertheless, in cases where low flows are reported based on March to October data, the low flows recorded during this period are taken to represent the annual minimum daily mean discharge. In general, low flows in the region occur in the winter, but the records do include some summer low flow data. Reported minimum daily mean discharges were compiled for each station's period of record. A frequency analysis of minimum events was undertaken to determine the 2-year, 10-year and 100-year low flow discharges at each station. The FRQ Frequency Analysis program, developed by G.W. Kite, was used for the minimum event frequency analysis. This program allowed the available data set to be analyzed using a number of frequency distributions, and the analysis involved selecting an appropriate distribution, based on the goodness-of-fit of the data.

3.2.5.2 Results and Discussion

Winter flows for all streams in the Oil Sands Region consist primarily of groundwater-fed baseflow. Due to the large watershed area of the Athabasca River below Fort McMurray, it sustains relatively large flows throughout the winter months. Other streams, with smaller watershed areas and lower storage capacities, have much smaller winter baseflows, even when compared on a unit area basis. Very small watersheds with low storage capacities may freeze to the stream bottom during the winter months.

Figures showing measured annual low flow discharges and derived low flow statistics for each station are provided in Figures 3.25 to 3.31. A summary of the low flow analysis for Oil Sands Region long-term hydrologic monitoring stations is provided in Table 3.12.

Table 3.12 Statistics of Low Flows for Long-Term Hydrologic Monitoring Stations in the Oil Sands Region

Statistic	Athabasca River 07DA001	Steepbank River 07DA006	Muskeg River 07DA008	Jackpine Creek 07DA009	Beaver River 07DA018	MacKay River 07DB001	Firebag River 07DC001
shown on figure	3.24	3.25	3.26	3.27	3.28	3.29	3.30
drainage area (km^2)	133,000	1,320	1,460	358	165	5,570	5,990
period of record	44 Years 1958-2001	28 Years 1974-2001	28 Years 1974-2001	26 Years 1975-93; 1995-2001	26 Years 1976-2001	29 Years 1973-2001	27 Years 1975-2001
mean annual discharge (m^3/s)	638	4.99	4.06	1.07	0.539	14.9	25.0
frequency distribution	Type 3 Extremal	Type 3 Extremal	Type 3 Extremal	Type 3 Extremal	Type 3 Extremal	Type 3 Extremal	Type 3 Extremal
highest observed (m^3/s)	211 (1997)	0.498 (1974)	0.480 (1996)	0.041 (1992)	0.054 (1988)	0.845 (1988)	11.8 (1987)
2-year return period (m^3/s)	132	0.280	0.231	0.004	0.024	0.290	7.79
10-year return period (m^3/s)	95.1	0.120	0.094	0.000	0.000	0.120	5.58
100-year return period (m^3/s)	73.8	0.000	0.016	0.000	0.000	0.060	3.97
lowest observed (m^3/s)	75 (2001)	0.022 (1981)	0.040 (1984)	0.000 (freq)	0.000 (freq)	0.023 (1973)	4.24 (1981)
mean annual unit discharge ($m^3/s/km^2$)	0.0048	0.0038	0.0028	0.0030	0.0033	0.0027	0.0042
highest observed ($m^3/s/km^2$)	0.00159	0.00038	0.00033	0.00011	0.00033	0.00015	0.00200
2-year return period ($m^3/s/km^2$)	0.00099	0.00021	0.00016	0.00001	0.00015	0.00005	0.00130
10-year return period ($m^3/s/km^2$)	0.00072	0.00009	0.00006	0.00000	0.00000	0.00002	0.00093
100-year return period ($m^3/s/km^2$)	0.00055	0.00000	0.00001	0.00000	0.00000	0.00001	0.00066
lowest observed ($m^3/s/km^2$)	0.00056	0.00002	0.00003	0.00000	0.00000	0.00000	0.00071
standard deviation of low flow (m^3/s)	30.5	0.120	0.114	0.013	0.019	0.181	1.68
coefficient of variation (C_v)	0.228	0.436	0.481	1.458	0.805	0.567	0.216
coefficient of skewness (C_s)	0.407	-0.3090	0.3000	3.298	0.0571	0.943	-0.0656

[a] Based on data set of annual minimum daily mean discharges.

Figure 3.25 Annual Minimum Daily Mean Discharges for Athabasca River below Fort McMurray (Environment Canada Station 07DA001)

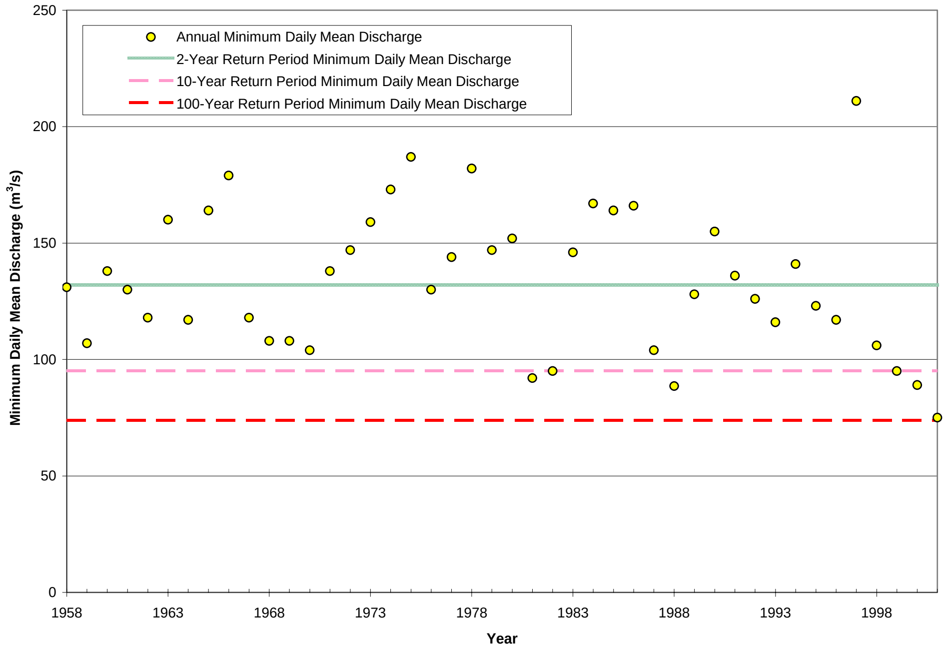


Figure 3.26 Annual Minimum Daily Mean Discharges for Steepbank River near Fort McMurray (Environment Canada Station 07DA006)

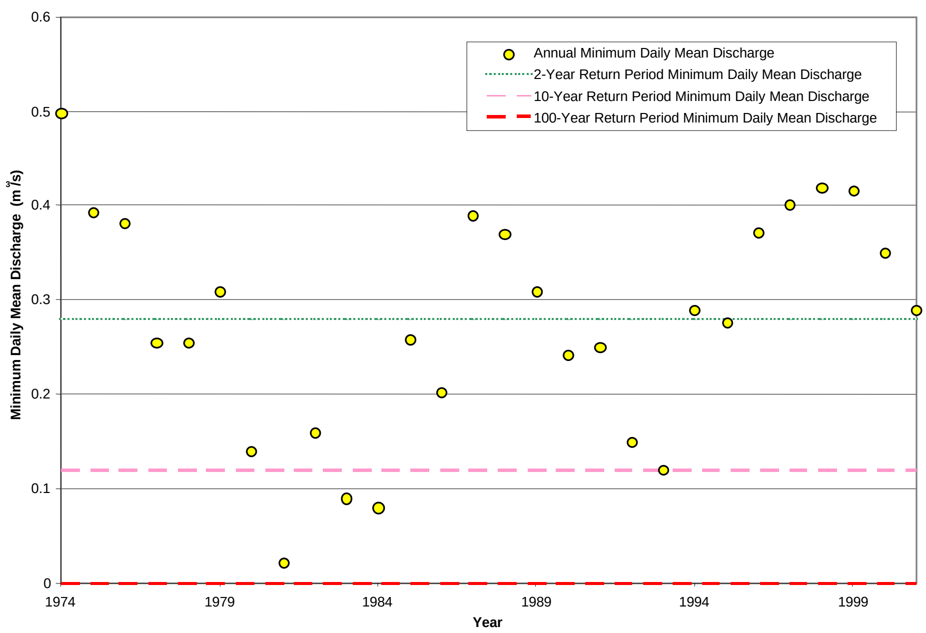


Figure 3.27 Annual Minimum Daily Mean Discharges for Muskeg River near Fort MacKay (Environment Canada Station 07DA008)

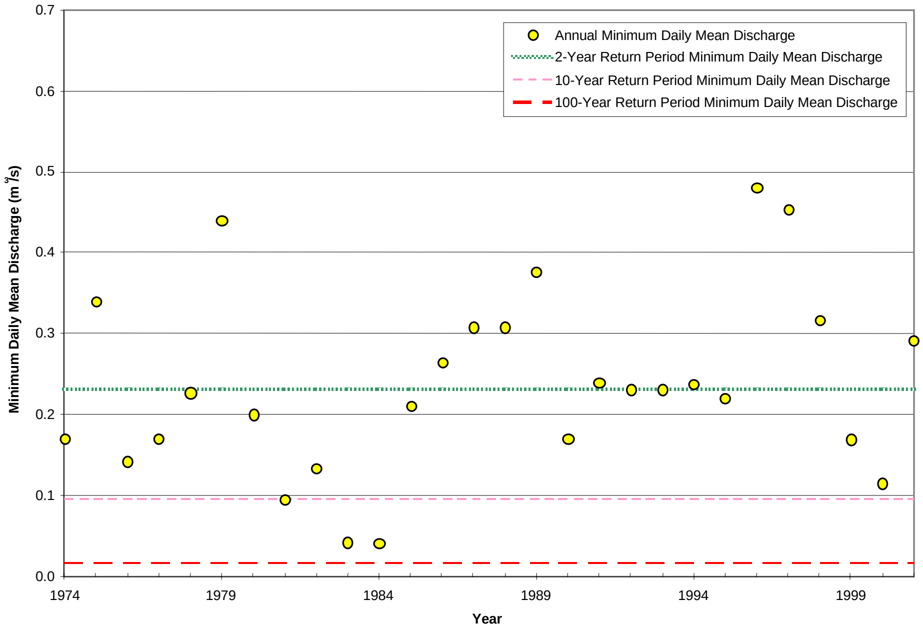


Figure 3.28 Annual Minimum Daily Mean Discharges for Jackpine Creek near Fort MacKay (Environment Canada Station 07DA009)

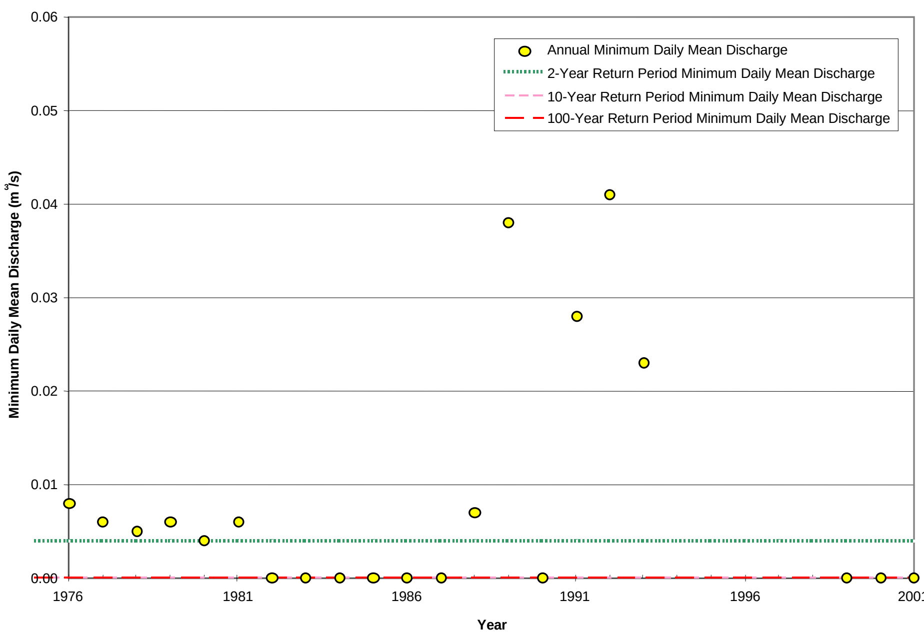


Figure 3.29 Annual Minimum Daily Mean Discharges for Beaver River above Syncrude (Environment Canada Station 07DA018)

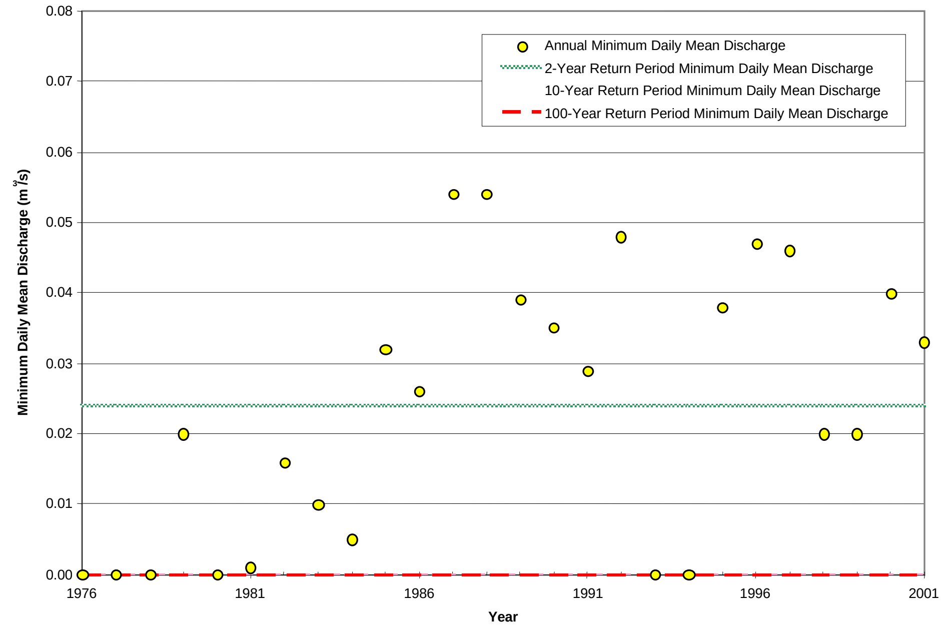


Figure 3.30 Annual Minimum Daily Mean Discharges for MacKay River near Fort MacKay (Environment Canada Station 07DB001)

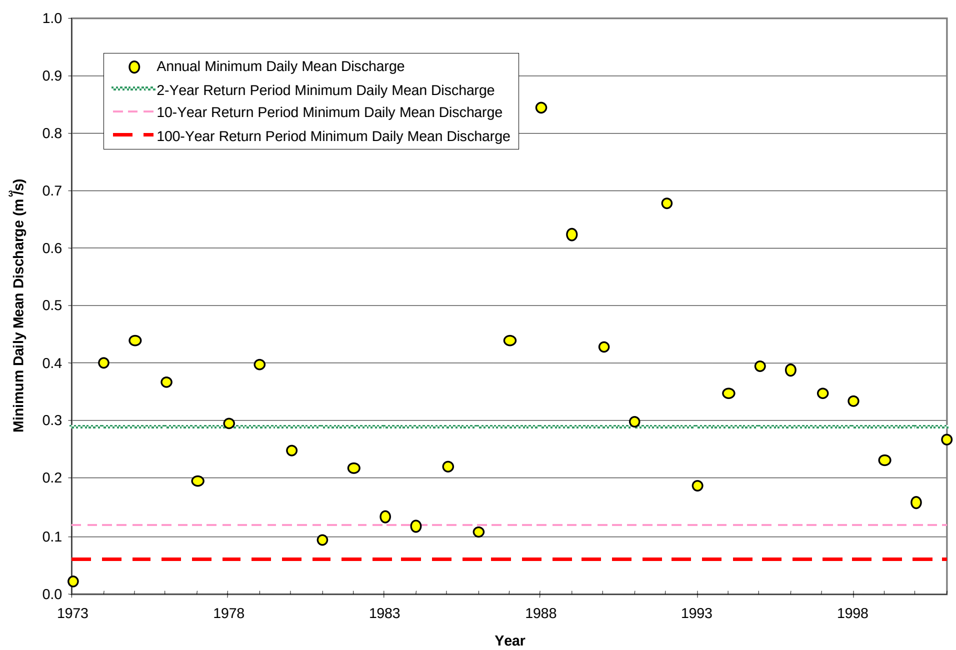
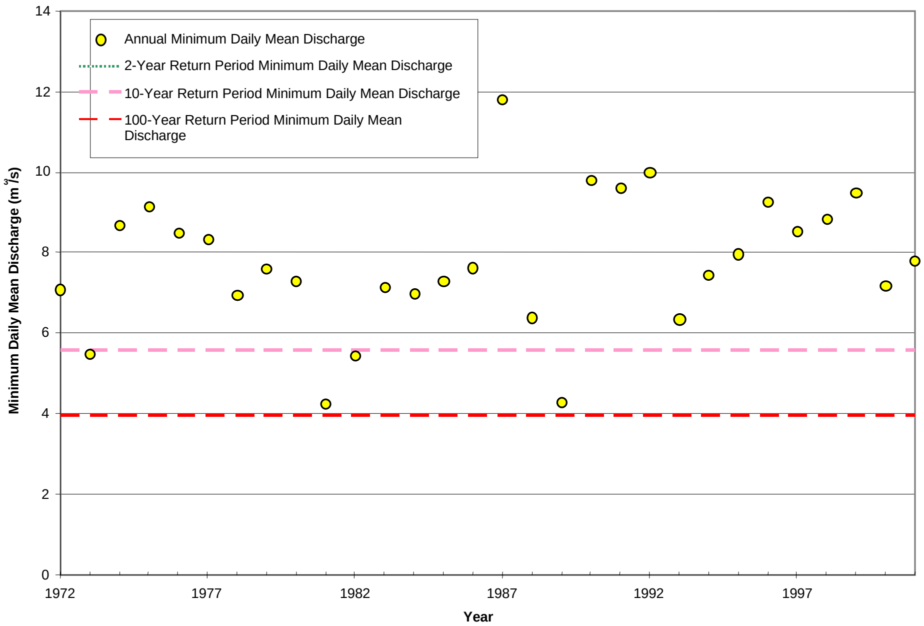


Figure 3.31 Annual Minimum Daily Mean Discharges for Firebag River near the Mouth (Environment Canada Station 07DC001)



The Athabasca River at Hydrologic Monitoring Station 07DA001 has a mean annual discharge of 638 m^3/s and the observed minimum daily mean discharge of 75 m^3/s occurred in 2001. The mean annual unit discharge at this station is larger than for any of the other long-term regional stations, likely due to wetter areas in the upper watershed. The low flow unit discharges are also higher than for any of the other long-term regional stations except the Firebag River. This is attributed to the large drainage area of the Athabasca River relative to those of the regional stations. The calculated coefficient of variation for the low flow data is 0.23, which is approximately the same as for the Firebag River and substantially lower than that for any of the other stations examined in this report.

The Steepbank River at Hydrologic Monitoring Station 07DA006 has a mean annual discharge of 4.99 m^3/s and the observed minimum daily mean discharge of 0.022 m^3/s occurred in 1981. The low flow unit discharges at this station are much smaller than those for the Athabasca River, which is attributed to the fact that the watershed area of the Steepbank River is approximately 1% of that of the Athabasca River below Fort McMurray. Small tributaries in the upper watershed likely freeze to the stream bottom during the winter, so the baseflow is typically much less than 1% of the Athabasca River baseflow. Reported low flows typically occur in March (late winter), though the record for this and other stations includes some annual low flows observed in the summer. Low flow unit discharges are similar to those for the Muskeg River, indicating similar groundwater supply characteristics, and slightly larger than those for the MacKay River. The calculated coefficient of variation for the low flow data is 0.44, which indicates a higher degree of variability than for the Athabasca River, but is similar to that for the Muskeg River. The variability of the baseflows that contribute to low flows on a smaller stream such as the Steepbank River is likely a function of both antecedent precipitation and winter temperatures.

The Muskeg River at Hydrologic Monitoring Station 07DA008 has a mean annual discharge of 4.06 m^3/s. The observed minimum daily mean discharge is 0.040 m^3/s and occurred in 1984. The low flow unit discharges at this station are similar to those for the Steepbank River and slightly larger than those for the MacKay River. The calculated coefficient of variation for the low flow data is 0.48, which is again similar to that for the Steepbank River, indicating similar groundwater supply characteristics.

Jackpine Creek at Hydrologic Monitoring Station 07DA009 has a mean annual discharge of 1.07 m^3/s. The observed minimum daily mean discharge is zero, which has occurred frequently. The Jackpine Creek watershed borders the Steepbank River watershed and comprises approximately 25% of the Muskeg River watershed. Low flow unit discharges at this station are significantly lower than for the Muskeg and Steepbank rivers. This is attributed to the frequent freezing of Jackpine Creek to the stream bottom during the winter. During warm winters, this may be limited to the upper watershed and flow may be sustained at the station. Variability in the baseflows contributing to low flows on a small stream such as this is likely also a function of antecedent precipitation. The calculated coefficient of variation for the low flow data is 1.46, which indicates a higher degree of variability than for the Steepbank and Muskeg rivers.

The Beaver River at Hydrologic Monitoring Station 07DA018 has a mean annual discharge of 0.539 m^3/s. The observed minimum daily mean discharge is zero, which has occurred frequently. Low flow unit discharges at this station are similar to those for Jackpine Creek, though the two-year low flow unit discharge is significantly higher. This may be due to low flows being sustained by the freer-draining, steep topography of the watershed during wetter than average years. The Beaver River above Syncrude is the smallest watershed near Fort McMurray for which long-term monitoring is available. The calculated coefficient of variation for the low flow data is 0.81, which is significantly higher than for all of the other long-term regional stations except for Jackpine Creek. Variability of the baseflows that contribute to low flows on a small stream such as this is likely a function of both antecedent precipitation, winter temperatures and the occurrence of summer droughts.

The MacKay River at Hydrologic Monitoring Station 07DB001 has a mean annual discharge of 14.9 m^3/s and the observed minimum daily mean discharge of 0.023 m^3/s occurred in 1973. The low flow unit discharges at this station are somewhat less than those observed on the Muskeg and Steepbank rivers, but flow is generally sustained over the winter months, in contrast to smaller watersheds such as the Beaver River and Jackpine Creek. The calculated coefficient of variation for the low flow data is 0.57, which is slightly larger than those observed on the Steepbank and Muskeg rivers. The lower, more variable baseflows of the MacKay River, despite its larger watershed area, are likely due to differences in surficial geology that cause a reduced supply of groundwater.

The Firebag River at Hydrologic Monitoring Station 07DC001 has a mean annual discharge of 25.0 m^3/s and the observed minimum daily mean discharge of 4.24 m^3/s occurred in 1985. The low flow unit discharges at this station are similar to those observed on the Athabasca River, although the Firebag River watershed has less than one-twentieth the area of the Athabasca River watershed. This is likely attributable to high groundwater storage capacity, and winter release, within the Firebag River watershed. The calculated coefficient of variation for the low flow data is 0.22, which is similar to that of the Athabasca River data and significantly lower than those observed on the Steepbank and Muskeg rivers.

3.2.6 Conclusions and Recommendations

3.2.6.1 Long-Term Climatic Data

The available long-term climatic data for the Oil Sands Region north of Fort McMurray consists of climatic data from the Environment Canada Climate Station at Fort McMurray Airport. This station was established at the start of 1944 and provides a period of record extending to the end of 2001. The precipitation and temperature records for this station are of particular interest in examining the variability of hydrologic conditions in the region.

The mean annual rainfall measured at Fort McMurray Airport is 314 mm. Annual values have varied from a low of 170 mm in 1945 to a high of 533 mm in 1973 (54% to 170% of the mean). The mean annual snowfall-to-runoff, that is, the amount measured from October to May of each year, is 148 mm. Annual values have varied from 46 mm in 1949 to a high of 298 mm in 1972 (31% to 201% of the mean). The mean annual precipitation-to-runoff measured at Fort McMurray Airport is 461 mm. Annual values have varied from a low of 238 mm in 1945 to a high of 813 mm in 1973 (52% to 176% of the mean). The analysis of precipitation data, presented in Section 3.2.1, shows that the annual precipitation, including rainfall and snowfall components, exhibits a degree of variability that is typical of natural hydrologic systems. The calculated coefficients of variability of 0.37, 0.27 and 0.23 for the snowfall-to-runoff, rainfall and precipitation-to-runoff data, respectively, show that snowfall is more variable than rainfall, and that total precipitation is less variable than rainfall. The calculated values also indicate that annual rainfall is not dependent on the antecedent snowfall-to-runoff, which is confirmed by the weak correlation (0.135) between the two data sets.

There were four consecutive years of below-average precipitation between 1998 and 2001. This span includes four of the first five years during which RAMP operated, and is the longest span of below-average precipitation since a nine-year period from 1945 to 1953. The recent 1998-to-2001 dry period may be contrasted with the five consecutive years of above-average precipitation that was observed from 1972 to 1976, a period where much historical aquatic environment data was collected in the Muskeg River basin.

The variability of temperature data from Fort McMurray Airport was examined in Section 3.2.2. The mean temperature at Fort McMurray Airport over the period 1944 to 2001 was 0.1°C, and annual mean temperatures have varied from -2.7 to 3.2°C. The mean summer (June to August) temperature measured at Fort McMurray Airport was 15.2°C, and annual mean summer temperatures have varied from 13.4 to 17.0°C. The mean winter (December to February) temperature measured at Fort McMurray Airport was -17.4°C, and annual mean winter temperatures have varied from -24.7 to -8.4°C. The data sets for annual mean, winter mean and summer mean temperatures exhibited standard deviations of 1.3°C, 3.3°C and 0.9°C, respectively. This shows that winter mean temperatures are more variable than annual mean temperatures, and that summer mean temperatures are less variable than annual mean temperatures. The observed data show that mean annual temperatures at Fort McMurray Airport are more likely to be influenced by the more variable winter temperatures than by less variable summer temperatures. The weak correlation (0.256) between the two data sets indicates that a cold winter is unlikely to be followed by a cold summer, or vice versa.

The climatic station at Fort McMurray Airport is the best station available for characterizing long-term natural variability in the Oil Sands Region, based on proximity and length of record. It is recommended that this station continue to be operated by Environment Canada and that RAMP continue to incorporate relevant climate data into its database on an annual basis.

Other climate stations operated in the Oil Sands Region north of Fort McMurray include the Environment Canada Climate Station at Mildred Lake (Station 3064528 and 3064531) and the RAMP Aurora Climate Station (Station C1). The Mildred Lake Climate Station has a period of record of 19 years (1973 to 1982 and 1993 to 2001) and the Aurora Climate Station has a period of record of seven years (1995 to 2001). Both of these stations have been used for recent calibrations of watershed hydrologic models and their continued operation is recommended to provide local climate information within the current oil sands developments. When long-term data from these stations are available, they will allow more subtle differences in climate between stations north of Fort McMurray and the station at Fort McMurray to be quantified, including effects of local elevation and topography.

Other RAMP sites incorporate rainfall and snowfall gauges and these are discussed further in Section 3.4.

3.2.6.2 Long-Term Hydrologic Data

The available long-term hydrologic data for the Oil Sands Region north of Fort McMurray consists of data from seven Environment Canada Hydrologic Stations, including those on the Athabasca River, Steepbank River, Muskeg River, Jackpine Creek, Beaver River, MacKay River and Firebag River. A summary of statistics for water yields, flood discharges and low flow discharges for these stations is provided in Table 3.13.

The Athabasca River station differs from others in the region, in that its large (133,000 km^2) watershed area extends to the Rocky Mountains in the west and across the Saskatchewan border in the east, encompassing areas with varying hydrologic conditions. The large watershed accounts for the relatively low coefficients of variation of water yield, flood discharge and low flow data, and for the relatively low correlation (+0.41) between annual precipitation at Fort McMurray Airport and annual water yield. This station has the highest mean annual water yield of any of the local long-term monitored watersheds, likely due to higher precipitation in its headwater areas. It also has among the lowest flood unit discharges and highest low flow unit discharges, again due to its relatively large watershed area.

The size of the Steepbank River station watershed area (1,320 km^2) is approximately 1% of that of the Athabasca River at Fort McMurray. The smaller watershed accounts for coefficients of variation of water yield, flood discharge and low flow data that are approximately twice that of the Athabasca River. The proximity of the entire Steepbank River watershed to Fort McMurray accounts for the high correlation (+0.74) between annual precipitation at Fort McMurray Airport and annual water yield. This station has a slightly lower mean annual water yield than the Athabasca River, likely due to lower mean annual precipitation. Its flood unit discharges are substantially larger and low flow unit discharges substantially lower than those of the Athabasca River, again due to its much smaller watershed area.

Table 3.13 Statistics of Discharges for Long-Term Hydrologic Monitoring Stations in the Oil Sands Region

Parameter	Statistic	Athabasca River 07DA001	Steepbank River 07DA006	Muskeg River 07DA008	Jackpine Creek 07DA009	Beaver River 07DA018	MacKay River 07DB001	Firebag River 07DC001
drainage area		133,000 km^2	1,320 km^2	1,460 km^2	358 km^2	165 km^2	5,570 km^2	5,990 km^2
period of record		44 Years 1958-2001	28 Years 1974-2001	28 Years 1974-2001	26 Years 1975-93; 1995-2001	26 Years 1976-2001	29 Years 1973-2001	27 Years 1975-2001
mean annual discharge		643 m^3/s (0.0048 $m^3/s/km^2$)	4.99 m^3/s (0.0038 $m^3/s/km^2$)	4.06 m^3/s (0.0028 $m^3/s/km^2$)	1.07 m^3/s (0.0030 $m^3/s/km^2$)	0.539 m^3/s (0.0033 $m^3/s/km^2$)	14.9 m^3/s (0.0027 $m^3/s/km^2$)	25.0 m^3/s (0.0042 $m^3/s/km^2$)
maximum daily mean discharge	highest observed	4,700 m^3/s in 1971 (0.0353 $m^3/s/km^2$)	81.0 m^3/s in 1985 (0.0614 $m^3/s/km^2$)	66.1 m^3/s in 1985 (0.0453 $m^3/s/km^2$)	17.3 m^3/s in 1997 (0.0483 $m^3/s/km^2$)	33.0 m^3/s in 1988 (0.2000 $m^3/s/km^2$)	339 m^3/s in 1985 (0.0609 $m^3/s/km^2$)	236 m^3/s in 1985 (0.0394 $m^3/s/km^2$)
	100-year return period	5,600 m^3/s (0.0421 $m^3/s/km^2$)	92.6 m^3/s (0.0705 $m^3/s/km^2$)	71.4 m^3/s (0.0489 $m^3/s/km^2$)	25.9 m^3/s (0.0723 $m^3/s/km^2$)	36.3 m^3/s (0.2200 $m^3/s/km^2$)	480 m^3/s (0.0862 $m^3/s/km^2$)	263 m^3/s (0.0439 $m^3/s/km^2$)
	10-year return period	3,780 m^3/s (0.0284 $m^3/s/km^2$)	64.5 m^3/s (0.0492 $m^3/s/km^2$)	46.8 m^3/s (0.0321 $m^3/s/km^2$)	17.0 m^3/s (0.0475 $m^3/s/km^2$)	20.7 m^3/s (0.1255 $m^3/s/km^2$)	258 m^3/s (0.0463 $m^3/s/km^2$)	162 m^3/s (0.0270 $m^3/s/km^2$)
	2-year return period	2,420 m^3/s (0.0182 $m^3/s/km^2$)	32.3 m^3/s (0.0242 $m^3/s/km^2$)	24.1 m^3/s (0.0165 $m^3/s/km^2$)	7.52 m^3/s (0.0210 $m^3/s/km^2$)	7.14 m^3/s (0.0433 $m^3/s/km^2$)	112 m^3/s (0.0201 $m^3/s/km^2$)	93.9 m^3/s (0.0157 $m^3/s/km^2$)
	lowest observed	1,280 m^3/s in 1993 (0.0096 $m^3/s/km^2$)	5.62 m^3/s in 1999 (0.0043 $m^3/s/km^2$)	3.84 m^3/s in 1999 (0.0026 $m^3/s/km^2$)	0.178 m^3/s in 1999 (0.0005 $m^3/s/km^2$)	0.579 m^3/s in 1999 (0.0035 $m^3/s/km^2$)	6.28 m^3/s in 1999 (0.0011 $m^3/s/km^2$)	43.5 m^3/s in 1999 (0.0073 $m^3/s/km^2$)
	standard deviation	871 m^3/s (0.0066 $m^3/s/km^2$)	21.7 m^3/s (0.0164 $m^3/s/km^2$)	15.5 m^3/s (0.0106 $m^3/s/km^2$)	5.30 m^3/s (0.0148 $m^3/s/km^2$)	8.45 m^3/s (0.0512 $m^3/s/km^2$)	49.4 m^3/s (0.0089 $m^3/s/km^2$)	45.9 m^3/s (0.0077 $m^3/s/km^2$)
	coefficient of variation, C_v	0.337	0.611	0.586	0.600	0.889	0.707	0.442
	coefficient of skewness, C_s	0.726	0.754	0.784	0.187	1.169	0.946	1.272
annual water yield	highest observed	240 mm in 1997	252 mm in 1975	172 mm in 1997	187 mm in 1997	214 mm in 1996	199 mm in 1997	188 mm in 1997
	100-year wet return period	244 mm	269 mm	193 mm	223 mm	305 mm	263 mm	215 mm
	10-year wet return period	193 mm	190 mm	143 mm	169 mm	179 mm	150 mm	177 mm
	long term average	151 mm	119 mm	89 mm	94 mm	103 mm	84 mm	132 mm
	10-year dry return period	112 mm	56 mm	37 mm	27 mm	35 mm	28 mm	90 mm
	100-year dry return period	94 mm	27 mm	7 mm	0 mm	7 mm	4 mm	63 mm

Table 3.13 Statistics of Discharges for Long-Term Hydrologic Monitoring Stations in the Oil Sands Region (continued)

Parameter	Statistic	Athabasca River 07DA001	Steepbank River 07DA006	Muskeg River 07DA008	Jackpine Creek 07DA009	Beaver River 07DA018	MacKay River 07DB001	Firebag River 07DC001
	lowest observed	101 mm in 2001	33 mm in 1999	16 mm in 1999	3 mm in 1999	13 mm in 1999	6 mm in 1999	79 mm in 1981
	standard deviation	30.5 mm	51.9 mm	40.5 mm	50.7 mm	56.9 mm	49.4 mm	32.5 mm
	coefficient of variation, C_v	0.209	0.435	0.462	0.564	0.552	0.588	0.247
	correlation with precipitation	0.414	0.741	0.527	0.460	0.565	0.586	0.569
minimum daily mean discharge	highest observed	211 m^3/s in 1997 (0.00159 $m^3/s/km^2$)	0.498 m^3/s in 1974 (0.00038 $m^3/s/km^2$)	0.480 m^3/s in 1996 (0.00033 $m^3/s/km^2$)	0.041 m^3/s in 1992 (0.00011 $m^3/s/km^2$)	0.054 m^3/s in 1988 (0.00033 $m^3/s/km^2$)	0.845 m^3/s in 1988 (0.00015 $m^3/s/km^2$)	11.8 m^3/s in 1987 (0.00200 $m^3/s/km^2$)
	2-year return period	132 m^3/s (0.00099 $m^3/s/km^2$)	0.280 m^3/s (0.00021 $m^3/s/km^2$)	0.231 m^3/s (0.00016 $m^3/s/km^2$)	0.004 m^3/s (0.00001 $m^3/s/km^2$)	0.024 m^3/s (0.00015 $m^3/s/km^2$)	0.290 m^3/s (0.00005 $m^3/s/km^2$)	7.79 m^3/s (0.00130 $m^3/s/km^2$)
	10-year return period	95.1 m^3/s (0.00072 $m^3/s/km^2$)	0.120 m^3/s (0.00009 $m^3/s/km^2$)	0.094 m^3/s (0.00006 $m^3/s/km^2$)	0.000 m^3/s (0.00000 $m^3/s/km^2$)	0.000 m^3/s (0.00000 $m^3/s/km^2$)	0.120 m^3/s (0.00002 $m^3/s/km^2$)	5.58 m^3/s (0.00093 $m^3/s/km^2$)
	100-year return period	73.8 m^3/s (0.00055 $m^3/s/km^2$)	0.000 m^3/s (0.00000 $m^3/s/km^2$)	0.016 m^3/s (0.00001 $m^3/s/km^2$)	0.000 m^3/s (0.00000 $m^3/s/km^2$)	0.000 m^3/s (0.00000 $m^3/s/km^2$)	0.060 m^3/s (0.00001 $m^3/s/km^2$)	3.97 m^3/s (0.00066 $m^3/s/km^2$)
	lowest observed	75 m^3/s in 1988 (0.00056 $m^3/s/km^2$)	0.022 m^3/s in 1981 (0.00002 $m^3/s/km^2$)	0.040 m^3/s in 1984 (0.00003 $m^3/s/km^2$)	0.000 m^3/s frequently (0.00000 $m^3/s/km^2$)	0.000 m^3/s frequently (0.00000 $m^3/s/km^2$)	0.023 m^3/s in 1973 (0.00000 $m^3/s/km^2$)	4.24 m^3/s in 1981 (0.00071 $m^3/s/km^2$)
	standard deviation	30.5 m^3/s (0.00022 $m^3/s/km^2$)	0.120 m^3/s (0.00009 $m^3/s/km^2$)	0.114 m^3/s (0.00008 $m^3/s/km^2$)	0.013 m^3/s (0.00004 $m^3/s/km^2$)	0.019 m^3/s (0.00012 $m^3/s/km^2$)	0.181 m^3/s (0.00003 $m^3/s/km^2$)	1.68 m^3/s (0.00028 $m^3/s/km^2$)
	coefficient of variation, (C_v)	0.228	0.436	0.481	1.458	0.805	0.567	0.216
	coefficient of skewness, (C_s)	0.407	-0.3090	0.3000	3.298	0.0571	0.943	-0.0656

The Muskeg River station watershed area (1,460 km^2) is similar to that of the Steepbank River, and the measured data from this station exhibit similar coefficients of variation of water yield, flood discharge and low flow. The Muskeg River watershed is located immediately north of the Steepbank River watershed, further from Fort McMurray. This, along with greater muskeg and wetlands storage, may account for the slightly lower correlation (+0.53) between annual precipitation at Fort McMurray Airport and annual water yield. This station has a slightly lower mean annual water yield than the Steepbank River, likely due to differences in watershed evapotranspiration, storage capacity and losses to groundwater. Its extreme flood unit discharges are slightly smaller than those of the Steepbank River, likely due to differences in watershed storage capacity. Its low flow unit discharges are similar to those of the Steepbank River, indicating similar groundwater flow characteristics.

Jackpine Creek is a tributary of the Muskeg River and comprises approximately 25% (358 km^2) of its watershed area. The smaller watershed size accounts for the coefficients of variation of water yield, flood discharge and low flow that are greater than those of the Muskeg River, and a correlation between annual precipitation at Fort McMurray Airport and annual water yield (+0.46) that is slightly lower than that of the Muskeg River. Jackpine Creek has a mean annual water yield similar to the Muskeg River. Its smaller watershed area again accounts for wet- and dry-year water yields that are more extreme, flood unit discharges that are greater, and low flow unit discharges that are smaller than those of the Muskeg River.

The Beaver River station watershed area (165 km^2) is the smallest of the long-term regional hydrologic stations. The small watershed accounts for relatively large coefficients of variation of water yield, flood discharge and low flow data. The proximity of the Beaver River watershed to Fort McMurray is tempered by the small watershed size to produce a slightly lower correlation (+0.57) between annual precipitation at Fort McMurray Airport and annual water yield than for the Steepbank River watershed. The small, upland watershed of the Beaver River accounts for wet- and dry-year water yields that are more extreme, flood unit discharges that are greater, and low flow unit discharges that are smaller than those of the Steepbank and Muskeg rivers. Its higher proportion of upland areas means that its flood unit discharges are larger than those of Jackpine Creek.

The MacKay River station watershed area (5,570 km^2) is approximately four times the size of those of the Steepbank and Muskeg rivers. All other factors being equal, this would normally result in lower coefficients of variation of water yield, flood discharge and low flow, but instead the opposite is true. Differences in watershed topography and surficial geology mean that, despite having a larger watershed area, unit flood discharges are similar to those of the Steepbank River and greater than those of the Muskeg River. Water yields are similar to those of the Muskeg River watershed, and low flow discharges are lower than those observed on the Steepbank and Muskeg rivers. The higher flood discharges and lower low flows are indicative of a faster-draining watershed, with less percolation to groundwater and less release of groundwater during baseflow. The MacKay River has a correlation (+0.59) between annual precipitation at Fort McMurray Airport and annual water yield similar to that of the adjacent Beaver River watershed.

The Firebag River station watershed area (5,990 km^2) is approximately the same as that of the MacKay River. All other factors being equal, this would normally result in similar coefficients of variation of water yield, flood discharge and low flow, but the Firebag River exhibits values of these coefficients that are similar to those of the much larger Athabasca River. Unit flood discharges, annual water yield and unit low flow discharges are also similar to those of the Athabasca River, though the Firebag River has a better correlation (+0.57) between annual precipitation at Fort McMurray Airport and annual water yield. The behaviour of the Firebag River is attributed to unusually large storage capacity in the surficial aquifer, which attenuates precipitation inputs to the watershed and sustains relatively large baseflows over the winter months.

During the dry hydrologic conditions observed in the region during the period 1998 to 2001, annual precipitation for all four years was below average. The second- and fifth-driest years on record occurred in 1998 and 1999, respectively. This dry period includes four of the first five years of RAMP. In 1999, these consecutive dry years produced the lowest-recorded water yields and flood discharges on the Steepbank, Muskeg, Beaver and MacKay rivers and Jackpine Creek. However, precipitation records indicate that a more extreme, longer-duration dry period occurred from 1945 to 1953. Hydrologic records are not available for that period.

Annual precipitation amounts for the years 1972 to 1976 were all above average, with 1973 the wettest recorded since 1945. Since no annual hydrologic monitoring data are available for the Muskeg River basin before 1974, it is not possible to calculate water yields, flood discharges and low flows for this wet year. The wet period of 1972 to 1976 coincided with the collection of much baseline water quality and fisheries data in the Muskeg River basin, and hydrologic conditions during that period should not be taken as representative of the average.

The highest observed flood was recorded in 1997 on Jackpine Creek and the highest observed water yields were recorded in 1997 on the Muskeg River, Mackay River, Firebag River and Jackpine Creek and in 1996 on the Beaver River.

The seven long-term hydrologic stations located north of Fort McMurray are the best stations available for characterizing long-term natural variability in the Oil Sands Region, based on proximity and length of record. It is recommended that Environment Canada continue to operate these stations and that RAMP continue to incorporate relevant hydrologic data into its database on an annual basis.

The Environment Canada hydrologic station on Jackpine Creek was discontinued in 1993 and is currently operated by RAMP since its reactivation in 1995. Environment Canada ceased winter operation of all regional hydrologic monitoring stations, with the exception of the Athabasca River, in 1987. In 1999, RAMP initiated winter monitoring at the Muskeg River station, and in 2002, RAMP initiated winter monitoring at the Mackay River and Firebag River stations. It is recommended that this supplementary monitoring continue and consideration should be given to reactivating winter monitoring on the Steepbank River. Jackpine Creek and the Beaver River frequently freeze to the bottom and cease to flow over the winter; therefore, they do not lend themselves to continuous year-round flow monitoring. However, consideration should be given to visiting these stations periodically over the winter months, and undertaking manual stream discharge measurements, if possible. Conditions have been drier than average for most of the duration of the RAMP program, and a return to wetter conditions may result in sustained flows over the winter.

Discontinued Environment Canada hydrologic stations in the Oil Sands Region north of Fort McMurray and west of the Athabasca River include stations on the Dover River (07DB002), Ells River (07DA017), Joslyn Creek (07DA016), Tar River (07DA015), Calumet River (07DA014), Pierre River (07DA013), Asphalt Creek (07DA012) and Unnamed Creek (07DA011). These stations were operated from 1975 to 1977, with the exceptions of the Ells River (1975 to 1986) and Joslyn Creek (1975 to 1993) stations. Monitoring on the Ells, Tar and Calumet rivers was reinitiated by RAMP in 2001 in support of the CNRL Horizon EIA, and it is recommended that these stations continue to be operated to collect baseline data and to measure effects after the start of project construction. It is recommended that consideration be given to reactivation of the remaining stations (Dover River, Joslyn Creek, Pierre River, Asphalt Creek and Unnamed Creek) to allow collection of long-term data in advance of project developments in the area. Reinstalling stations at, or near, their previous locations has the advantage of allowing the previously acquired data to be integrated into the data set without major adjustment.

Other RAMP hydrologic monitoring stations, as listed in Table 3.1, are intended to measure discharges from areas affected by mining activities. They provide short-term baseline data, but as project developments begin to affect runoff, they will cease to be useful for defining natural variability.

3.3 DETECTING AND ASSESSING REGIONAL TRENDS

3.3.1 Temporal Trends

3.3.1.1 Precipitation

Methods

Annual precipitation available for runoff was analyzed using long-term data from Fort McMurray Airport (Environment Canada Climate Station 3062693), as examined in Section 3.2.1. Statistical tests for temporal trend and serial dependence were performed on the data set, using the Environment Canada CFA program:

- *Spearman Test for Trend*: This test determines whether successive measurements in the data set were made during a period of gradually changing conditions. The test determines whether a significant temporal trend exists in the data set by correlating the rank of an event to the chronological order of the event. The results of the Spearman Test for Trend was examined at 5% (significant) and 1% (highly significant) levels of significance.
- *Spearman Test for Independence*: Two events are defined as independent if the occurrence or non-occurrence of one event does not affect the probability of occurrence or non-occurrence of an event. This is a rank order test that identifies serial dependence for entries in the data set; that is, whether a high precipitation year is likely to follow a high precipitation year, or a low precipitation year is likely to follow a low precipitation year. The results of the test at 5% (significant) and 1% (highly significant) levels of significance were examined.

Results and Discussion

The Spearman Test for Trend indicated that the precipitation data do not display significant trend. That is, the region has not become wetter or drier over the period of record.

The Spearman Test for Independence indicated that the precipitation data display some degree of serial dependence. This means that high precipitation in any given year is likely to have been preceded by high precipitation in the previous year, and low precipitation in any given year is likely to have been preceded by low precipitation in the previous year. The dependence may be a result of climatic changes on a larger spatial and temporal scale; however, no analysis was carried out for this report to identify the possible causes of such a dependence.

Winter snowfall at 36 long-term climate stations in Alberta, including Fort McMurray Airport, has been shown to be higher during the La Nina phase of the Southern Oscillation (Keller 1999). This oscillation has a frequency of three to eight years. However, the difference observed at Fort McMurray Airport was not significant at the 90% confidence interval. For 28 of the 36 stations analyzed, the difference was shown to be significant at the 95% confidence interval.

3.3.1.2 Temperature

Methods

Mean annual temperatures were analyzed using long-term data from Fort McMurray Airport (Environment Canada Climate Station 3062693), as presented in Section 3.2.2. The available data were analyzed using two of the statistical tests described in Section 3.3.1.1.

Results and Discussion

The Spearman Test for Trend indicated that the mean annual temperature data display a highly significant trend. That is, the region has become (based solely on the temperature data at Fort McMurray airport) significantly warmer over the period of record.

A Mann-Whitney split sample test for homogeneity was undertaken to determine whether any abrupt change occurred during the sampling period. This test showed that there was a significant difference, at the 1% level, between the data for the period 1944 to 1971 and the data for the period 1972 to 2001. The observed, abrupt change after 1971 could be due to general climatic change or due to a change in instrument location, type of instrument, land cover or other factors, but no attempt is made in this report to determine the cause of the change.

The Spearman Test for Independence indicated that the annual mean temperature data display some degree of serial dependence. As for precipitation, cold years are likely to have been preceded by cold years and warm years by warm years. As stated for serial dependence in annual precipitation, the dependence may be a result of climatic changes on a larger spatial and temporal scale; however, no analysis was carried out to identify the possible causes of such a dependence for this report.

Winter (December to February) temperature data from fifteen long-term climate stations in Alberta, including Fort McMurray Airport, have been shown to be dependent on extreme phases of the Southern Oscillation, known as El Nino and La Nina events (Keller 1999). This oscillation has a frequency of three to eight years. Recorded winter temperatures average approximately four degrees warmer during El Nino years than during La Nina years.

3.3.1.3 Water Yield

Methods

Annual water yields were analyzed by analyzing long-term data from the seven long-term hydrologic monitoring stations examined in Section 3.2.3:

- Station 07DA001 – Athabasca River below Fort McMurray;
- Station 07DA006 – Steepbank River near Fort McMurray;
- Station 07DA008 – Muskeg River near Fort MacKay;
- Station 07DA009 – Jackpine Creek near Fort MacKay;
- Station 07DA018 – Beaver River above Syncrude;
- Station 07DB001 – MacKay River near Fort MacKay; and
- Station 07DC001 – Firebag River near the Mouth.

The available data were analyzed using the two statistical tests described in Section 3.3.1.1.

Results and Discussion

Results of the tests for trend and serial dependence are summarized in Table 3.14.

Given that water yield is highly dependent on precipitation, and that the precipitation data at Fort McMurray Airport display highly significant serial dependence, it is expected that local hydrologic monitoring stations would display some serial dependence. This is the case for long-term stations on the Muskeg, Beaver and MacKay rivers and Jackpine Creek. Data from the Athabasca River display less significant serial dependence, while data from the Steepbank and Firebag rivers do not display significant serial dependence. For the Athabasca River, the mix of climate regimes and physiographic characteristics over its large watershed may mask any serial dependence. For the Steepbank and Firebag rivers, serial dependence may be masked by other non-climatic factors.

Table 3.14 Results of Statistical Tests on Water Yield Data for Long-Term Hydrologic Monitoring Stations in the Oil Sands Region

Station	Trend	Independence
Athabasca River Station 07DA001	no trend	data display significant serial dependence at 5% level; no serial dependence at 1% level
Steepbank River Station 07DA006	no trend	no serial dependence
Muskeg River Station 07DA008	no trend	data display significant serial dependence at 5% level; no serial dependence at 1% level
Jackpine Creek Station 07DA009	no trend	data display significant serial dependence at 1% level
Beaver River Station 07DA018	no trend	data display significant serial dependence at 1% level
MacKay River Station 07DB001	no trend	data display significant serial dependence at 1% level
Firebag River Station 07DC001	no trend	no serial dependence

None of the water yield data for long-term hydrologic monitoring stations displays a significant trend. This is expected, since no trend is exhibited by the precipitation data.

Annual runoff volumes for six long-term hydrologic monitoring stations in Alberta, including the Athabasca River at Athabasca (watershed area 74,600 km^2), have been shown to be higher during the La Nina phase of the Southern Oscillation (Keller 1999). This oscillation has a frequency of three to eight years. This difference was shown to be significant at the 90% confidence interval.

3.3.1.4 Flood Discharges

Methods

The maximum daily mean discharge data from the seven long-term hydrologic stations examined in the previous section were analyzed using the two statistical tests described in Section 3.3.1.1.

Results and Discussion

Results of the tests for trend and serial dependence are summarized in Table 3.15.

Table 3.15 Results of Statistical Tests on Maximum Mean Daily Discharge Data for Long-Term Hydrologic Monitoring Stations in the Oil Sands Region

Station	Trend	Independence
Athabasca River Station 07DA001	no trend	no serial dependence
Steepbank River Station 07DA006	no trend	no serial dependence
Muskeg River Station 07DA008	no trend	no serial dependence
Jackpine Creek Station 07DA009	no trend	no serial dependence
Beaver River Station 07DA018	no trend	no serial dependence
MacKay River Station 07DB001	no trend	data display significant serial dependence at 5% level; no serial dependence at 1% level
Firebag River Station 07DC001	no trend	no serial dependence

Floods are generally caused by rapid snowmelt or large rainfall events, which have not been analyzed for these stations. Large snowmelt or rainfall events may influence water yields, but there is no direct correlation between annual water yields and flood-causing events. The only station for which any serial dependence is identified is the MacKay River, and that is only at a 5% level of significance.

None of the flood discharge data for long-term hydrologic monitoring stations displays a significant trend.

3.3.1.5 Low Flows

Methods

The minimum daily mean discharge data from the seven long-term hydrologic stations examined in the previous section were analyzed using the two statistical tests described in Section 3.3.1.1.

Results and Discussion

Results of the tests for trend and serial dependence are summarized in Table 3.16.

Table 3.16 Results of Statistical Tests on Minimum Mean Daily Discharge Data for Long-Term Hydrologic Monitoring Stations in the Oil Sands Region

Station	Trend	Independence
Athabasca River Station 07DA001	no trend	data display significant serial dependence at 5% level; no serial dependence at 1% level
Steepbank River Station 07DA006	no trend	data display significant serial dependence at 1% level
Muskeg River Station 07DA008	no trend	data display significant serial dependence at 5% level; no serial dependence at 1% level
Jackpine Creek Station 07DA009	no trend	data display significant serial dependence at 5% level; no serial dependence at 1% level
Beaver River Station 07DA018	data display highly significant trend at 1% level	data display significant serial dependence at 1% level
MacKay River Station 07DB001	no trend	no serial dependence
Firebag River Station 07DC001	no trend	no serial dependence

Low flows in the region are typically winter baseflows, though some observed annual low flows occurred during the summer or fall of dry years. Low flows primarily comprise groundwater seepage into the stream. Thus, they are a function of antecedent precipitation, surficial aquifer storage and permeability, and watershed size. For small watersheds, the stream may freeze to the bottom and cease to flow during an extended cold period. Low flows are dependent to some degree on precipitation. The precipitation data at Fort McMurray Airport display highly significant serial dependence. It follows that low flows at the local hydrologic monitoring stations display some serial dependence. Long-term stations on the Steepbank and Beaver rivers display serial dependence at a 1% level of significance, and long-term stations on the Muskeg and Athabasca rivers and Jackpine Creek display serial dependence at a 5% level of significance. Data from the Mackay and Firebag rivers do not display significant serial dependence, and non-climatic factors may mask any serial dependence.

Low flow data from the Beaver River display a significant upwards trend with time, which in this case is highly significant. This could be due to the observed warming change reducing the extent of the watershed that freezes to the bottom in the winter, when low flows are likeliest to occur, since this is the smallest of the long-term monitored watersheds. None of the water yield data for other long-term hydrologic monitoring stations displays a significant trend. This is what would be expected based on the absence of trend exhibited by the precipitation data.

3.3.2 Spatial Trends

3.3.2.1 Precipitation

Precipitation in the Oil Sands Region varies with elevation, latitude and topography. Analyses of data from the Fort McMurray Airport, Mildred Lake and Aurora climatic monitoring stations, as well as regional forestry lookouts, shows (Golder 2002e) that, in general:

- mean seasonal rainfall increases with elevation;
- the magnitude of extreme rainfall events (storms) increases with elevation; and
- the Birch Mountains produce a mild rain shadow effect on stations located to the east and in the Athabasca River valley.

The activities of local industry are not expected to have a significant effect on regional precipitation.

3.3.2.2 Temperature

The daily air temperature variations between the Fort McMurray Airport, Mildred Lake and Aurora climatic monitoring stations indicate that air temperature has little spatial variation in the region (Golder 2002e). However, data from seasonal stations located at forestry lookouts in the region indicate that air temperature decreases with increasing elevation at a lapse rate of approximately 0.5°C per 100 metres. The activities of local industry are not expected to have a significant effect on regional temperatures.

3.3.2.3 Water Yield

Annual water yield is a function of climatic conditions, including annual precipitation and evaporation, and watershed characteristics, including terrain type, surficial geology, and lake and wetlands storage. The greatest effects on water yield within the Oil Sands Region are due to the terrain types within the tributary watershed, since climatic conditions are relatively homogeneous within the region and the effects of surficial geology are more subtle than those of terrain types. Upland terrain produces the highest water yield, since it is faster draining and less water is lost to evapotranspiration or deep percolation. Lowland terrain yields less water, since more water is lost to evapotranspiration and deep percolation. Lakes and wetlands, where free water is exposed to the atmosphere, reduce water yields by allowing water to evaporate.

All of these factors must be taken into account in order to determine representative mean annual water yields. Therefore, spatial trends are dependent on the stream location and watershed characteristics. Mean annual water yields for long-term regional monitoring stations and selected short-term RAMP stations are presented in this report. Water yields for other nodes within the region have been calculated by hydrologic modelling undertaken during recent EIAs (CNRL 2002; Shell 2002).

3.3.2.4 Flood Discharges

Flood discharges are a function of climatic conditions, including rainfall or snowmelt intensity and duration, and watershed characteristics, including drainage area, terrain type, surficial geology, and lake and wetlands storage. The greatest effects on flood discharges within the Oil Sands Region are due to the terrain types within the tributary watershed, since climatic conditions are relatively homogeneous within the region and the effects of surficial geology are more subtle than those of terrain types. Upland terrain produces the highest flood discharges, since it is faster draining than lowland terrain. The short duration of flood discharges means that losses to deep percolation or evaporation are relatively small. Lakes and wetlands, where water is stored, attenuate floods and reduce flood peak discharges. In general, larger watersheds will exhibit larger flood discharges.

To determine representative flood discharges, all of these factors must be taken into account. Therefore, spatial trends are dependent on the stream location and watershed characteristics. Flood discharges for long-term regional monitoring stations and selected short-term RAMP stations are presented in this report. Flood discharges for other nodes within the region have been calculated by hydrologic modelling undertaken during recent EIAs (CNRL 2002; Shell 2002).

3.3.2.5 Low Flows

Low flows are a function of climatic conditions, including precipitation, evaporation and temperature, and watershed characteristics, including drainage area, terrain type, surficial geology, and lake and wetlands storage. The greatest effects on low flows are due to watershed size, temperature and storage in lakes, wetland and surficial aquifers. Streams with small watershed areas often freeze to the bottom during cold temperatures. Larger watersheds, and those with large surficial aquifer storage capacity, tend to sustain flows over the winter months.

To determine representative low flow discharges, all of these factors must be taken into account. Therefore, spatial trends are dependent on the stream location and watershed characteristics. Low flow discharges for long-term regional monitoring stations and selected short-term RAMP stations are presented in this report. Low flow discharges for other nodes within the region have been calculated by hydrologic modelling undertaken during recent EIAs (CNRL 2002; Shell 2002).

3.3.3 Ability to Detect Change

The long-term climatic and hydrologic stations in the Oil Sands Region are well-suited for detecting regional trends in water yield. Annual precipitation has the greatest influence on the annual water yield of a watershed in any given year. The long-term precipitation data from Fort McMurray Airport (Environment Canada Climate Station 3062693) provide an adequate record to characterize regional precipitation. The long-term data from seven regional hydrologic stations provide an adequate record to characterize water yields at those locations. These data have been used to calibrate a regional hydrologic model that provides predicted baseline characteristics for selected short-term monitoring stations, as discussed in Section 3.4, and at other selected nodes in the region. This model was used as the basis for hydrologic impact analysis in several recent EIAs (CNRL 2002; Shell 2002). Ongoing data collection at existing long-term and short-term stations will better define natural variability and variation due to local geographic and geologic conditions.

It would not be possible to identify changes in water yields, flood discharges, or low flows due to development simply on the basis of a short period of measured discharges and the results of a frequency analysis for a given stream. However, if required, stream discharge and precipitation data for a stream and watershed area could be used as part of a water balance model, to estimate changes to stream discharge attributable to developments within the watershed. The model would necessarily incorporate physical data for the natural areas within the watershed, as well as for disturbed areas, including changes to terrain types, drainage patterns, closed-circuited areas and artificial discharges. The accuracy of any water balance model would be enhanced by incorporating detailed, local precipitation data. For large watershed areas, a network of precipitation gauges would more accurately record the temporal and spatial variation of specific rainfall events that might need to be modelled.

3.3.4 Conclusions and Recommendations

As shown in Section 3.2, climatic and hydrologic data from the Oil Sands Region north of Fort McMurray exhibit some degree of natural variability. Therefore, in order to identify temporal trends in climate and hydrology, reasonably long-term data sets are required. These are provided by one long-term climate station, located at Fort McMurray Airport, and seven long-term hydrologic stations, located on the Athabasca, Steepbank, Muskeg, Beaver, Mackay and Firebag rivers and Jackpine Creek.

Annual precipitation data from Fort McMurray Airport display a high degree of serial dependence. The precipitation data did not display any significant trend.

Mean annual temperature data from Fort McMurray Airport also display a high degree of serial dependence. This may be related to the El Nino/La Nina phases of the Southern Oscillation. Mean annual temperature data were also shown to exhibit a warming trend over the monitoring period of 1944 to 2001, though an abrupt change appears to have occurred after 1971 and this could be related to a change in instrument type or surroundings.

Water yield data for the Beaver River, Mackay River and Jackpine Creek displayed a high degree of serial dependence at a 1% level of significance, while water yield data for the Athabasca and Muskeg rivers displayed serial dependence at a 5% level of significance. This is attributable to the dependence of water yield on precipitation, which was also found to be serially dependent. However, the Steepbank and Firebag rivers did not exhibit serial dependence. Annual water yields did not display any significant temporal trend, as would be expected since annual precipitation did not.

Maximum daily mean discharge data for all long-term regional stations were without trend. Only maximum mean daily discharge data for the MacKay River displayed serial dependence at a 5% level of significance.

Low flow data for the Beaver and Steepbank rivers displayed a high degree of serial dependence at a 1% level of significance, while low flow data for the Athabasca and Muskeg rivers and Jackpine Creek displayed serial dependence at a 5% level of significance. This is attributable to the dependence of water yield to precipitation, which was also found to be serially dependent. However, the MacKay and Firebag rivers did not exhibit serial dependence. Low flow data did not display any significant temporal trend, except for the Beaver River, where an upward trend in low flows may be affected by the observed warming trend.

Spatial trends in precipitation and temperature are subtle and due to geographic factors. They should not be affected by the activities of local industry.

Spatial trends in annual water yields, flood discharges and low flows are dependent on climatic conditions and physical characteristics of the tributary watershed. The hydrologic characteristics at any location on a stream are a function of precipitation, evaporation and temperature regimes, as well as watershed area, terrain, surficial geology, and lake and wetlands storage. The hydrologic characteristics for long-term regional monitoring stations and selected short-term RAMP stations are presented in this report, and hydrologic characteristics of other nodes within the region have been calculated by hydrologic modelling undertaken during recent EIAs (CNRL 2002; Shell 2002).

Data from the long-term climatic and hydrologic stations in the Oil Sands Region have been used to calibrate a regional hydrologic model that provides predicted baseline characteristics for selected nodes in the region. Ongoing data collection at existing long-term and short-term stations will better define natural variability and variation due to local geographic and geologic conditions. If required, to assess the hydrologic changes at a particular location, measured stream discharge and precipitation data could be used in a calibrated water balance model to estimate changes to stream discharge attributable to developments within the watershed. Accurate model results would be highly dependent on accurately quantifying the temporal and areal variation of precipitation in the modelled watershed.

3.4 MONITORING TO VERIFY EIA PREDICTIONS

Whether RAMP Climatic and Hydrologic Monitoring stations can be used to verify EIA predictions was addressed by examining the following questions:

- Are RAMP Climatic and Hydrologic Monitoring Stations located at appropriate sites?
- Are monitoring periods sufficient (e.g., are the data adequate to construct an annual water balance and describe annual precipitation and runoff hydrographs)?
- Is RAMP collecting or otherwise obtaining data required to differentiate natural variability from changes due to human activities?

3.4.1 Monitoring Locations

Most of the RAMP Climatic and Hydrologic Monitoring stations listed in Table 3.4 were installed to monitor the effects of mine developments or to indirectly help assess these effects. In many cases, a short period of baseline monitoring preceded the collection of data from disturbed areas. For some stations, this period of predisturbance monitoring is currently ongoing. Rationales for monitoring of climatic and hydrologic parameters at specific locations are provided in the annual RAMP Program Design and Rationale Document (Golder 2002f). Details of the rationales for monitoring the RAMP stations examined in this report follow.

RAMP Station C1 is located on Shell Lease 13, near the Canterra Road crossing of Jackpine Creek. Parameters monitored at this site include rainfall, snowfall, temperature, relative humidity, global solar radiation, wind speed and direction. The Aurora Climate Station is the only year-round, comprehensive climate station that operates in the region, except for the Environment Canada Climate Stations at Mildred Lake and Fort McMurray Airport. The station was established by Syncrude in May 1995 and was incorporated into RAMP in 2000. The Aurora Climate Station is well-situated to measure precipitation inputs in the Muskeg River watershed and adjacent areas. All parameters are monitored year-round and can be used to construct an annual water balance.

RAMP Hydrologic Monitoring Station S1 is located at the outlet of the Albian Sands Muskeg River Mine Pond #2, just upstream of the Muskeg River. This station measures surface runoff and surficial aquifer releases from the Muskeg River Mine and has a watershed area of 15.6 km^2, all of which is lowland terrain. Flow past this station also comes from the Syncrude Aurora North mine, via the Aurora Boundary Weir (RAMP Station S23). The station was established by Syncrude in August 1995 during the baseline study for the Aurora Project and was incorporated into RAMP in 2000. RAMP Hydrologic Monitoring Station S1 is well-situated to measure surface water discharges from the Muskeg River Mine into the Muskeg River. The exposed weir structure makes it difficult to measure flows during cold weather, when ice formation can affect the accuracy of measurements. If the weir is intended to be operational during freezing temperatures, it is recommended that installation of an insulated structure around the weir be considered.

RAMP Hydrologic Monitoring Station S2 is located on Jackpine Creek, upstream of its confluence with the Muskeg River. Station S2 is located just upstream of the inactive Environment Canada Hydrologic Monitoring Station 07DA009 and was established by Syncrude in May 1995 to continue flow measurements at the site. This station was discussed in detail in Section 3.2 and monitoring results are not addressed in this section. This station is well-situated to measure hydrologic effects on the Jackpine Creek watershed. It is currently operated only during the open water season. However, consideration should be given to periodic, manual measurements of flow during ice-covered conditions, if the effects of planned developments on low flows are to be assessed.

RAMP Hydrologic Monitoring Station S3 is located in an upland area of Iyinimin Creek, upstream of Kearl Lake. This station measures open-water surface water runoff from an upland west slope area of Muskeg Mountain and has a watershed area of 32.3 km^2, all of which is upland terrain. The station was established by Syncrude in August 1995 during the baseline study for the Aurora Project and was incorporated into RAMP in 2001. Station S3 is located within Oil Sands Lease 31 and is well situated to measure the future effects of developments at the proposed Aurora South Mine. Data from this station would also contribute to a water balance model that could quantify effects of developments on Kearl Lake, if required, and could potentially be used to assess groundwater-surface water interaction effects of the Suncor Firebag Project. Flows are generally very low during winter months, and the current open-water monitoring at this station should be adequate to describe the annual runoff hydrograph.

RAMP Hydrologic Monitoring Station S4 is located in an upland area of Blackfly Creek, upstream of its confluence with Khahago Creek. This station measures open-water surface water runoff from an upland west slope area of Muskeg Mountain and has a watershed area of 31.1 km^2, all of which is upland terrain. The station was established by Syncrude in May 1995 during the baseline study for the Aurora Project and was discontinued at the end of 1998. Station S4 is located within Oil Sands Lease 31 and is well situated to measure the future effects of developments at the proposed Aurora South Mine. The 2001 RAMP report (Golder 2002d) recommended that this station be reactivated three to five years before development commences at Aurora South. Data from this station could potentially be used to assess groundwater-surface water interaction effects of the Suncor Firebag Project. Flows are generally very low during winter months, and open-water monitoring at this station should be adequate to describe the annual runoff hydrograph, should this station be reactivated.

RAMP Hydrologic Monitoring Station S5A is located on the Muskeg River, below Stanley Creek. This station measures surface water runoff from the south slopes of the Fort Hills and north and west slopes of Muskeg Mountain and has a current watershed area of 552 km^2, of which 53% is upland terrain. Station S5 was established by Syncrude at a site upstream of Stanley Creek in August 1995 during the baseline study for the Aurora Project and was relocated to its present location at Station S5A in March 1998. Prior to its relocation, the station had a watershed area of 390 km^2, of which 55% was upland terrain. It monitors potential effects of the Albian Sands Muskeg River Mine and the Syncrude Aurora North Mine. This station would, in the future, be used to measure the effects of other projects including the Suncor Firebag Project, the Syncrude Aurora South Project, the ExxonMobil Kearl Project and developments by Shell on Oil Sands Leases 88 and 89. RAMP Hydrologic Monitoring Station S5A is well-situated to measure surface water discharges on the Muskeg River, upstream of the Albian Sands Muskeg River Mine. However, the planned diversion of water from the Syncrude Aurora North Project into Stanley Creek means that it will measure flows affected by that project. It is recommended that the station previously operated upstream on the Muskeg River (RAMP Station S5) be reactivated to measure flows upstream of the Syncrude Aurora North Project. Continued operation of Station S5A is recommended, because it has a reliable, well-established stage-discharge rating curve, is currently unaffected by beaver activity, and will provide redundancy should there be operational problems with Station S5. The year-round monitoring at Station S5A is adequate to describe the annual runoff hydrograph, and should be specified for Station S5 as well.

RAMP Hydrologic Monitoring Station S6 is located on Mills Creek above Isadore's Lake. This station measures surface water runoff from the Mills Creek fen, located on Oil Sands Leases 12, 13 and 34, and has a watershed area of 23.8 km^2, all of which is lowland terrain. Station S6 was established by Syncrude and Shell in April 1997. Future development of the Syncrude Aurora North Mine and the Albian Sands Muskeg River Mine could have significant effects on Mills Creek. Data from this station would also contribute to a water balance model that could quantify the effects of developments on Isadore's Lake, if required. RAMP Hydrologic Monitoring Station S6 is well-situated to measure surface water discharges from the Mills Creek fen. This station is currently operated only during the open-water season and discharges are low in winter. However, since the creek is fed from the fen, significant flow persists throughout the winter, and consideration should be given to operating this station year-round.

RAMP Hydrologic Monitoring Station S7 is located on the Muskeg River, upstream of the mouth. Station S7 is located just upstream of Environment Canada Hydrologic Monitoring Station 07DA008 and was established by Syncrude in November 1999 to provide winter flow measurements at the site. This station was discussed in detail in Section 3.2 and is not addressed in this section. Albian Sands also reports monthly mean flows in the Muskeg River downstream of the Muskeg River Mine (Lease 13 West) to Alberta Environment. This station is well-situated to measure hydrologic effects on the upstream Muskeg River watershed, including those from the Albian Sands Muskeg River Mine and Syncrude Aurora North Project. The year-round monitoring at Station S7 is adequate to describe the annual runoff hydrograph.

RAMP Hydrologic Monitoring Station S9 is located approximately one kilometre downstream of the outlet of Kearl Lake. The station was established by Syncrude and Shell in April 1998 and was incorporated into RAMP in 2001. This station measures the open-water discharge from Kearl Lake and has a watershed area of 91.3 km^2, of which 71% is upland terrain and 6% is lake area. Albian Sands reports lake levels and outflows from Kearl Lake to Alberta Environment. This station would, in the future, be used to measure the effects of other projects including the Suncor Firebag Project, the Syncrude Aurora South Project and the ExxonMobil Kearl Project. This station is well-situated to measure hydrologic effects on the Kearl Lake watershed. It is currently operated only during the open water season. However, consideration should be given to periodic, manual measurements of flow during ice-covered conditions, if the effects of planned developments on low flows are to be assessed.

RAMP Hydrologic Monitoring Station S10 is located on Wapasu Creek, upstream of its confluence with the Muskeg River. This station measures surface water runoff from the north slope of Muskeg Mountain and has a watershed area of 87.6 km^2, of which 74% is upland terrain. The station was established by Mobil in 1998 and was incorporated into RAMP in 2001. This station would, in the future, be used to measure the effects of projects including the Suncor Firebag Project, the Syncrude Aurora South Project and the ExxonMobil Kearl Project. This station is well-situated to measure hydrologic effects on the Wapasu Creek watershed. It is currently operated only during the open water season. However, consideration should be given to periodic, manual measurements of flow during ice-covered conditions, if the effects of planned developments on low flows are to be assessed.

RAMP Hydrologic Monitoring Station S11 is located approximately on Poplar Creek, upstream of its confluence with the Athabasca River and downstream of the Syncrude Base Mine. This station measures surface water runoff from disturbed and diverted areas of the Syncrude Base Mine and has a drainage area of 422 km^2. Environment Canada Hydrometric Station 07DA007 was located at this site from 1972 to 1986 and had an undisturbed drainage area of 151 km^2. The station was established by Syncrude in May 1995 and was incorporated into RAMP in 2000. This station is well-situated to measure hydrologic effects on the Poplar Creek watershed. It is currently operated only during the open water season. However, consideration should be given to periodic, manual measurements of flow during ice-covered conditions, if the effects of planned developments on low flows are to be assessed.

RAMP Hydrologic Monitoring Station L1 is located at the outlet of McClelland Lake. This station has a watershed area of 204 km^2, of which 35% is upland terrain, 15% is lake area and 13% comprises McClelland Fen. The station was established by Syncrude in June 1997. This station is well-situated to measure hydrologic effects on the McClelland Lake watershed. In autumn of 2002, the station was upgraded to year-round monitoring and it is recommended that this continue.

In addition to the RAMP Climatic and Hydrologic Monitoring Stations noted here, additional long-term regional data are available from the Environment Canada stations discussed in Sections 3.2 and 3.3. These data are purchased by RAMP on an annual basis and compiled in the RAMP climate and hydrology database. These data will be required in any analysis that attempts to differentiate natural variability from the effects of on-site activities, and continued collection of these data are recommended.

3.4.2 Precipitation

3.4.2.1 Methods

Since 1995, rainfall has been measured at RAMP Station C1 by a tipping-bucket rain gauge that records rainfall by registering a tip for each 0.2 mm depth of rain. From 1995 to present, the station has measured the depth of snow on ground using an ultrasonic sensor. However, this method provides no direct measure of the actual snow water equivalent depth of snowfall. In 2000, the station was retrofitted with a tipping-bucket snow gauge that records snowfall by melting it in an antifreeze reservoir, and registering a tip for each 0.254 mm depth of snow.

Rainfall data were compiled by calculating the total rainfall measured in each calendar year, from 1996 to 2001. Where data gaps existed, they were filled with data from the Fort McMurray Airport (Environment Canada Climate Station 3062693). The annual rainfall depths were plotted and compared to measured data from Fort McMurray Airport, as well as the results of the frequency analysis from Fort McMurray Airport, as presented in Section 3.2.1.

Snowfall data were analyzed by determining the total annual snowfall measured up to the end of May in each year, from 1996 to 2001. This period was selected to characterize the amount of snowfall that would contribute to spring runoff in that calendar year. Where data gaps existed, they were filled with data from the Fort McMurray Airport (Environment Canada Climate Station 3062693). The annual snowfall depths were plotted and compared to measured data from Fort McMurray Airport, as well as the results of the frequency analysis from Fort McMurray Airport, as presented in Section 3.2.1.

Total precipitation data were analyzed by adding the total annual rainfall for each calendar year to the total snowfall depth that would contribute to spring runoff in that calendar year, from 1996 to 2001. The annual precipitation depths were plotted and compared to measured data from Fort McMurray Airport, as well as the results of the frequency analysis from Fort McMurray Airport, as presented in Section 3.2.1.

3.4.2.2 Results and Discussion

Annual precipitation data from the Aurora Climate Station (RAMP Station C1), including rainfall, snowfall-to-runoff and precipitation-to-runoff, are provided in Table 3.17. Statistics of precipitation data from the Climate Station at Fort McMurray Airport (Environment Canada Station 3062693) are also provided in Table 3.17. Graphs of annual rainfall, snowfall-to-runoff and precipitation-to-runoff depths, including the results of the frequency analysis, are provided in Figures 3.32, 3.33 and 3.34, respectively.

Table 3.17 Annual Precipitation Data for Aurora Climate Station

Year	Snowfall-to-Runoff (mm water)	Rainfall (mm water)	Precipitation-to-Runoff (mm water)
Data from Aurora Climate Station			
1996	176	474	650
1997	94	378	472
1998	71	185	256
1999	98	234	332
2000	68	385	454
2001	85	254	339
Statistics from Fort McMurray Airport			
length of record	57 years	58 years	57 years
high of record	298 (1972)	533 (1973)	813 (1973)
100-year wet	284	574	741
10-year wet	220	427	601
mean	148	314	461
10-year dry	80	211	323
100-year dry	46	167	233
low of record	46 (1949)	170 (1945)	238 (1945)

Figure 3.32 Annual Rainfall Data for Aurora Climate Station (RAMP Station C1)

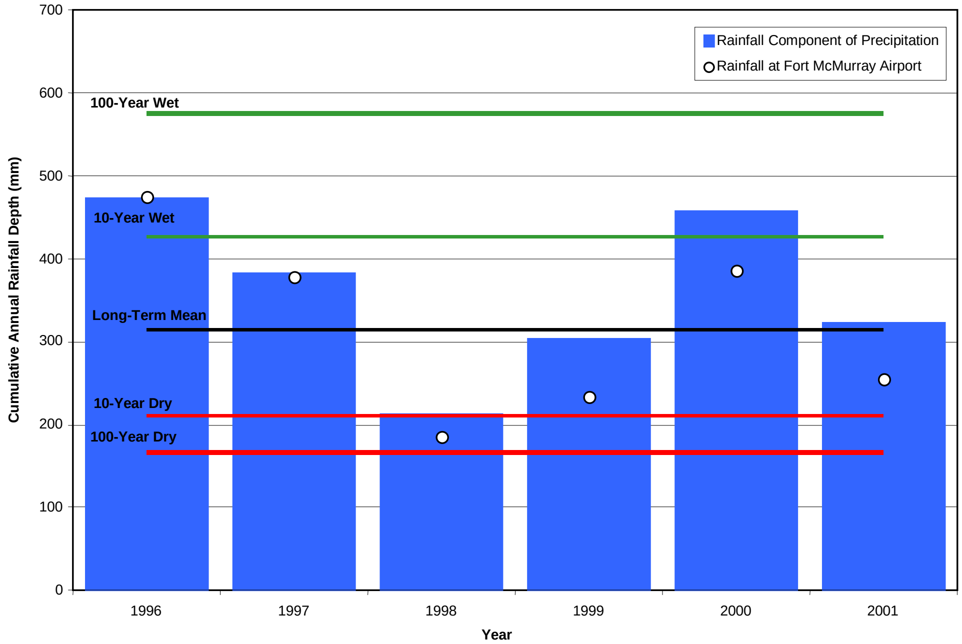


Figure 3.33 Annual Snowfall-to-Runoff Data for Aurora Climate Station (RAMP Station C1)

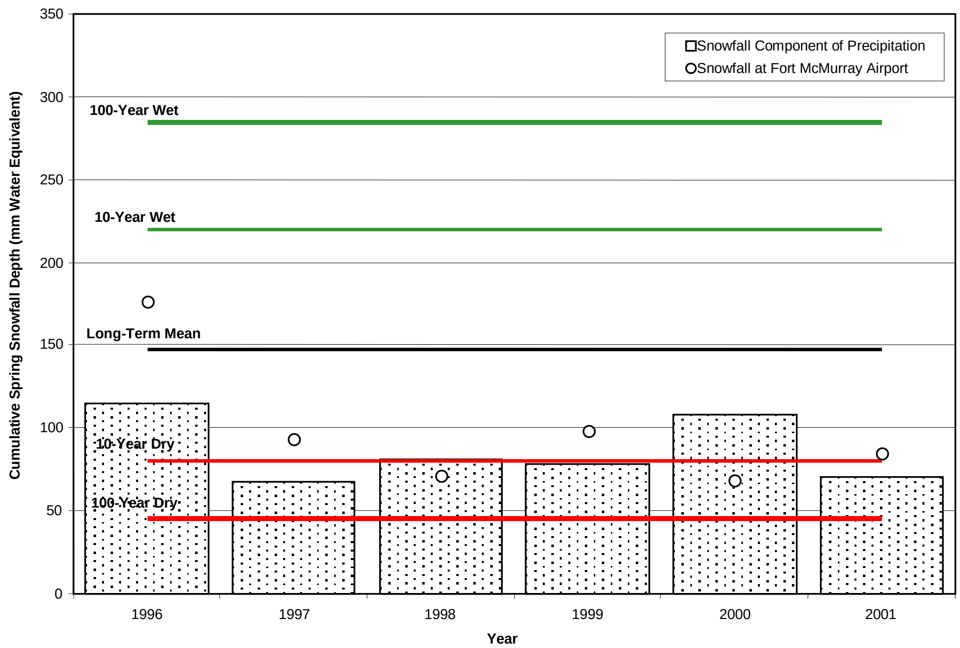
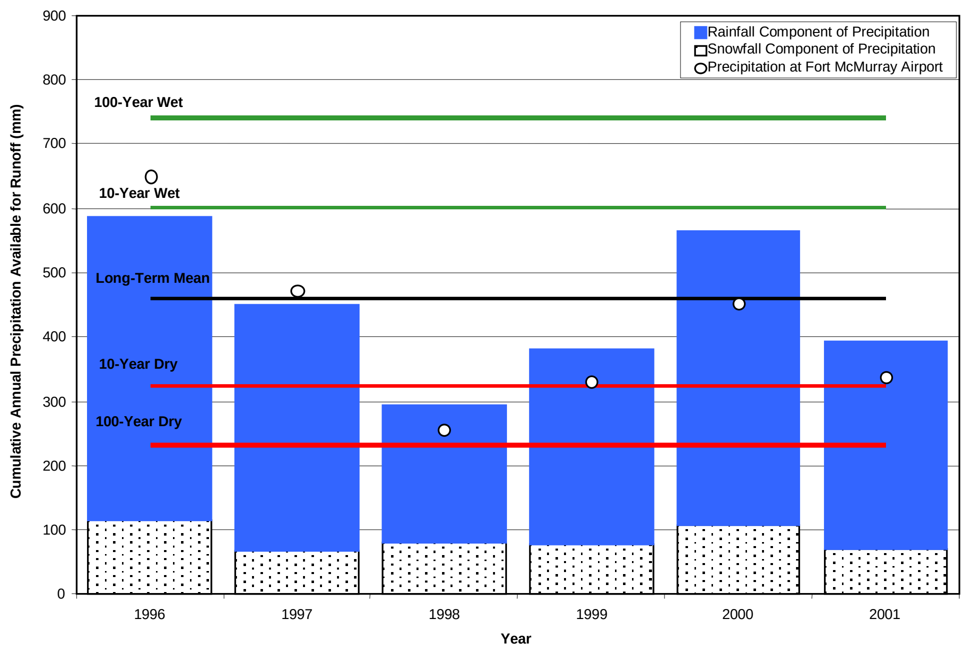


Figure 3.34 Annual Precipitation-to-Runoff Data for Aurora Climate Station (RAMP Station C1)



The data measured between 1996 and 2001 show a good agreement between the annual rainfall, snowfall and precipitation measured at the Aurora Climate Station and those measured at Fort McMurray Airport. Measured rainfall was virtually identical for 1996 and 1997, and slightly higher at the Aurora Climate Station in 1998, 1999, 2000 and 2001. Measured snowfall at the Aurora Climate Station was higher than that at Fort McMurray Airport in 1998 and 2000, and lower in 1996, 1997, 1999 and 2001. Measured total precipitation at the Aurora Climate Station was lower than that at Fort McMurray Airport in 1996 and 1997 and higher in 1998, 1999, 2000 and 2001. Differences in measured precipitation may be due to differing exposure to local precipitation events or be attributable to physical differences, such as elevation or topography, that can affect precipitation. Overall, there is a good agreement between precipitation measured at the two stations, indicating that the Aurora Climate Station should provide reliable data that is more representative of local conditions within the Muskeg River watershed. However, without a long-term record of data from the Aurora Climate Station with which to undertake a frequency analysis, it is not possible to perform a more detailed comparison.

3.4.3 Temperature

3.4.3.1 Methods

The Aurora Climate Station (RAMP Station C1) provides mean daily temperature data for the period of record 1995 to 2001. Since May 1995, hourly mean, minimum and maximum temperatures have been measured using a solid-state thermistor installed in a vented radiation shield.

Temperature data were analyzed by calculating the mean annual temperature measured in each calendar year, from 1996 to 2001. Where data gaps existed, they were filled with data from the Fort McMurray Airport (Environment Canada Climate Station 3062693). The mean annual temperatures were plotted and compared to measured data from Fort McMurray Airport, as well as to the results of the frequency analysis from Fort McMurray Airport, as presented in Section 3.2.2.

Winter and summer temperatures were also examined. The period from December to February was selected to represent winter temperatures, since this is the three-month period with the lowest mean temperature. The period from June to August was selected to represent summer temperatures, since this is the three-month period with the highest mean temperature. Since the Aurora Climate Station was installed in May 1995, summer data were also available for 1995. The mean annual temperatures were plotted and compared to measured data from Fort McMurray Airport, as well as to the results of the frequency analysis from Fort McMurray Airport, as presented in Section 3.2.2.

3.4.3.2 Results and Discussion

Temperature data from the Aurora Climate Station (RAMP Station C1), including mean annual, mean winter (December to February) and mean summer (June to August) temperatures, are provided in Table 3.18. Statistics of temperature data from the Climate Station at Fort McMurray Airport (Environment Canada Station 3062693) are also provided in Table 3.18. Graphs of mean annual, mean winter and mean summer temperatures, including the results of the frequency analysis, are provided in Figures 3.35, 3.36 and 3.37, respectively.

Table 3.18 Annual Temperature Data for Aurora Climate Station

Year	Mean Winter (Dec-Feb) Temperature (°C)[a]	Mean Annual Temperature (°C)	Mean Summer (Jun-Aug) Temperature (°C)
Data from Aurora Climate Station			
1995	not available	not available	14.6
1996	-20.9	-1.9	15.7
1997	-13.9	1.1	16.5
1998	-15.6	2.0	17.1
1999	-14.4	2.0	15.7
2000	-17.7	0.0	14.7
2001	-14.5	1.6	16.2
Statistics from Fort McMurray Airport			
length of record	57 years	58 years	58 years
high of record	-8.4 (1987)	3.2 (1987)	17.0 (1991)
100-year warm	-9.9	3.2	17.6
10-year warm	-13.1	1.8	16.5
mean	-17.4	0.2	15.2
10-year cold	-22.7	-1.5	14.0
100-year cold	-26.1	-2.8	13.4
low of record	-24.7 (1950)	-2.7 (1951)	13.4 (1959)

[a] Winter data include January-February of noted year and December of previous year.

Figure 3.35 Annual Mean Temperature Data at Aurora Climate Station (RAMP Station C1)

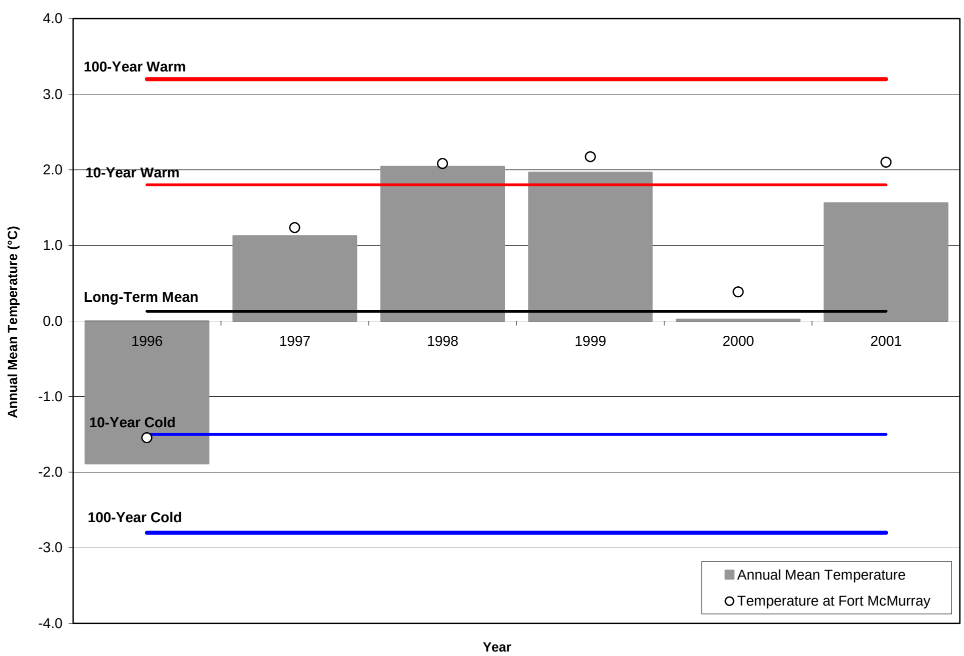


Figure 3.36 Winter Mean Temperature Data at Aurora Climate Station (RAMP Station C1)

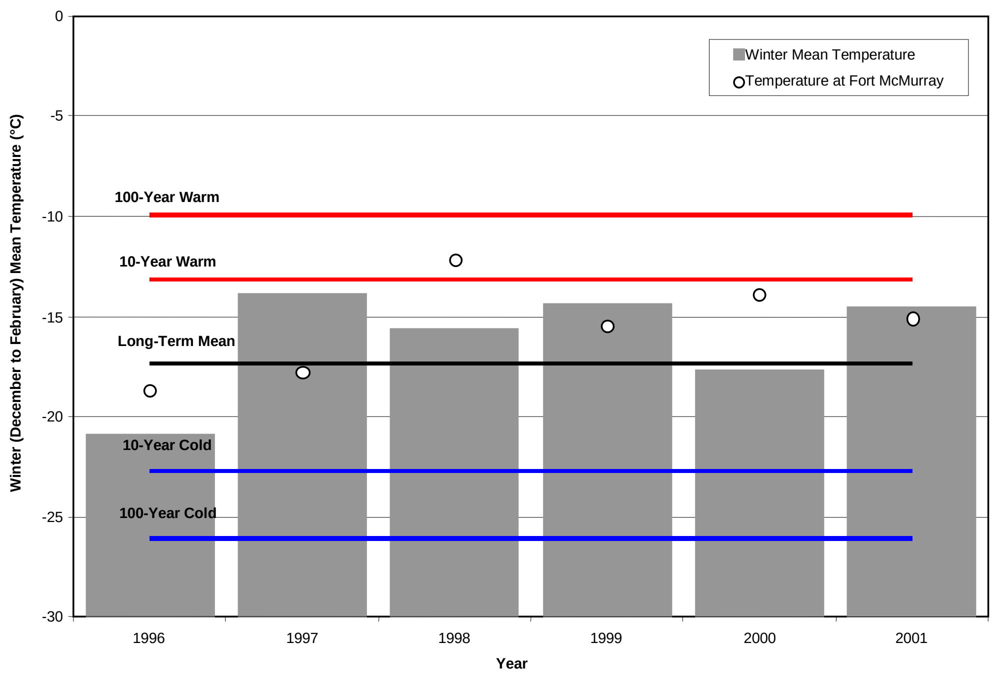
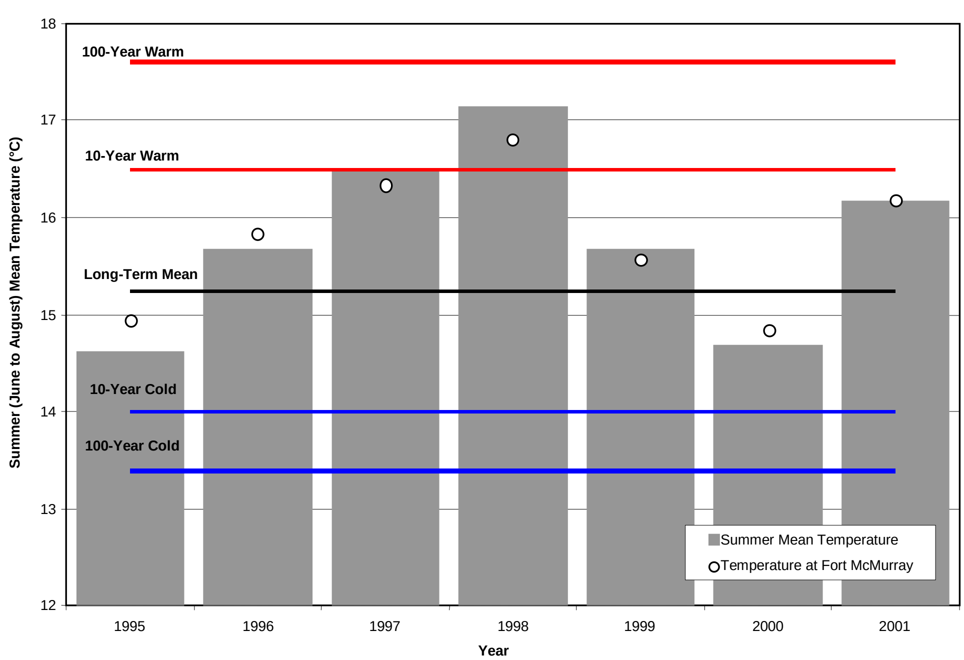


Figure 3.37 Summer Mean Temperature Data at Aurora Climate Station (RAMP Station C1)



The data measured between 1995 and 2001 show a very good agreement between the mean annual, mean winter and mean summer temperatures measured at the Aurora Climate Station and those measured at Fort McMurray Airport. Measured mean annual temperatures are within 0.5°C of those at Fort McMurray Airport, as are measured mean summer temperatures. However, as for Fort McMurray Airport, there is greater variability and a greater difference in mean winter temperatures, with a difference in mean winter temperatures between the Aurora Climate Station and Fort McMurray Airport of up to 4°C measured in 2000.

Differences in recorded temperature may be due to differing exposure to solar radiation, cloud cover or local precipitation events or be attributable to physical differences, such as elevation or topography, that can affect temperature. Overall, there is a very good agreement between temperature recorded at the two stations. However, without a long-term record of data from the Aurora Climate Station with which to undertake a frequency analysis, it is not possible to perform a more detailed comparison.

3.4.4 Water Yield

3.4.4.1 Methods

Annual water yield is defined as the mean depth equivalent of total runoff from a watershed over the course of the year. It is calculated by dividing the cumulative discharge volume measured over the year by the area of the watershed. Water yields are a function of climatic conditions and watershed characteristics as discussed in Section 3.2.3.1.

Water yields were analyzed by examining annual stream discharge data from the nine short-term RAMP hydrologic monitoring stations noted in Table 3.5:

- Station S1 – Alsands Drain;
- Station S3 – Iyinimin Creek;
- Station S4 – Blackfly Creek;
- Station S5A – Muskeg River Aurora;
- Station S6 – Mills Creek;
- Station S9 – Kearl Lake Outlet;
- Station S10 – Wapasu Creek;
- Station S11 – Poplar Creek; and

- Station L1 – McClelland Lake Outlet.

Most of the noted RAMP stations are on small watersheds, with channels that either freeze to the bottom or sustain flows too small to be accurately monitored under ice-covered conditions. The only exception to this is Station S5A on the Muskeg River, for which year-round monitoring is available since 1999.

Data gaps for the RAMP stations were filled using the approach discussed in Section 3.2.2. Because calculation of annual water yields requires a complete January to December data set, consideration was given to filling in data gaps based on best estimates of stream discharges during periods where records were unavailable. Data gaps were first examined by considering the duration and expected stream behaviour during the gap. From mid-November to late March, baseflow discharges are generally unaffected by snowmelt or rainfall and frequently fall to zero as streams freeze to the bottom. For cases where observations suggested that flows were sustained over the winter, gaps were filled by assuming a linear recession to baseflow in mid-November and interpolating between measurements at the start and finish of the gap. For cases where observations suggested that discharges ceased over the winter period, gaps were filled by assuming a linear recession to zero flow in mid-November and interpolating between zero flow at the end of March and the first measurement of the year. These assumptions are coarse, but are justified by the existence of very low flows during the winter season, meaning that water yield calculations are less sensitive to possible inaccuracies than they would be to those applied to higher discharges.

Data gaps during periods that could be affected by snowmelt or rainfall were filled by estimating variable discharges, based on available data from adjacent stations, stations upstream or downstream on the same stream, and/or local precipitation data.

As for the long-term hydrologic stations discussed in Section 3.2.2, cumulative annual discharge volumes were divided by the tributary watershed area at the monitoring station to calculate a runoff depth for each year of available data. However, since no long-term data were available for any of these stations, it was not possible to undertake frequency analyses of maximum and minimum events. Where hydrologic model results were available, modelled low flows were used to undertake a frequency analysis of minimum events to determine the likely mean annual water yield from the tributary watershed, as well as the 10-year and 100-year wet and dry water yields.

The annual precipitation available for runoff, as measured at Fort McMurray and presented in Section 3.2.1, is also plotted on each water yield graph. This should provide some idea of the response of the watershed to precipitation. However, it must be noted that values measured at Fort McMurray may not be representative of precipitation on the local watershed, especially for localized storm events.

3.4.4.2 Results and Discussion

For watersheds of similar size, subject to similar precipitation inputs, annual water yields are larger for those that are steeper and have high drainage densities and a low proportion of open water. Conversely, watersheds that are flatter, with low drainage densities and a high proportion of open water, tend to have lower water yields. Water yields are reduced by losses to groundwater and may be increased by inflows of groundwater from adjacent watersheds or by significant releases from groundwater storage during baseflow. This behaviour applies to water yields from natural watersheds. For monitoring stations that are intended to measure impacts of human activity in the Oil Sands Region, other factors may affect water yields. Closed-circuiting of mine, plant and tailings areas may render some portion of the watershed area non-contributing, thus reducing water yields if they are calculated based on the natural watershed area. Diversions into and out of the watershed may similarly increase or decrease calculated water yields. Discharges from muskeg drainage and overburden dewatering can show up as elevated water yields, as water is released from storage in the surficial aquifer. Changes to terrain types, such as the establishment of an overburden stockpile in a lowland area or reclamation of a dam embankment, can produce changes in water yield due to differences in slope, drainage density, surficial geology or storage from the natural terrain.

Figures showing calculated annual water yields and derived water yield statistics for the natural watershed for each station are provided in Figures 3.38 to 3.46. The measured annual precipitation at Fort McMurray Airport is also shown on each figure. A summary of the water yield analysis for RAMP short-term hydrologic monitoring stations is provided in Table 3.19.

Flows at RAMP Station S1 are generally zero during midwinter. Water yields are not calculated for 1995, since the station was not installed until late summer, and for 1997, since the station was washed out in August of that year by a floodwave caused by the sequential break of beaver dams. The water yield measured in 1996 at Station S1 is close to the mean annual water yield, though this occurred in a wetter-than-average year. From 1998 to 2001, water yields were significantly higher than the calculated 100-year wet values, with the water yield in 1998 being 10 times the calculated mean year value. These high water yields are explained by the fact that the Alsands Drain receives muskeg drainage and overburden dewatering discharges from the Syncrude Aurora North Mine and from the Albian Sands Muskeg River Mine. At the end of 2002, the Alsands

Drain watershed will no longer receive any flow from the Aurora North Mine, and all flows will consist of surface runoff, muskeg drainage and overburden dewatering water from the Muskeg River Mine.

Flows at RAMP Station S3 are not monitored from November until spring snowmelt and are generally zero during midwinter. Water yields are not calculated for 2000, when the station was not operated. The watershed tributary to Station S3 is at present largely undisturbed, so the observed water yields may be taken as natural. Measured water yields vary from a low of 20 mm in 1999, to a high of 266 mm in 1997. The observed water yields correlate well to the measured precipitation, as discussed in Section 3.2.1.

Flows at RAMP Station S4 are generally zero during midwinter and are not monitored from November until spring snowmelt. Water yields are not calculated for 1999 to 2001, when the station was not operated. The watershed tributary to Station S4 is at present largely undisturbed, so the observed water yields may be taken as natural. Measured water yields vary from a low of 98 mm in 1999, to a high of 279 mm in 1997. The observed water yields correlate well to the measured precipitation, discussed in Section 3.2.1. They also compare well to those from Iyinimin Creek, which is nearby and has similar characteristics. Differences in water yields between the two stations may be attributable in part to local variations in precipitation.

The watershed tributary to RAMP Station S5A is at present largely undisturbed, except for a small area of closed-circuiting in the Stanley Creek watershed, so the observed water yields may be taken as natural. Water yields are not calculated for 1995, since the station was not installed until late summer. Measured water yields vary from a low of 17 mm in 1999, to a high of 164 mm in 1997. The observed water yields correlate well to the measured precipitation, discussed in Section 3.2.1. Water yields at this station are lower than those observed on Iyinimin Creek and Blackfly Creek. This can be attributed to the higher proportion of lowland terrain in the Muskeg River watershed. Water yields from lowland areas tends to be lower than from steeper, better-drained upland areas. Starting in 2003, the Syncrude Aurora North Mine will discharge water from muskeg drainage and overburden dewatering to Stanley Creek, raising flows and water yields in the Muskeg River below Stanley Creek.

Table 3.19 Statistics of Water Yields for Short-Term RAMP Hydrologic Monitoring Stations

Statistic	Precipitation at Fort McMurray Airport	Alsands Drain S1	Iyinimin Creek S3	Blackfly Creek S4	Muskeg River Aurora S5A	Mills Creek S6	Kearl Lake Outlet S9	Wapasu Creek S10	Poplar Creek S11	McClelland Lake Outlet L1
drainage area (km^2)	n/a	15.6	32.3	31.1	552	23.8	91.3	87.6	422	204
natural mean annual discharge[(b)] (m^3/s)	n/a	0.025	0.125	0.120	1.75	0.038	0.261	0.286	n/a	0.310
period of record	1995-2001	1996, 1998-2001	1995-1999, 2001	1995-1998	1996-2001	1997-2001	1998-1999, 2001	1999, 2001	1995-1996, 1998-2001	1998-2001
measured 1995 (mm)	509	n/a	67	114	n/a	n/a	n/a	n/a	82	n/a
measured 1996 (mm)	650	44.0	244	249	164	n/a	n/a	n/a	229	n/a
measured 1997 (mm)	472	n/a	266	279	140	107	n/a	n/a	n/a	n/a
measured 1998 (mm)	256	522	66	98	24	111	0.5	n/a	29	1.8
measured 1999 (mm)	332	169	20	n/a	17	28	0.1	18	9	0.1
measured 2000 (mm)	454	122	n/a	n/a	76	25	n/a	n/a	33	0.4
measured 2001 (mm)	339	92.6	56	n/a	50	28	8	73	46	1.4
highest observed (mm)	813 (1973)	522 (1998)	266 (1997)	279 (1997)	164 (1996)	111 (1998)	8 (2001)	73 (2001)	229 (1996)	1.8 (1998)
100-year wet return period[(a)] (mm)	741	148[(b)]	283[(b)]	283[(b)]	244[(b)]	148[(b)]	240[(a)]	249[(a)]	n/a	n/a
10-year wet return period[(a)] (mm)	601	102[(b)]	209[(b)]	209[(b)]	174[(b)]	102[(b)]	164[(a)]	180[(a)]	n/a	n/a
long term average[(a)] (mm)	461	51[(b)]	122[(b)]	122[(b)]	100[(b)]	51[(b)]	90[(a)]	103[(a)]	n/a	48[(c)]
10-year dry return period[(a)] (mm)	323	11[(b)]	47[(b)]	47[(b)]	40[(b)]	11[(b)]	16[(a)]	37[(a)]	n/a	n/a
100-year dry return period[(a)] (mm)	233	3[(b)]	22[(b)]	22[(b)]	20[(b)]	3[(b)]	0.4[(a)]	17[(a)]	n/a	n/a
lowest observed (mm)	238 (1945)	44 (1996)	20 (1999)	98 (1998)	17 (1999)	25 (2000)	0.1 (1999)	18 (1999)	9 (1999)	0.1 (1999)

(a) Model results for the adjacent Alsands Drain watershed from the Shell Jackpine EIA (Shell 2002).

(b) Model results from the Shell Jackpine EIA (Shell 2002).

(c) Model results from the TrueNorth Fort Hills Oil Sands Project EIA (TrueNorth 2001).

n/a = Not available.

The watershed tributary to Station S6 is at present affected only by access roads to the Syncrude Aurora North Mine and the Albian Sands Muskeg River Mine, as well as by the Susan Lake Gravel Pit, so the observed water yields may be taken as close to natural. There is no defined channel on Mills Creek until a point several hundred metres upstream of Station S6, where water is released from the fen. Measured water yields vary from a low of 17 mm in 1999, to a high of 164 mm in 1997. The observed water yields do not correlate well to the measured precipitation, discussed in Section 3.2.1. This may be due to the low ground slopes in the watershed and the high degree of storage available in the muskeg and sand surficial aquifer of the Mills Creek fen. Future mining activity at the Aurora North and Muskeg River Mines will close-circuit areas of the Mills Creek watershed and it is expected that flows will be greatly reduced from natural rates.

Water yields for RAMP Station S9 are not calculated for 2000, when the station was not operated. The watershed tributary to this station is at present largely unaffected by industry, so the observed water yields may be taken as natural. Measured water yields vary from a low of 0.1 mm in 1999, to a high of 8 mm in 2001. The observed water yields correlate well to the measured precipitation, discussed in Section 3.2.1. All three years of monitoring at the Kearl Lake Outlet coincided with years of very low precipitation. The Kearl Lake watershed contains a relatively large proportion of upland terrain, but the lake surface allows direct evaporation of substantial quantities of water in the summer months.

Water yields for RAMP Station S10 are not calculated for 1998, when only periodic manual measurements were undertaken, and for 2000, when the station was not operated. The watershed tributary to Station S10 is at present largely unaffected by industry, so the observed water yields may be taken as natural. Measured water yields vary from a low of 18 mm in 1999, to a high of 73 mm in 2001. The observed water yields correlate well to the measured precipitation, discussed in Section 3.2.1.

Water yields are not calculated for RAMP Station S11 for 1997, when no data were recorded until July. The watershed tributary to Station S11 is substantially affected by development and has been for the duration of RAMP monitoring. No hydrologic model results are available for this station. Measured water yields vary from a low of 9 mm in 1999, to a high of 229 mm in 1997. The observed water yields correlate well to the measured precipitation, discussed in Section 3.2.1.

Water yields are not calculated for RAMP Station L1 for 1997, since the station was not installed until late June. The watershed tributary to this station is at present largely undisturbed, so the observed water yields may be taken as natural. Measured water yields vary from a low of 0.4 mm in 2000, to a high of 1.8 mm in 1998. The observed water yields correlate well to the measured precipitation, discussed in Section 3.2.1. The four complete years of monitoring at the McClelland Lake Outlet coincided with years of below average precipitation. The McClelland Lake watershed contains a very large proportion of lake surface area, which allows direct evaporation of substantial quantities of water in the summer months. Historical airphotos indicate that McClelland Lake dried up to approximately 1/3 of its current surface area in the early 1950's and it is likely that lake discharges ceased for several years at that time.

Figure 3.38 Annual Water Yields for Alsands Drain at the Muskeg River Mine (RAMP Station S1)

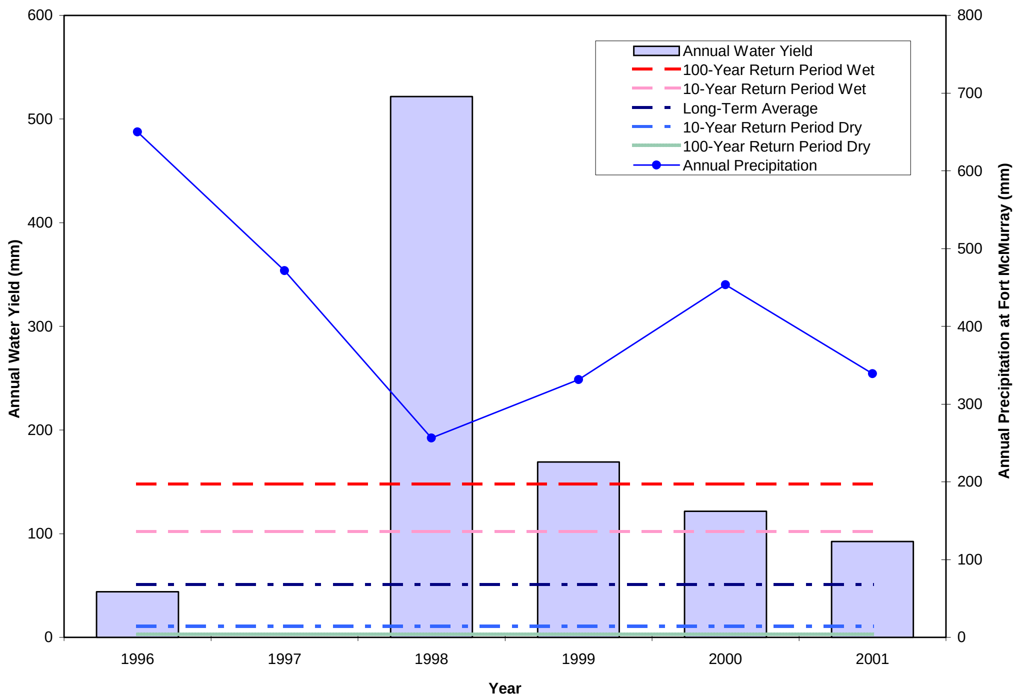


Figure 3.39 Annual Water Yields for Iyinimin Creek above Kearl Lake (RAMP Station S3)

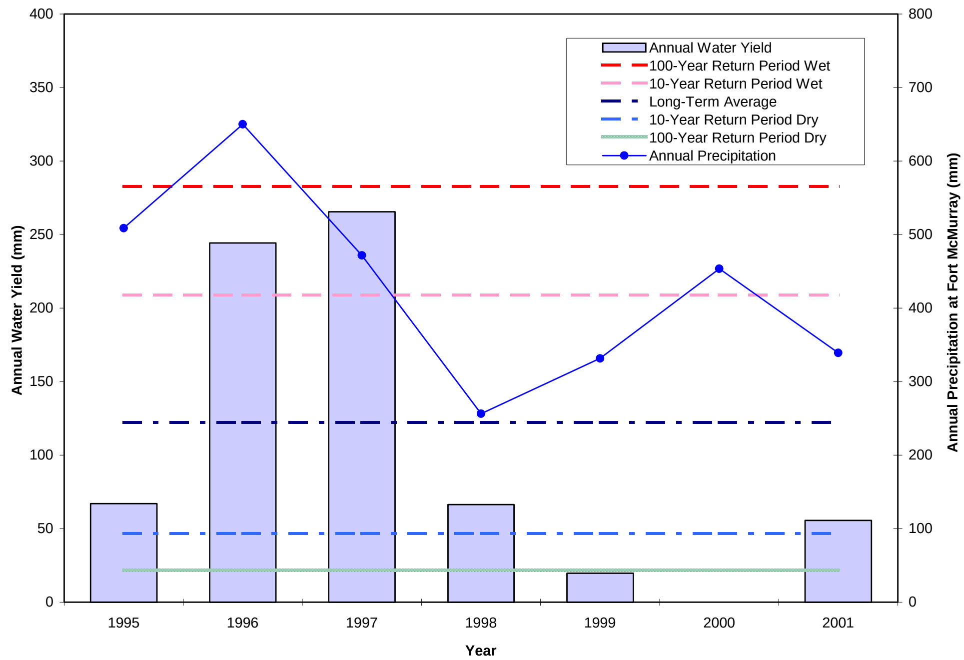


Figure 3.40 Annual Water Yields for Blackfly Creek above Khahago Creek (RAMP Station S4)

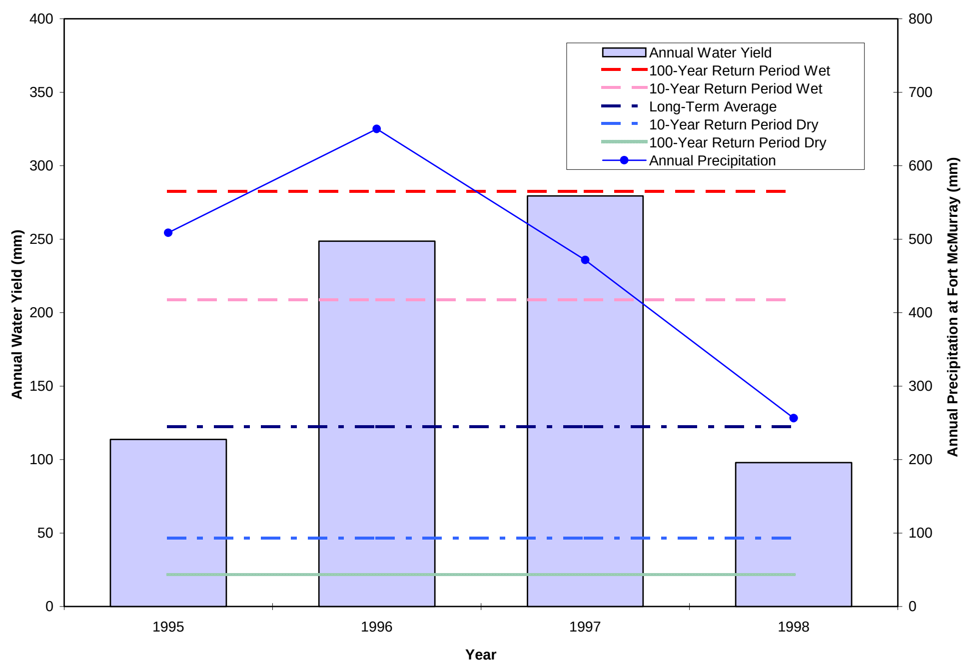


Figure 3.41 Annual Water Yields for Muskeg River below Stanley Creek (RAMP Station S5A)

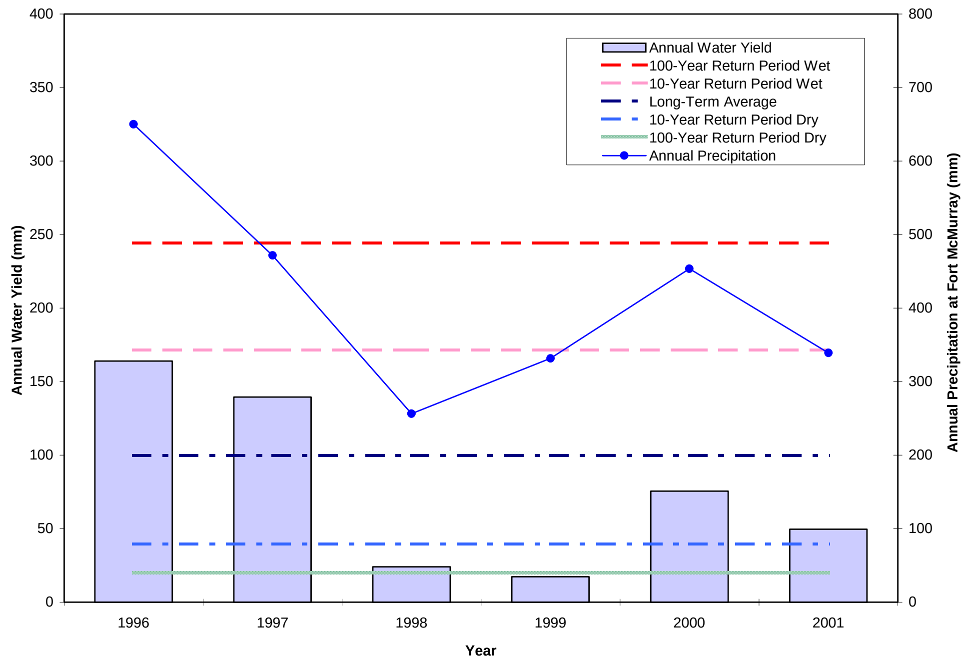


Figure 3.42 Annual Water Yields for Mills Creek above Isadore's Lake (RAMP Station S6)

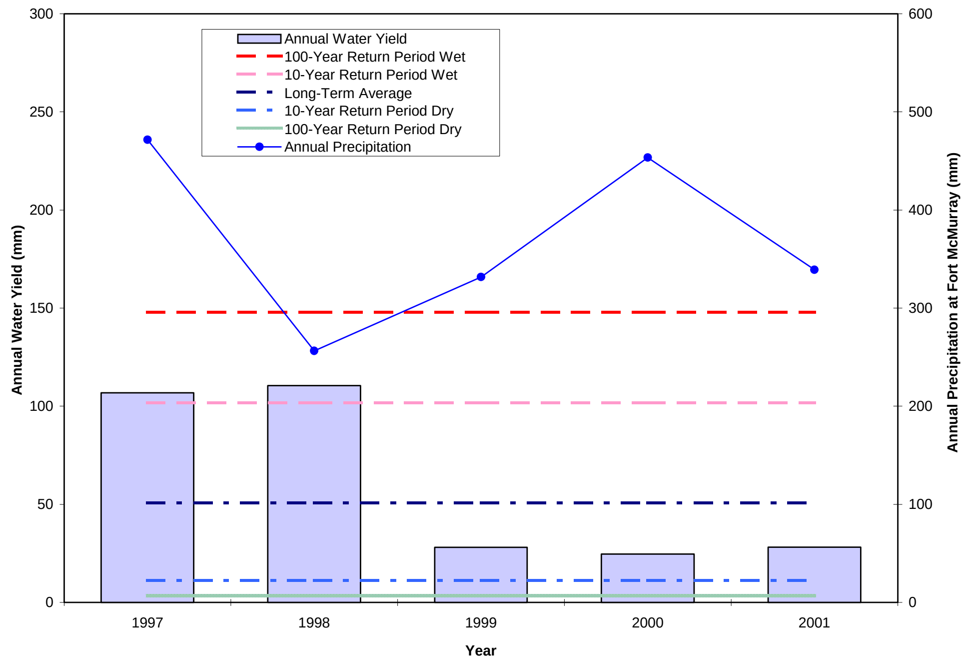


Figure 3.43 Annual Water Yields for Kearl Lake Outlet (RAMP Station S9)

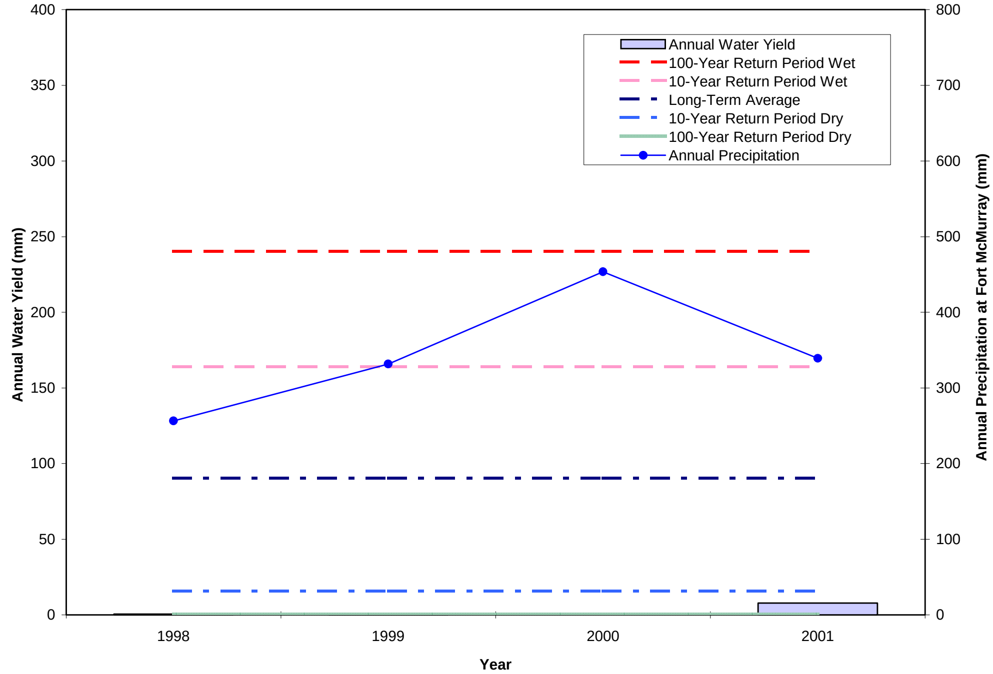


Figure 3.44 Annual Water Yields for Wapasu Creek above Muskeg River (RAMP Station S10)

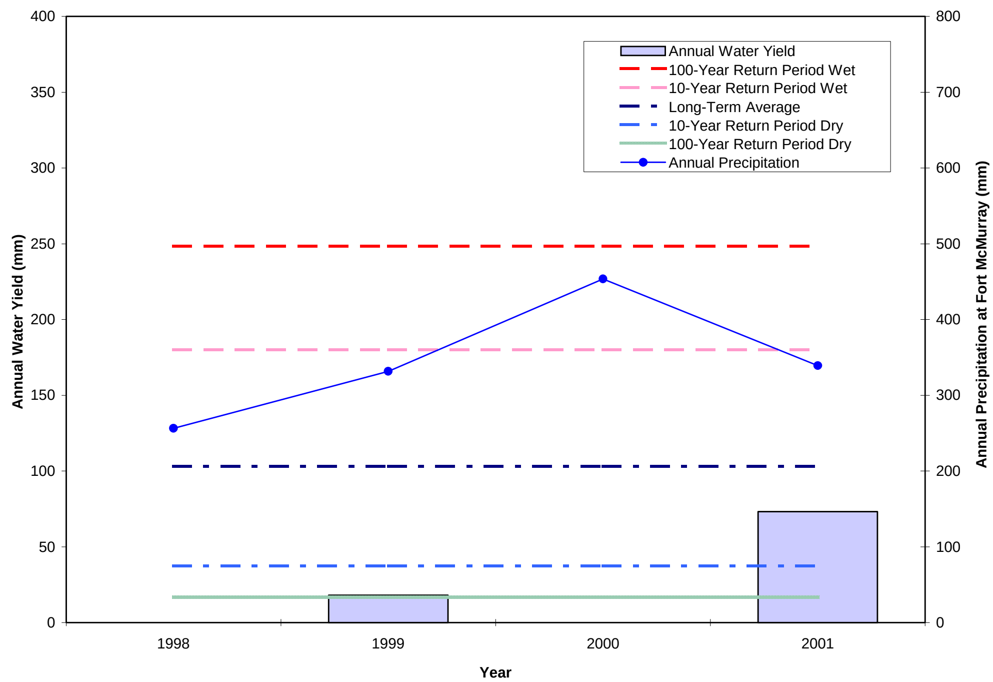


Figure 3.45 Annual Water Yields for Poplar Creek near the Mouth (RAMP Station S11)

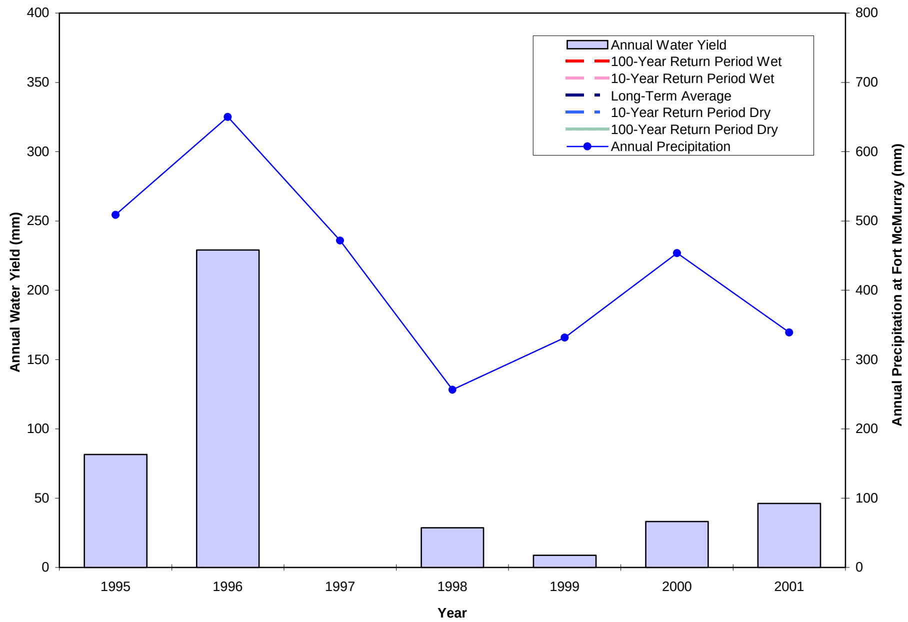
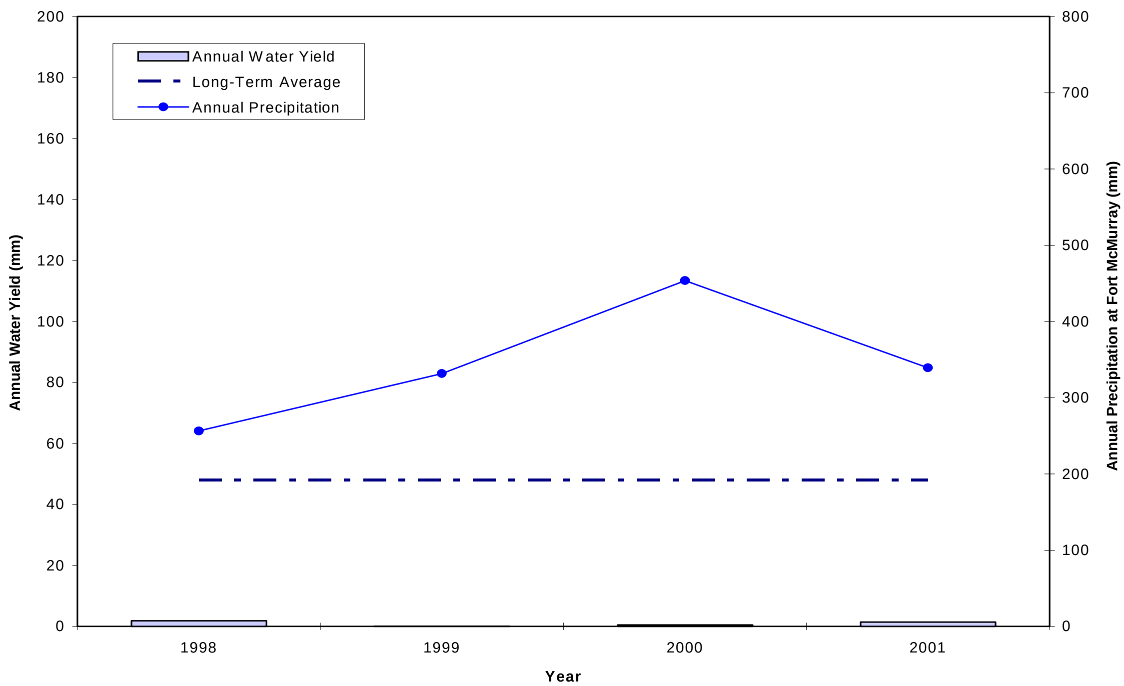


Figure 3.46 Annual Water Yields for McClelland Lake Outlet (RAMP Station L1)



3.4.5 Flood Discharge

3.4.5.1 Methods

Annual flood peak discharges may be characterized by the maximum daily mean discharge or by the maximum instantaneous discharge measured at a point. Since a more complete set of maximum daily mean discharges is available for the RAMP data set, these are analyzed in this report. The annual maximum daily mean discharge is defined as the largest daily mean discharge measured at a hydrologic monitoring station over the course of a calendar year. It is calculated by averaging readings taken at a constant interval over a day (midnight to midnight). As for water yields, flood discharges are a function of climatic conditions and watershed characteristics as discussed in Section 3.2.4.1.

Annual flood discharges were analyzed by examining annual stream discharge data from the nine short-term RAMP hydrologic monitoring stations noted in Table 3.5:

- Station S1 – Alsands Drain;
- Station S3 – Iyinimin Creek;
- Station S4 – Blackfly Creek;
- Station S5A – Muskeg River Aurora;
- Station S6 – Mills Creek;
- Station S9 – Kearl Lake Outlet;
- Station S10 – Wapasu Creek;
- Station S11 – Poplar Creek; and
- Station L1 – McClelland Lake Outlet.

No filling of data gaps for flood discharges was undertaken for these stations. If a data gap existed during flood conditions in the region, data from that year was not included in the analysis. Reported maximum mean daily discharges were compiled for each station's period of record. However, since no long-term data were available for any of these stations, it was not possible to undertake frequency analyses of maximum events. Where hydrologic model results were available, modelled annual maximum mean daily discharges were used to undertake a frequency analysis of maximum events to determine the maximum mean daily discharges 2-year, 10-year and 100-year return periods.

3.4.5.2 Results and Discussion

For watersheds of similar size, subject to similar precipitation inputs, flood response is quicker and flood magnitude is larger for those that are steeper and have high drainage densities and low storage capacities. Conversely, watersheds that are flatter, with low drainage densities and high storage capacities, tend to have slower flood responses and lower peaks. For watersheds with similar topography, subject to similar precipitation inputs, the flood magnitude is larger for larger watersheds. However, smaller watersheds have a quicker flood response and a higher unit flood magnitude (discharge divided by watershed area). This behaviour applies to water yields from natural watersheds. For monitoring stations that are intended to measure impacts of human activity in the Oil Sands Region, other factors may affect flood discharges. Closed-circuiting of mine, plant and tailings areas may render some portion of the watershed area non-contributing, thus reducing flood discharges. Diversions into and out of the watershed may similarly increase or decrease flood magnitude and duration. Discharges from muskeg drainage and overburden dewatering can elevate base flows, as water is released from storage in the surficial aquifer, and thereby increase flood peaks. However, storage and attenuation of flood waters in water management infrastructure, such as deep ditches and polishing ponds, may reduce flood peaks. Changes to terrain types, such as the establishment of an overburden stockpile in a lowland area or reclamation of a dam embankment, can produce changes in flood characteristics due to differences in slope, drainage density, surficial geology or storage from the natural terrain.

Figures showing measured annual maximum daily mean discharges and derived flood statistics for the natural watershed for each station are provided in Figures 3.47 to 3.55. A summary of the flood discharge analysis for RAMP short-term hydrologic monitoring stations is provided in Table 3.20.

The maximum daily mean discharge for RAMP Station S1 is not available for 1995, when the station did not operate for the entire open-water season, or for 1997, when a floodwave passing through the channel caused the station to wash out. This flood occurred when a beaver dam upstream was breached and initiated a sequential failure of other dams downstream, releasing a substantial quantity of water from storage. As noted in Section 3.4.2.2, for the monitoring period, the Alsands Drain received surface runoff, muskeg drainage and overburden dewatering discharges from the Syncrude Aurora North Mine and from the Albian Sands Muskeg River Mine. However, mine drainage and dewatering flows are often pumped and tend to be relatively steady, with drainage from precipitation events attenuated by storage in ditches, sumps and ponds. Therefore, though annual water yields at this station were observed to be very high, maximum annual discharges are not as extreme, compared to the values for the natural watershed.

The maximum daily mean discharge for RAMP Station S3 is not available for 2000, when the station was not operated. The watershed tributary to this station is at present largely undisturbed, so the observed flood peak discharges may be taken as natural. The magnitudes of the observed flood peaks compare well to the measured flood peaks on the Muskeg and Steepbank rivers and Jackpine Creek, as presented in Section 3.2.4.

The maximum mean daily discharge RAMP Station S4 is not available for 1999 to 2001, when the station was not operated. The watershed tributary to this station is at present largely undisturbed, so the observed flood peak discharges may be taken as natural. The magnitudes of the observed flood peaks compare well to the measured flood peaks on the Muskeg and Steepbank rivers and Jackpine Creek, as presented in Section 3.2.4, and to flood peaks measured at Iyinimin Creek, which is nearby and has similar characteristics.

Table 3.20 Statistics of Flood Discharges for Short-Term RAMP Hydrologic Monitoring Stations

Statistic	Alsands Drain S1	Iyinimin Creek S3	Blackfly Creek S4	Muskeg River Aurora S5A	Mills Creek S6	Kearl Lake Outlet S9	Wapasu Creek S10	Poplar Creek S11	McClelland Lake Outlet L1
watershed area (km^2)	15.6	32.3	31.1	552	23.8	91.3	87.6	422	204
natural mean annual discharge[(a)] (m^3/s)	0.025	0.125	0.120	1.75	0.038	0.261	0.286	n/a	0.310
period of record	1996, 1998-2001	1995-1999, 2001	1995-1998	1996-2001	1997-2001	1998-1999, 2001	1999, 2001	1995-2001	1998-2001
measured 1995 (m^3/s)	n/a	0.329	0.931	n/a	n/a	n/a	n/a	7.50	n/a
measured 1996 (m^3/s)	0.157	2.407	1.750	8.80	n/a	n/a	n/a	22.1	n/a
measured 1997 (m^3/s)	n/a	2.301	1.087	7.19	0.21	n/a	n/a	6.38	n/a
measured 1998 (m^3/s)	0.721	0.774	0.630	2.30	0.28	0.007	n/a	2.18	0.093
measured 1999 (m^3/s)	0.479	0.187	n/a	1.33	0.07	0.003	0.464	1.13	0.003
measured 2000 (m^3/s)	0.228	n/a	n/a	15.0	0.06	n/a	n/a	4.03	0.010
measured 2001 (m^3/s)	0.233	0.547	n/a	4.64	0.08	0.297	1.59	6.93	0.095
highest observed (m^3/s)	0.721 (1998)	2.41 (1996)	1.75 (1996)	15.0 (2000)	0.028 (1998)	0.297 (2001)	1.59 (2001)	22.1 (1996)	0.095 (2001)
100-year return period (m^3/s)	1.70[(b)]	11.3[(b)]	11.0[(b)]	49.6[(b)]	2.50[(a)]	5.10[(b)]	19.6[(b)]	n/a	4.11[(c)]
10-year return period (m^3/s)	0.72[(b)]	4.34[(b)]	4.20[(b)]	24.0[(b)]	1.20[(a)]	2.45[(b)]	8.86[(b)]	n/a	2.80[(c)]
2-year return period (m^3/s)	0.26[(b)]	1.40[(b)]	1.38[(b)]	10.4[(b)]	0.50[(a)]	1.07[(b)]	3.36[(b)]	n/a	0.94[(c)]
lowest observed (m^3/s)	0.157 (1996)	0.187 (1999)	0.63 (1998)	1.33 (1999)	0.06 (2000)	0.003 (1999)	0.464 (1999)	1.13 (1999)	0.003 (1999)

(a) Model results from the Shell Jackpine EIA (Shell 2002).

(b) Model results from the Shell Muskeg River Mine EIA (Shell 1997).

(c) Model results from the TrueNorth Fort Hills Oil Sands Project EIA (TrueNorth 2001).

n/a = Not available.

Figure 3.47 Annual Maximum Daily Mean Discharges for Alsands Drain at the Muskeg River Mine (RAMP Station S1)

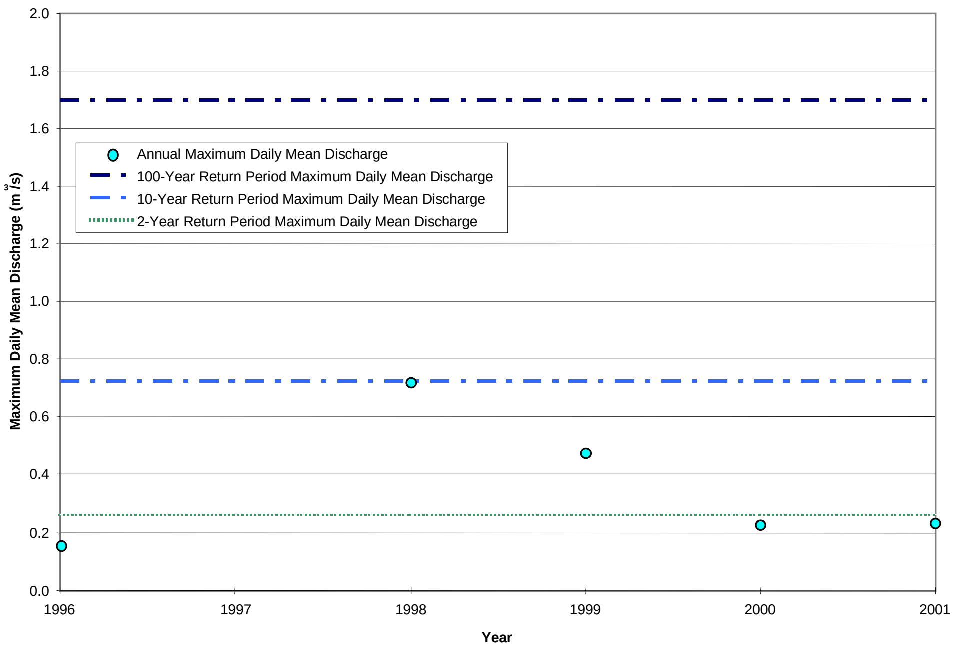


Figure 3.48 Annual Maximum Daily Mean Discharges for Iyinimin Creek above Kearl Lake (RAMP Station S3)

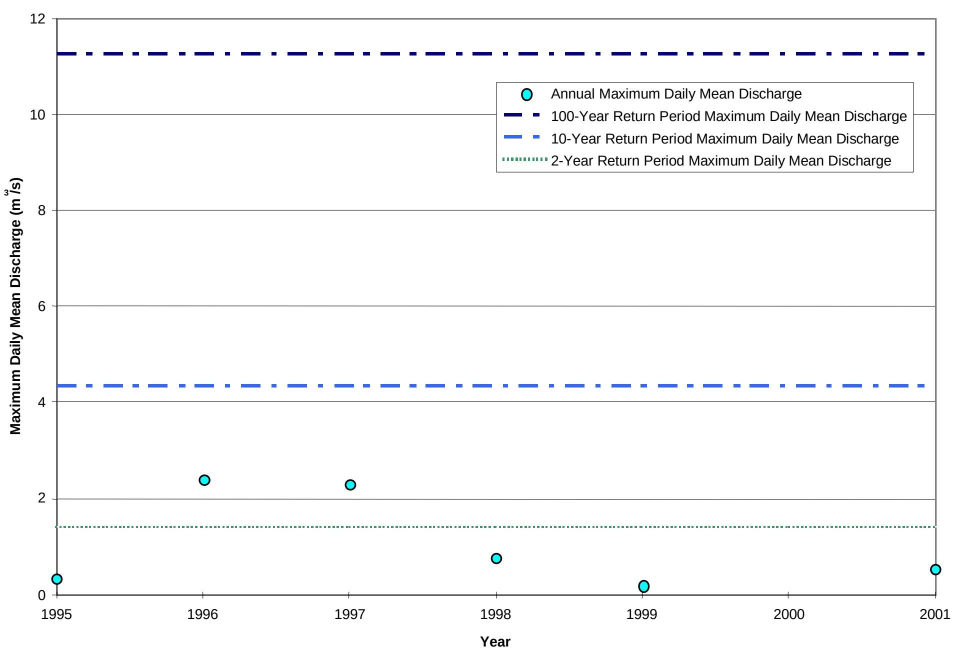


Figure 3.49 Annual Maximum Daily Mean Discharges for Blackfly Creek above Khahago Creek (RAMP Station S4)

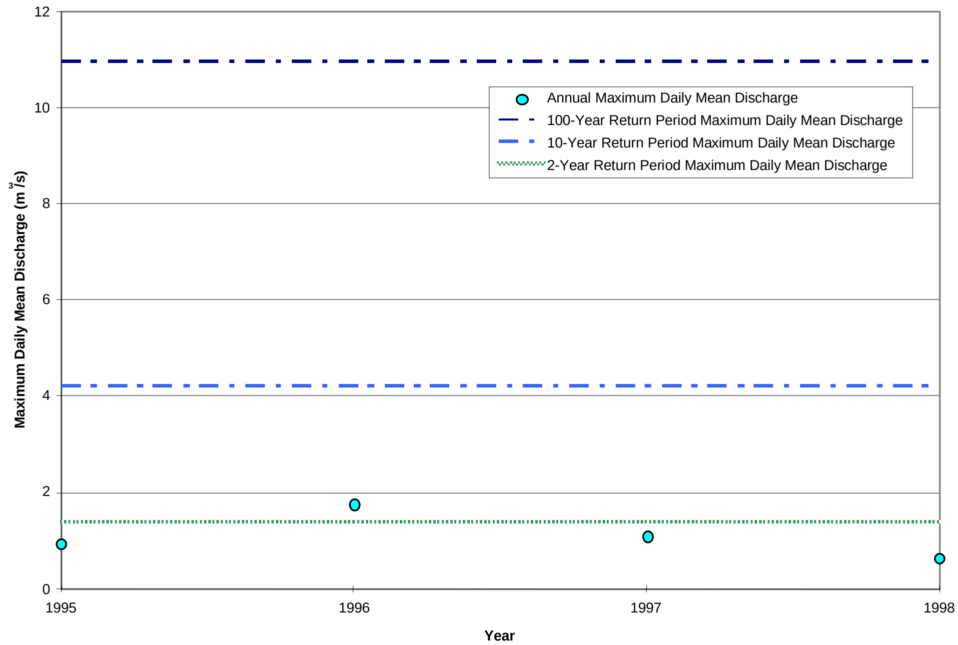


Figure 3.50 Annual Maximum Daily Mean Discharges for Muskeg River below Stanley Creek (RAMP Station S5A)

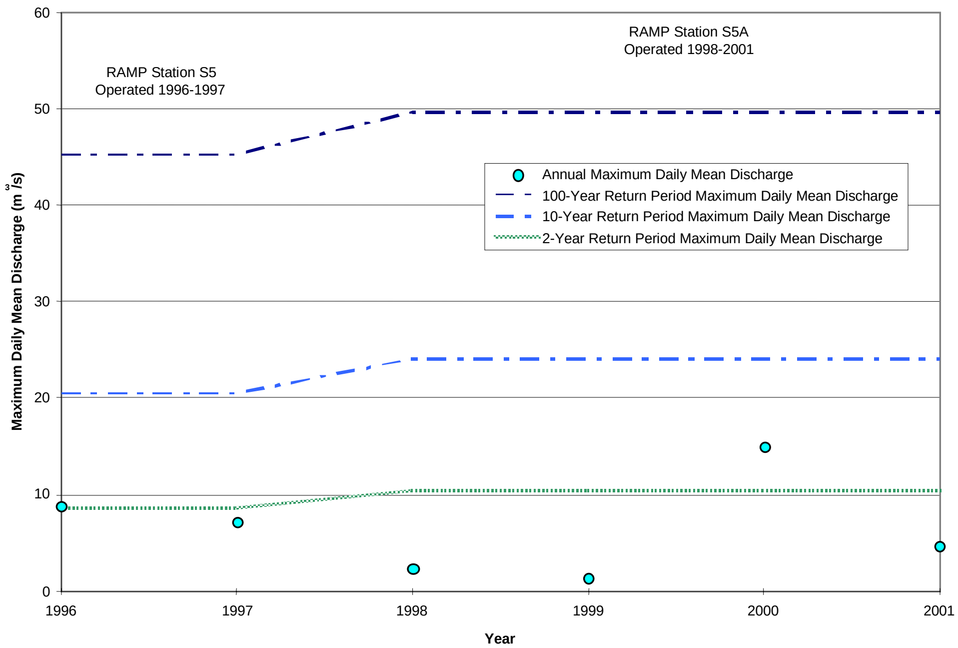


Figure 3.51 Annual Maximum Daily Mean Discharges for Mills Creek above Isadore's Lake (RAMP Station S6)

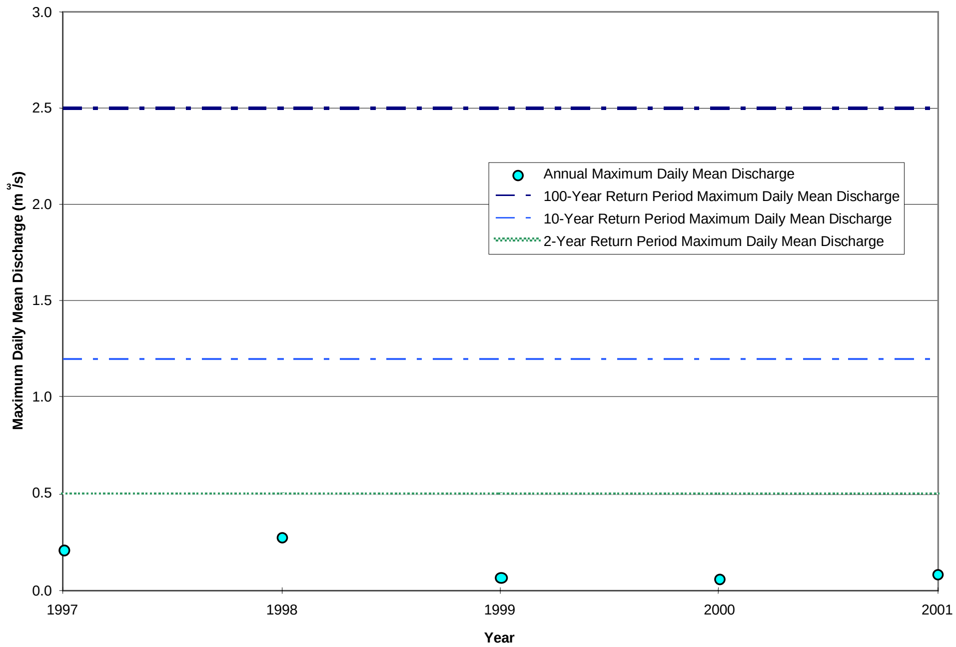


Figure 3.52 Annual Maximum Daily Mean Discharges for Kearl Lake Outlet (RAMP Station S9)

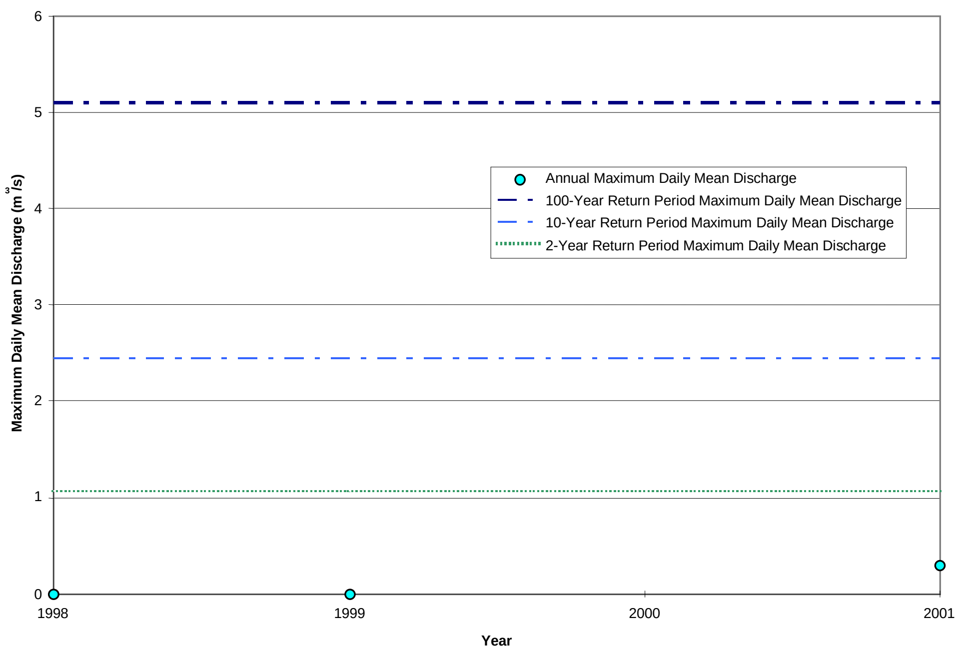


Figure 3.53 Annual Maximum Daily Mean Discharges for Wapasu Creek above Muskeg River (RAMP Station S10)

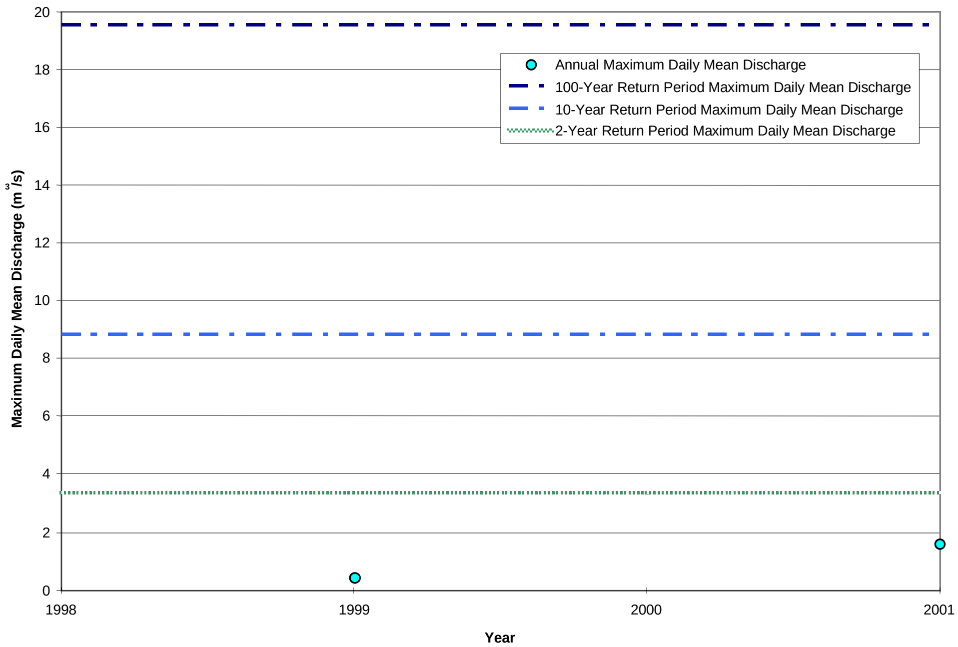


Figure 3.54 Annual Maximum Daily Mean Discharges for Poplar Creek near the Mouth (RAMP Station S11)

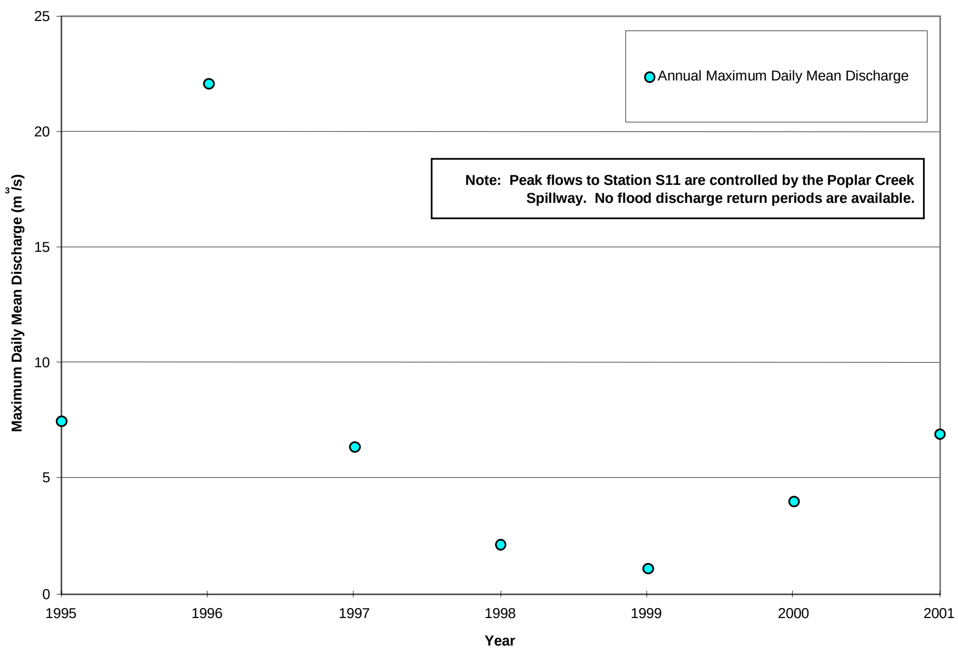
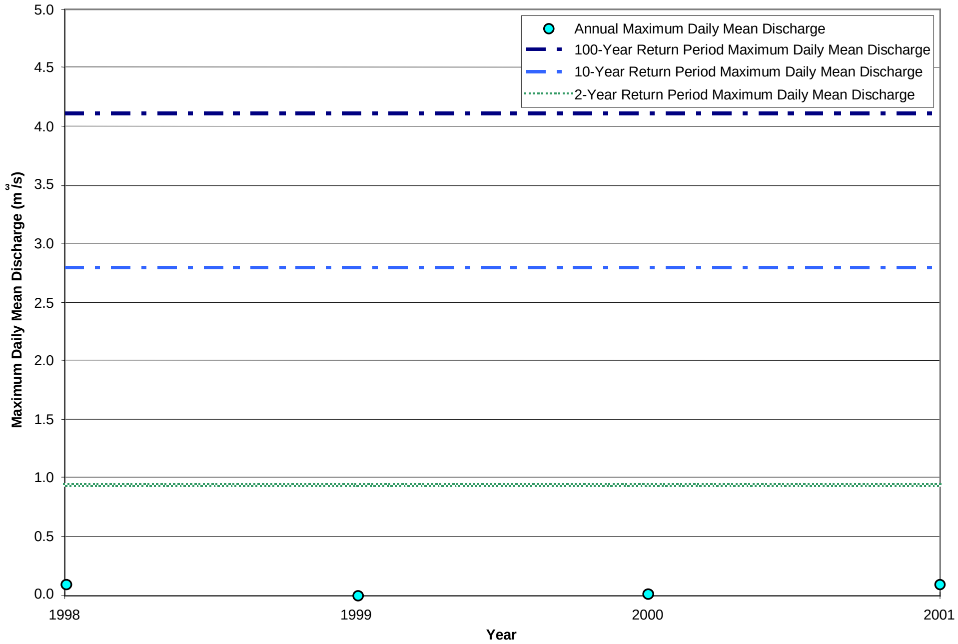


Figure 3.55 Annual Maximum Daily Mean Discharges for McClelland Lake Outlet (RAMP Station L1)



The maximum mean daily discharge for RAMP Station S5A is not available for 1995, since the station was not installed until late summer. Measurements from 1995 and 1996 were obtained at RAMP Station S5, above Stanley Creek. The watershed tributary to this station is at present largely undisturbed, so the observed flood peak discharges may be taken as natural. The magnitudes of the observed flood peaks compare well to the measured flood peaks on the Steepbank River and Jackpine Creek, as presented in Section 3.2.4, and to flood peaks measured on Iyinimin and Blackfly creeks, which are nearby. The larger watershed area of the Muskeg River accounts for the larger flood peak discharges. Starting in 2003, the Syncrude Aurora North Mine will discharge water from muskeg drainage and overburden dewatering to Stanley Creek, raising discharges in the Muskeg River below Stanley Creek. However, this activity is unlikely to significantly affect flood peak discharges on the Muskeg River.

The watershed tributary to RAMP Station S6 is at present affected only by access roads to the Syncrude Aurora North Mine and the Albian Sands Muskeg River Mine, as well as by the Susan Lake Gravel Pit, so the observed flood peak discharges may be taken as close to natural. There is no defined channel on Mills Creek until a point several hundred metres upstream of Station S6, where water is released from the fen. The observed flood discharges do not correlate well to the measured precipitation, discussed in Section 3.2.1. This may be due to the low ground slopes in the watershed and the high degree of storage available in the muskeg and sand surficial aquifer of the Mills Creek fen. Future mining activity at the Aurora North and Muskeg River Mines will close-circuit areas of the Mills Creek watershed and it is expected that flood discharges will be greatly reduced from natural rates.

The maximum daily mean discharge for RAMP Station S9 is not available for 2000, when the station was not operated. The watershed tributary to this station is at present largely undisturbed, so the observed flood peak discharges may be taken as natural. The magnitudes of the observed flood peaks compare well to the measured flood peaks on other local streams and to the measured precipitation, discussed in Section 3.2.1. All three years of monitoring at the Kearl Lake Outlet coincided with years of very low precipitation. The Kearl Lake watershed contains a relatively large proportion of upland terrain, but the lake surface allows direct evaporation of substantial quantities of water in the summer months.

The maximum daily mean discharge for RAMP Station S10 is not available for 1998, when only periodic manual measurements are available, and 2000, when the station was not operated. The watershed tributary to this station is at present largely undisturbed, so the observed flood peak discharges may be taken as natural. The magnitudes of the observed flood peaks compare well to the measured flood peaks on the Muskeg and Steepbank rivers and Jackpine Creek, as presented in Section 3.2.4, and to flood peaks measured at Iyinimin Creek, which is nearby and has similar characteristics.

The watershed tributary to RAMP Station S11 is substantially affected (i.e., the majority of the watershed tributary is affected) and has been for the duration of RAMP monitoring. No hydrologic modelling results are available for this station. The peak flood on Poplar Creek frequently occurs during the annual release of water from Ruth Lake via the Poplar Creek spillway. The magnitudes of the measured flood peaks compare well to the measured precipitation, discussed in Section 3.2.1.

The maximum mean daily discharge for RAMP Station L1 is not available for 1997, since the station was not installed until late June. The watershed tributary to this station is at present largely unaffected by industry, so the observed flood peak discharges may be taken as natural. The four complete years of monitoring at the McClelland Lake Outlet coincided with years of below average precipitation. The McClelland Lake watershed contains a very large proportion of lake surface area, which allows direct evaporation of substantial quantities of water in the summer months. The magnitudes of the observed flood peaks compare well to the measured flood peaks on the Muskeg and Steepbank rivers and Jackpine Creek, as presented in Section 3.2.4, though the flood peak in 2000 is lower than might be predicted by regional stream discharges. This may be due to the two antecedent dry years reducing lake levels to below the lake spill level, meaning that the initial 2000 runoff needed to fill lake dead storage before discharging through the outlet channel.

3.4.6 Low Flow Discharge

3.4.6.1 Methods

Annual low flows may be characterized by the minimum mean daily discharge or by the minimum instantaneous discharge measured at a point. More so than for maximum flows, there is generally little difference between the two, because of the steady nature of low flows. The annual minimum mean daily discharge is defined as the lowest mean daily discharge measured at a hydrologic monitoring station over the course of a calendar year. It is calculated by averaging readings taken at a constant interval over a calendar day. Low flow discharges are a function of climatic conditions and watershed characteristics as discussed in Section 3.2.5.1.

Annual low flow discharges were analyzed by examining annual stream discharge data from the nine short-term RAMP hydrologic monitoring stations shown in Figure 3.4 and noted in Table 3.5:

- Station S1 – Alsands Drain;
- Station S3 – Iyinimin Creek;
- Station S4 – Blackfly Creek;
- Station S5A – Muskeg River Aurora;
- Station S6 – Mills Creek;
- Station S9 – Kearl Lake Outlet;
- Station S10 – Wapasu Creek;
- Station S11 – Poplar Creek; and
- Station L1 – McClelland Lake Outlet.

Of the noted stations, only Mills Creek and Muskeg River Aurora have been observed to regularly sustain flows over the winter months during the period over which they have been monitored by RAMP.

Reported minimum mean daily discharges were compiled for each station's period of record. However, since no long-term data were available for any of these stations, it was not possible to undertake frequency analyses of minimum events. Where hydrologic modelling results were available, modelled annual minimum mean daily discharges were used to undertake a frequency analysis of minimum events to determine the minimum mean daily discharges 2-year, 10-year and 100-year return periods.

3.4.6.2 Results and Discussion

Winter flows for all streams in the Oil Sands Region consist primarily of groundwater-fed baseflow. Local streams with relatively small watershed areas and low storage capacities have much smaller winter baseflows. This is true even when compared on a unit area basis, since upper tributaries and in many cases, the mainstem of the stream, may freeze to the stream bottom during the winter months. This behaviour applies to water yields from natural watersheds. For monitoring stations that are intended to measure impacts of human activity in the Oil Sands Region, other factors may affect low flows. Closed-circuiting of mine, plant and tailings areas may render some portion of the watershed area non-contributing, thus reducing the magnitude of low flows and increasing their duration. Diversions into and out of the watershed may similarly increase or decrease low flows. Discharges from muskeg drainage and overburden dewatering can increase low flows and even sustain them over the winter months, as water is released from storage in the surficial aquifer. Changes to terrain types, such as the establishment of an overburden stockpile in a lowland area or reclamation of a dam embankment, can produce changes in low flow characteristics due to differences in slope, drainage density, surficial geology or storage from the natural terrain.

A summary of the low flow analysis for the Oil Sands Region long-term hydrologic monitoring stations is provided in Table 3.21. No figures of annual low flow discharges are provided, since most modelled discharges are zero and many measured low flows do not consider the late winter period, in which flow may have ceased.

At RAMP Station S1 (locations of stations are shown in Figure 3.4), no flows were measured in late winter of 1995 to 1999, when sustained frozen conditions would have been most likely to cause flows to fall to zero. Zero flow conditions were observed in the summer of 1997. The Alsands Drain has a very small (15.6 km^2) watershed area and frozen conditions in the winter result in a no-flow condition. Since 1999, flow to the outlet has been controlled by pumped discharges from Pond #2 at the Albian Sands Muskeg River Mine, so it would be possible for the drain to flow at any time of the year if there was free water available in Pond #2.

Table 3.21 Statistics of Low Flows for Short-Term RAMP Hydrologic Monitoring Stations

Statistic	Alsands Drain S1	Iyinimin Creek S3	Blackfly Creek S4	Muskeg River Aurora S5A	Mills Creek S6	Kearl Lake Outlet S9	Wapasu Creek S10	Poplar Creek S11	McClelland Lake Outlet L1
drainage area (km^2)	15.6	32.3	31.1	552	23.8	91.3	87.6	422	204
natural mean annual discharge(c) (m^3/s)	0.025	0.125	0.120	1.75	0.038	0.261	0.286	n/a	0.310
period of record	1995-2001	1995-1999, 2001	1995-1998	1995-2001	1997-2001	1998-1999, 2001	1998-1999, 2001	1995-2001	1997-2001
measured 1995 (m^3/s)	0.020(b)	0.071(b)	0.007(b)	0.105(a) (b)	n/a	n/a	n/a	0.423(b)	n/a
measured 1996 (m^3/s)	0.015(b)	0.145(b)	0.102(b)	1.747(a) (b)	n/a	n/a	n/a	1.709(b)	n/a
measured 1997 (m^3/s)	0.000(b)	0.002(b)	0.000(b)	0.560(a) (b)	0.034(b)	n/a	n/a	0.074(b)	0.166(b)
measured 1998 (m^3/s)	0.276(b)	0.001(b)	0.000(b)	0.095(a) (b)	0.053(b)	0.000(b)	0.000(b)	0.009(b)	0.000(b)
measured 1999 (m^3/s)	0.007(b)	0.007(b)	station inactive	0.009	0.011(b)	0.000(b)	0.000(b)	0.001(b)	0.000(b)
measured 2000 (m^3/s)	0.000	station inactive	station inactive	0.019	0.008(b)	station inactive	station inactive	0.037(b)	0.000(b)
measured 2001 (m^3/s)	0.000	0.072(b)	station inactive	0.084	0.015(b)	0.000(b)	0.047(b)	0.004(b)	0.009(b)
2-year return period(c) (m^3/s)	0.000	0.000	0.000	0.012	n/a	0.000	0.000	n/a	n/a
10-year return period(c) (m^3/s)	0.000	0.000	0.000	0.003	n/a	0.000	0.000	n/a	n/a
100-year return period(c) (m^3/s)	0.000	0.000	0.000	0.001	n/a	0.000	0.000	n/a	n/a

(a) Station located at S5, upstream of Stanley Creek (drainage area 390 km^2).

(b) Late winter flows are not recorded and may have been zero.

(c) Based on a frequency analysis of hydrologic model results.

n/a = not available.

At RAMP Station S3, flows are not monitored in late winter, when sustained frozen conditions would be most likely to cause flows to fall to zero. Very low flows were observed in 1997, 1998 and 1999. Iyinimin Creek above Kearl Lake has a very small (32.3 km^2) watershed area and frozen conditions in the winter generally result in a no-flow condition.

At RAMP Station S4, flows are not monitored in late winter, when sustained frozen conditions would be most likely to cause flows to fall to zero. Very low flows were observed in 1997 and zero flows were observed in the summers of 1998 and 1999. Blackfly Creek above Khahago Creek has a very small (31.1 km^2) watershed area and frozen conditions in the winter generally result in a no-flow condition.

At RAMP Station S5A, flows were not monitored in late winter until early 2000. The Muskeg River below Stanley Creek has a watershed area of 552 km^2 and is able to sustain flows through frozen conditions in the winter due to the release of water from storage in the lowland muskeg and sandy surficial aquifer.

At RAMP Station S6, flows are not monitored in late winter, when sustained frozen conditions would be most likely to cause flows to fall to zero. Mills Creek above Isadore's Lake has a watershed area of only 23.8 km^2, but appears to be able to sustain flows through frozen conditions in the winter due to the release of water from storage in the muskeg and sandy surficial aquifer of the Mills Creek fen.

At RAMP Station S9, flows are not monitored in late winter, when sustained frozen conditions would be most likely to cause flows to fall to zero. Zero flows were observed in the summers of 1998, 1999 and 2001, which were all low-precipitation years. Kearl Lake Outlet has a watershed area of 91 km^2, including 5.6 km^2 of lake area, but tributaries to the lake are small enough to freeze up during winter conditions and lake storage does not appear to sustain outflows during most years.

At RAMP Station S10, flows are not monitored in late winter, when sustained frozen conditions would be most likely to cause flows to fall to zero. Zero flows were observed in the summer of 1998 and spring of 1999. Wapasu Creek above Muskeg River has a small (87.6 km^2) watershed area and frozen conditions in the winter generally result in a no-flow condition.

The watershed tributary to RAMP Station S11 is substantially disturbed by the existing Syncrude base mine. This development includes a large spillway that discharges water from Ruth Lake, generally during late summer or fall. Water from the Beaver River, upstream of the mine, is currently diverted into Ruth Lake. Flows are not monitored in late winter at this station, when sustained frozen conditions would be most likely to cause flows to fall to zero. Poplar Creek near the mouth has a small (151 km^2) natural watershed area, into which controlled flows are diverted, and frozen conditions in the winter generally result in a no-flow condition.

At RAMP Station L1, flows are not monitored in late winter, when sustained frozen conditions would be most likely to cause flows to fall to zero. Zero flows were observed in the summers of 1998, 1999 and 2000, which were all low-precipitation years. McClelland Lake Outlet has a watershed area of 203 km^2, including 30 km^2 of lake area and 27 km^2 of fen area. Its relatively high ratio of lake and fen area to total watershed area means that evaporative losses from the watershed are high. The lake has no significant tributaries and there is no well-defined channel at the lake outlet. Rather, the lake discharges through a shallow, slow-flowing wetlands area that is prone to freezing during the winter months. Lake storage does not appear to sustain outflows during most years.

3.4.7 Conclusions and Recommendations

3.4.7.1 Monitoring to Verify EIA Predictions

As discussed in Section 3.4.1, all of the RAMP Climatic and Hydrologic Monitoring Stations examined in this report are located in appropriate locations. Many stations are operated year-round, and thus there is no question that their monitoring period is adequate to construct an annual water balance and describe annual precipitation or runoff hydrographs. However, it is recommended that for stations that sustain flows during ice-covered conditions, additional monitoring be implemented to adequately quantify these flows. This includes continuous monitoring at RAMP Hydrologic Monitoring Stations S1 and S6, and the periodic manual discharge measurements at RAMP Hydrologic Monitoring Stations S2, S9, S10 and S11.

Long-term regional climatic and hydrologic data from Environment Canada stations, as discussed in Sections 3.2 and 3.3, should continue to be purchased by RAMP on an annual basis and compiled in the RAMP climate and hydrology database. These data will be required in any analysis that attempts to differentiate natural variability from changes due to human activities.

3.4.7.2 Short-Term Climatic Data

The available short-term climatic data for the Oil Sands Region north of Fort McMurray consists of climatic data from the Aurora Climate Station, located on

Oil Sands Lease 13 near the intersection of Canterra Road and Jackpine Creek. This station was established in May 1995 and provides a period of record extending to the end of 2001. The precipitation and temperature records for this station are of particular interest in examining local aquatic conditions.

The analysis of precipitation data, presented in Section 3.4.1, shows that measured annual precipitation, including rainfall and snowfall components, compares well to that measured at Fort McMurray Airport (Environment Canada Climate Station 3062693). The data from the Aurora Climate Station confirm that 1998, 1999 and 2001 were all significantly drier than the regional (Fort McMurray Airport) average. Measurements of chemical and biological parameters must be considered in the context of this dry period.

The analysis of temperature data, presented in Section 3.4.2, shows that annual mean, winter mean and summer mean temperatures measured at the Aurora Climate Station compare well to those recorded at Fort McMurray Airport. Comparing temperatures from the Aurora Climate Station to long-term statistics from Fort McMurray Airport shows that 1996 was approximately a 10-year cold year, while 1998, 1999 and 2001 were approximately 10-year warm years and 1997 and 2000 were also warmer than average. Measurements from the Aurora Climate Station also confirm that winter temperatures are more variable than summer ones, as is the case for Fort McMurray Airport. Differences between mean winter temperatures measured at the Aurora Climate Station and Fort McMurray Airport are larger than those for mean summer or mean annual temperatures.

The Aurora Climate Station is the best station available for measuring local temperature and precipitation in the Muskeg River basin, based on proximity and length of record. It is recommended that this station continue to be operated by RAMP as long as mining and reclamation activities occur in the region. The station currently has seven years of record and continued operation will allow future analysis of long-term data to quantify subtle differences in climate from Fort McMurray, including effects of local elevation and topography.

Tipping bucket rainfall gauges are currently installed at hydrologic monitoring stations at Iyinimin Creek (RAMP Station S3), Calumet River (RAMP Station S16), Tar River Lowland (RAMP Station S19) and McClelland Lake (RAMP Station S1), and a tipping bucket snowfall gauge is currently installed at the hydrologic monitoring station at the Calumet River (RAMP Station S16). It is recommended that operation of these gauges continue, to supplement data from the Aurora Climate Station and provide more information on the areal extent and variation of precipitation events.

The current monitoring is adequate to characterize climatic conditions in the Oil Sands Region. However, in addition to the current monitoring, it is recommended that consideration be given to installing tipping bucket rain gauges at other hydrologic stations where measurements would not be affected by the tree canopy. These installations would be able to make use of the existing data logger at the station. The low capital cost, and negligible operation and maintenance costs, for these gauges means that valuable data could be gathered at minimal cost.

Furthermore, it is recommended that two small watersheds be fitted with a dense network of rainfall and snowfall gauges. One natural watershed and one reclaimed watershed should be examined to measure the temporal and areal variation of precipitation inputs. The density of gauges would depend on the size, shape and topography of the selected watersheds. In conjunction with the operation of rain and snow gauges, regular snowcourse surveys should be undertaken along a defined traverse within each watershed, to allow calibration of undercatch factors for the snowfall gauges and more accurate measurement of the snowpack contributing to spring runoff. These precipitation measurements would be more detailed than any previously undertaken within RAMP, and would be used in conjunction with stream gauging data to allow more detailed analysis of watershed response to rainfall and snowfall. The results of the analysis would be used to develop future reclamation drainage designs. Monitoring to support an updated hydrologic analysis of reclaimed areas was recommended in Section 5.3.1.1.6 of the Aurora Mine EIA (BOVAR 1996).

3.4.7.3 Short-Term Hydrologic Data

The available short-term hydrologic data for the Oil Sands Region north of Fort McMurray consists of data from nine RAMP Hydrologic Stations, including those on the Alsands Drain, Iyinimin Creek, Blackfly Creek, Muskeg River Aurora, Mills Creek, Kearl Lake Outlet, Wapasu Creek, Poplar Creek and McClelland Lake Outlet. A summary of statistics for water yields, flood discharges and low flow discharges for these stations is provided in Table 3.22.

Table 3.22 Statistics of Discharges for Short-Term RAMP Hydrologic Monitoring Stations

Parameter	Statistic	Alsands Drain S1	Iyinimin Creek S3	Blackfly Creek S4	Muskeg River Aurora S5A	Mills Creek S6	Kearl Lake Outlet S9	Wapasu Creek S10	Poplar Creek S11	McClelland Lake Outlet L1
drainage area		15.6 km^2	32.3 km^2	31.1 km^2	552 km^2	23.8 km^2	91.3 km^2	87.6 km^2	422 km^2	204 km^2
natural mean annual discharge[(a)]		0.025 m^3/s	0.125 m^3/s	0.120 m^3/s	1.75 m^3/s	0.038 m^3/s	0.261 m^3/s	0.286 m^3/s	n/a	0.310 m^3/s
maximum mean daily discharge	period of record	1996, 1998-2001	1995-1999, 2001	1995-1998	1996-2001	1997-2001	1998-1999, 2001	1999, 2001	1995-2001	1998-2001
	highest observed	0.721 m^3/s (1998)	2.41 m^3/s (1996)	1.75 m^3/s (1996)	15.0 m^3/s (2000)	0.028 m^3/s (1998)	0.297 m^3/s (2001)	1.59 m^3/s (2001)	22.1 m^3/s (1996)	0.095 m^3/s (2001)
	100-year return period[(a)]	1.70 m^3/s	11.3 m^3/s	11.0 m^3/s	49.6 m^3/s	2.50 m^3/s	5.10 m^3/s	19.6 m^3/s	n/a	4.11 m^3/s
	10-year return period[(a)]	0.72 m^3/s	4.34 m^3/s	4.20 m^3/s	24.0 m^3/s	1.20 m^3/s	2.45 m^3/s	8.86 m^3/s	n/a	2.80 m^3/s
	2-year return period[(a)]	0.26 m^3/s	1.40 m^3/s	1.38 m^3/s	10.4 m^3/s	0.50 m^3/s	1.07 m^3/s	3.36 m^3/s	n/a	0.94 m^3/s
	lowest observed	0.157 m^3/s (1996)	0.187 m^3/s (1999)	0.63 m^3/s (1998)	1.33 m^3/s (1999)	0.06 m^3/s (2000)	0.003 m^3/s (1999)	0.464 m^3/s (1999)	1.13 m^3/s (1999)	0.003 m^3/s (1999)
annual water yield	period of record	1996, 1998-2001	1995-1999, 2001	1995-1998	1996-2001	1997-2001	1998-1999, 2001	1999, 2001	1995-1996, 1998-2001	1998-2001
	highest observed	522 mm (1998)	266 mm (1997)	279 mm (1997)	164 mm (1996)	111 mm (1998)	8 mm (2001)	73 mm (2001)	229 mm (1996)	1.8 mm (1998)
	100-year wet return period[(a)]	148 mm	283 mm	283 mm	244 mm	148 mm	240 mm	249 mm	n/a	n/a
	10-year wet return period[(a)]	102 mm	209 mm	209 mm	174 mm	102 mm	164 mm	180 mm	n/a	n/a
	long term average[(a)]	51 mm	122 mm	122mm	100 mm	51 mm	90 mm	103 mm	n/a	48 mm
	10-year dry return period[(a)]	11 mm	47 mm	47 mm	40 mm	11 mm	16 mm	37 mm	n/a	n/a
	100-year dry return period[(a)]	3 mm	22 mm	22 mm	20 mm	3 mm	0.4 mm	17 mm	n/a	n/a
	lowest observed	44 mm (1996)	20 mm (1999)	98 mm (1998)	17 mm (1999)	25 mm (2000)	0.1 mm (1999)	18 mm (1999)	9 mm (1999)	0.1 mm (1999)
minimum mean daily discharge	period of record	1995-2001	1995-1999, 2001	1995-1998	1995-2001	1997-2001	1998-1999, 2001	1998-1999, 2001	1995-2001	1997-2001
	2-year return period[(a)]	0.000 m^3/s	0.000 m^3/s	0.000 m^3/s	0.012 m^3/s	n/a	0.000 m^3/s	0.000 m^3/s	n/a	n/a
	10-year return period[(a)]	0.000 m^3/s	0.000 m^3/s	0.000 m^3/s	0.003 m^3/s	n/a	0.000 m^3/s	0.000 m^3/s	n/a	n/a
	100-year return period[(a)]	0.000 m^3/s	0.000 m^3/s	0.000 m^3/s	0.001 m^3/s	n/a	0.000 m^3/s	0.000 m^3/s	n/a	n/a
	lowest observed	0.000 m^3/s (frequent)	0.001 m^3/s (1998)	0.000 m^3/s (frequent)	0.009 m^3/s (1999)	0.008 m^3/s (2000)	0.000 m^3/s (frequent)	0.000 m^3/s (frequent)	0.001 m^3/s (1999)	0.000 m^3/s (frequent)

(a) For stations marked n/a, late winter flows are not recorded and may have been zero.

(b) Based on a frequency analysis of hydrologic model results.

n/a = Not available.

The Alsands Drain (RAMP Station S1) has been monitored since 1995, but water yield and flood discharge data are unavailable for 1995 and 1997. This station currently drains a very small (15.6 km^2) watershed area that is substantially affected by development and receives surface runoff, muskeg drainage and overburden dewatering discharges from the Syncrude Aurora North Mine and from the Albian Sands Muskeg River Mine. Mine drainage and dewatering flows are often pumped and tend to be relatively steady, with drainage from precipitation events attenuated by storage in ditches, sumps and ponds. This means that, though annual water yields at this station were observed to be very high (up to 10 times the predicted mean annual value), annual flood discharges were not as extreme, compared to the values for the natural watershed. The small watershed area and frozen conditions generally result in a zero flow condition by late winter. Since 1999, flow to the outlet has been controlled by pumped discharges from Pond #2 at the Albian Sands Muskeg River Mine. Data are unavailable for 1997 because a flood washed out the station when a beaver dam upstream was breached and initiated a sequential failure of other dams downstream, releasing a substantial quantity of water from storage.

Iyinimin Creek (RAMP Station S3) was monitored for the period 1995 to 1999 and 2001, and Blackfly Creek was monitored for the period 1995 to 1998. These stations are similar in size and topography, are located close to each other, and their watersheds are currently largely unaffected by industry. Both watersheds are exclusively upland terrain. Iyinimin Creek has a watershed area of 32.3 km^2 and Blackfly Creek has a watershed area of 31.1 km^2. Measured water yields, flood discharges and low flows compare well between the two watersheds, indicating that 1996 and 1997 were wetter than average years and 1995, 1998, 1999 and 2001 were drier than average. The wettest year on record was 1997, when the water yield approached the 100-year wet value for both stations, and the flood of record for both stations was recorded in 1996. The driest year on record was 1999, when the water yield fell below the 100-year dry value for Iyinimin Creek. Blackfly Creek was not monitored in 1999. The small watershed area, upland terrain and frozen conditions generally result in a zero flow condition at these stations by late winter.

The Muskeg River below Stanley Creek (RAMP Station S5A) was monitored for the period 1995 to 1997 (above Stanley Creek at Station S5) and from 1998 to 2001. The watershed contributing to this station is roughly half upland and half lowland terrain and is currently largely unaffected by industry. The Muskeg River below Stanley Creek has a watershed area of 552 km^2. The watershed area of Station S5, located above Stanley Creek, was 390 km^2. Measured water yields, flood discharges and low flows correlate well to precipitation measured at Fort McMurray Airport. Wetter than average years occurred in 1996 and 1997, and 1998 to 2001 were drier than average. The wettest year on record was 1996, when the water yield approached the 10-year wet value. The flood of record occurred in 2000. The driest year on record was 1999, when the water yield fell below the 100-year dry value. The larger watershed area and lowland terrain with wetlands storage means that the Muskeg River at this station generally sustains flows through the winter.

Mills Creek above Isadore's Lake (RAMP Station S6) was monitored for the period 1997 to 2001. The watershed contributing to this station is exclusively upland terrain and is currently affected only by access roads to the Aurora North Mine and the Muskeg River Mine, as well as by the Susan Lake Gravel Pit. Mills Creek above Isadore's Lake has a watershed area of 23.8 km^2. Measured water yields, flood discharges and low flows do not correlate well to precipitation measured at Fort McMurray Airport or values measured on other local streams. However, this may be due to the temporary discharge of water from muskeg drainage and overburden dewatering into drainage ditches in the Mills Creek fen watershed during the initial development of the Aurora North Mine, as acknowledged in EPEA Approval 18942-00-00. Wetter than average years occurred in 1997 and 1998, and 1999 to 2001 were drier than average. The wettest year on record was 1998, when the water yield exceeded the 10-year wet value, despite the fact that 1998 was a dry year in the region. The flood of record occurred in 1998. The driest year on record was 2000, but the water yield that year was higher than the 10-year dry value. The Mills Creek fen upstream of this station likely attenuates runoff; the fen stores precipitation and gradually releases it. Though no discharge measurements are undertaken at this station over the winter months, Mills Creek has been observed to sustain flows through the winter.

The Kearl Lake Outlet (RAMP Station S9) was monitored for the period 1998 to 1999 and 2001. The watershed area contributing to this station is 91.3 km^2 and comprises 71% upland and 23% lowland terrain, with 6% lake area. The watershed area is currently largely unaffected by industry. All three years of monitoring at the Kearl Lake Outlet coincided with years of very low precipitation, and despite the predominantly upland nature of the watershed, the lake at its the downstream end is subject to large evaporative losses in the summer and also attenuates flood discharges. Measured water yields, flood discharges and low flows correlate well to precipitation measured at Fort McMurray Airport. The wettest year on record was 2001, when the water yield was still less than the 10-year dry value. The flood of record also occurred in 2001, when it was only 30% of the two-year flood. The driest year on record was 1999, when the water yield fell below the 100-year dry value. Lake storage does not generally appear to sustain outlet flows through the winter.

Wapasu Creek above Muskeg River (RAMP Station S10) was monitored for the period 1998 to 1999 and 2001, though only periodic manual discharge measurements are available for 1998. The watershed contributing to this station is roughly three-quarters upland and one-quarter lowland terrain and is currently largely unaffected by industry. Wapasu Creek above the Muskeg River has a watershed area of 87.6 km^2. Measured water yields and flood discharges correlate well to precipitation measured at Fort McMurray Airport. The wettest year of the two measured was 2001, when the water yield was still below the mean annual value and the maximum mean daily discharge was smaller than the two-year flood. The driest year of the two was 1999, when the water yield was approximately equal to the 100-year dry value. The relatively small watershed area and proportion of upland terrain means that Wapasu Creek at this station generally freezes to the bottom and does not sustain flows through the winter.

Poplar Creek near the Mouth (RAMP Station S11) was monitored for the period 1995 to 2001, though no measurements were undertaken during the first half of 1997. The natural Poplar Creek watershed, monitored by Environment Canada at this site, had a watershed area of 151 km^2, but the current watershed is substantially affected by the Syncrude Base Mine development, and has a tributary area of 422 km^2. Discharges to Poplar Creek from Ruth Lake, which receives water diverted from the Beaver River watershed, are controlled at the Syncrude Poplar Creek spillway. Measured water yields and flood discharges correlate well to precipitation measured at Fort McMurray Airport. The wettest year on record was 1996, when the flood of record was also recorded. The driest year on record was 1999. Flows on Poplar Creek do not generally appear to be sustained over the winter.

The McClelland Lake Outlet (RAMP Station L1) was monitored for the period 1997 to 2001. Since the station was not established until June 1997, no measurements of water yield or flood discharge are available for that year. The watershed contributing to this station is 204 km^2 and comprises 35% upland and 37% lowland terrain, with 15% lake area and 13% fen area. The watershed area is currently largely unaffected by industry. The four complete years of monitoring at the Kearl Lake Outlet coincided with years of low precipitation. The lake and fen are subject to large evaporative losses in the summer and serve to attenuate flood discharges. The wettest year on record was 1998, when the water yield was only 1.8 mm. The flood of record occurred in 2001, when it was only 10% of the predicted two-year flood. The driest year on record was 1999, when the water yield was only 0.1 mm. Lake storage did not appear to sustain outlet flows through winter during the monitoring period.

Of particular note are the dry hydrologic conditions observed in the region during the period 1998 to 2001. Water yields, floods and low flows are dependent on precipitation. Annual precipitation measured at Fort McMurray Airport for the four years from 1998 to 2001 were all below average, with 1998 and 1999 the second- and fifth-driest years recorded since 1945. In 1999, these consecutive dry years produced the lowest-recorded water yields and flood discharges on the Steepbank, Muskeg, Beaver and MacKay rivers and Jackpine Creek. Lows of record for water yield and flood discharge were also recorded in 1999 for the local, natural watersheds of Iyinimin Creek, Muskeg River below Stanley Creek, Kearl Lake Outlet, Wapasu Creek and McClelland Lake Outlet, as well as for the disturbed watershed of Poplar Creek. However, it must be noted that precipitation records indicate that a more extreme, longer-duration dry period occurred from 1945 to 1953. Hydrologic records are not available for that period, but it is likely that water yields, floods and low flows were even lower at that time. In particular, airphoto evidence indicates that water levels at McClelland Lake fell below the spill elevation in the early 1950s.

Likewise, though 1996 and 1997 were wet years in the region, the period from 1972 to 1976 was wetter. No stream discharge data are available for the RAMP hydrologic monitoring stations for those years, which may have produced even higher values than those recorded in 1996 and 1997.

The short-term hydrologic stations operated by RAMP were generally installed to provide baseline data for EIAs and/or to meet regulatory reporting requirements during mine operations. It is recommended that stations installed to provide baseline data be operated for as long as possible to provide data for characterizing the natural behaviour of the monitored stream. When developments are initiated, the stations should be used to collect data to quantify the impact of developments on the stream. If further assessment of water quantity impacts at the station and on downstream waterbodies is required in the future, stream discharge data could be combined with precipitation data, hydrologic models and knowledge of mine layout and activities to construct a water balance. Station deactivation should only be considered if the upstream watershed is closed-circuited or diverted to the extent that discharges at the station become negligible.

Most of the RAMP stations on smaller watersheds are not operated during the winter months, since they typically freeze to the bottom and cease to flow over the winter, and do not lend themselves to continuous year-round flow monitoring. However, the most recent monitoring was undertaken during relatively dry conditions when compared with the available record of precipitation, and it is possible that wetter conditions in the future may result in higher winter flows. Consideration should be given to visiting all RAMP stations periodically over the winter months, and undertaking manual stream discharge measurements if possible.

Furthermore, it is recommended that year-round hydrologic monitoring be undertaken at the two small watersheds where intensive rainfall and snowfall monitoring was recommended in Section 3.4.6.1. One natural watershed and one reclaimed watershed should be examined to measure the temporal variation of stream discharge. These measurements would be used in conjunction with detailed precipitation data to allow more detailed analysis of watershed response to rainfall and snowfall. The results of the analysis would be used to develop future reclamation drainage designs. Monitoring to support an updated hydrologic analysis of reclaimed areas was recommended in Section 5.3.1.1.6 of the Aurora Mine EIA (BOVAR 1996).

In addition to the stream discharge and lake water level monitoring currently being performed by RAMP, it is recommended that additional data collection and analysis be undertaken to characterize the geomorphology of natural streams in the Oil Sands Region. An understanding of the physical nature of these streams is essential to developing sustainable stream diversions and reclamation drainage channels that replicate the features of natural channels with similar hydrologic characteristics. It is recommended that the hydraulics of low flow periods be investigated for sites where reliable stage-discharge rating curves are available. Channel roughnesses should be examined for multiple natural streams to help characterize low flow hydraulics and assist in natural channel replication designs.

Limited collection of geomorphologic data for streams in the Oil Sands Region has been undertaken during EIAs for recent oil sands projects (Shell 1997, 2002; CNRL 2002). However, these data have generally been limited to sites within the project Local Study Area (LSA) and the samples sizes are relatively small. It is recommended that efforts be made to collect additional geomorphology data on representative streams in the region, even if located outside of the LSA. It is recommended that all available data be compiled in a common database and that physical data should be linked to hydrologic data, whether from monitoring stations measurements or model results.

Data from long-term regional and short-term RAMP hydrologic monitoring stations were used in 2002 to recalibrate a regional hydrologic model (Golder 2002e). This was used as the basis for the hydrologic impact assessment in the CNRL Horizon and Shell Jackpine EIAs. It is recommended that as more data become available, this model be updated as required to provide a basis for future EIAs, operational water management plans and reclamation drainage designs. This recalibration would, in particular, use larger data sets from short-term RAMP stations to verify the applicability of the model to areas where currently no data or limited data sets are available. The recalibration would be particularly valuable if it is undertaken after the occurrence of wet conditions, since most RAMP hydrologic data has been collected under conditions that are drier than average and not representative of average or wet conditions.

3.5 SUMMARY

3.5.1 Characterizing Existing Variability

Data from the Environment Canada Climate Station at Fort McMurray Airport were used to examine the natural variability of precipitation and temperature in the Oil Sands Region. The precipitation data show that the annual precipitation, including rainfall and snowfall components, exhibits a degree of variability that is typical of natural hydrologic systems. The calculated coefficients of variability of 0.37, 0.27 and 0.23 for the snowfall-to-runoff, rainfall and precipitation-to-runoff data, respectively, show that snowfall is more variable than rainfall, and that total precipitation is less variable than rainfall.

The first five years during which RAMP operated included four consecutive years of below-average precipitation between 1998 and 2001, which was the longest span of below-average precipitation since a nine-year period from 1945 to 1953. These periods are in contrast to the five consecutive years of above-average precipitation that was observed from 1972 to 1976.

The temperature data sets for annual mean, winter mean and summer mean temperatures exhibited standard deviations of 1.3, 3.3 and 0.9°C, respectively. This shows that winter mean temperatures are more variable than annual mean temperatures, and that summer mean temperatures are less variable than annual mean temperatures. The observed data show that mean annual temperatures at Fort McMurray Airport are more likely to be influenced by the more variable winter temperatures than by less variable summer temperatures.

The climatic station at Fort McMurray Airport is the best station available for characterizing long-term natural variability in the Oil Sands Region, based on proximity and length of record. It is recommended that this station continue to be operated by Environment Canada and that RAMP continue to incorporate relevant climate data into its database on an annual basis. The Mildred Lake Climate Station has a period of record of 19 years and the Aurora Climate Station has a period of record of seven years. Continued operation of these stations is recommended to provide local climate information within the current oil sands developments.

Data from seven long-term Environment Canada Hydrologic Monitoring Stations were used to examine the natural variability of water yields, floods and low flows in the Oil Sands Region. The monitored streams included the Athabasca River, Steepbank River, Muskeg River, Jackpine Creek, Beaver River, MacKay River and Firebag River.

Annual water yields at the six smaller streams were highly correlated to the measured annual precipitation at Fort McMurray Airport, while those for the Athabasca River were the lowest of the monitored streams, due to its large watershed that encompasses areas with varying hydrologic conditions. The Athabasca River also has the highest mean annual water yield of any of the local long-term monitored watersheds, likely due to higher precipitation in its headwater areas. Relatively large water yields were also observed for the Firebag River, where large surficial aquifer storage attenuates precipitation inputs to the watershed and sustains unusually large baseflows over the winter months. The natural variability of water yield was generally related to watershed size and storage capacity. Water yield data from the Athabasca and Firebag rivers had similar coefficients of variation, while other local stations showed coefficients of variation two to three times as large. For these five stations, coefficients of variation were larger for stations with smaller watersheds and lower baseflows.

Flood discharges for the seven streams were examined. Flood unit discharges tend to be larger for streams with well-drained or small watersheds and those with limited storage capacity. In contrast to their high water yields, the Athabasca River (large watershed) and Firebag River (large storage capacity) had relatively low flood unit discharges, as did the Muskeg River (large storage capacity). The MacKay and Steepbank rivers and Jackpine Creek had flood unit discharges approximately twice as large, while the small, steep watershed of the Beaver River resulted in the highest flood unit discharges. The natural variability was related to the magnitude of the flood unit discharges, with lower unit discharges displaying lower variability and higher unit discharges displaying higher variability.

Low flow discharges for the seven streams were examined. Low flow unit discharges tend to be smaller for streams with well-drained or small watersheds and those with limited storage capacity. In contrast to their relatively low flood unit discharges, the Athabasca River (large watershed) and Firebag River (large storage capacity) had relatively high low flow unit discharges. The Steepbank, Muskeg and MacKay rivers had significantly smaller low flow unit discharges, while the small watersheds of the Beaver River and Jackpine Creek produced the lowest low flow unit discharges. The natural variability was related to the magnitude of the low flow unit discharges, with higher unit discharges generally displaying lower variability and lower unit discharges displaying higher variability.

The second- and fifth-lowest precipitation years on record at Fort McMurray Airport occurred in 1998 and 1999, respectively. In 1999, these consecutive dry years produced the lowest-recorded water yields and flood discharges on the Steepbank, Muskeg, Beaver and MacKay rivers and Jackpine Creek. However, precipitation records indicate that a more extreme, longer-duration dry period occurred from 1945 to 1953. Hydrologic records are not available for that period.

Annual precipitation for the years 1972 to 1976 were all above average, with 1973 the wettest recorded since 1945. Since no annual hydrologic monitoring data are available for the Muskeg River basin before 1974, it is not possible to calculate water yields, flood discharges and low flows for this wet year. The highest observed flood was recorded in 1997 on Jackpine Creek and the highest observed water yields were recorded in 1997 on the Muskeg, Mackay and Firebag rivers and Jackpine Creek and in 1996 on the Beaver River.

The seven long-term hydrologic stations located north of Fort McMurray are the best stations available for characterizing long-term natural variability in the Oil Sands Region, based on proximity and length of record. Continued monitoring of active stations by Environment Canada is recommended.

Supplementary monitoring at Environment Canada hydrologic stations is undertaken by RAMP at the Jackpine Creek station, which was discontinued in 1993. Winter measurements at the Environment Canada Muskeg River station have been undertaken by RAMP since 1999, winter monitoring at the Mackay and Firebag river stations commenced in 2002. This supplementary monitoring should continue and consideration should be given to reactivating continuous winter monitoring on the Steepbank River and undertaking periodic manual measurements on Jackpine Creek and the Beaver River, which frequently freeze to the bottom and cease to flow over the winter.

Several other discontinued Environment Canada hydrologic stations are present in the Oil Sands Region north of Fort McMurray and west of the Athabasca River. Monitoring on the Ells, Tar and Calumet rivers was reinitiated by RAMP in 2001 in support of the CNRL Horizon EIA, these stations should continue to be operated to collect baseline data and to measure effects after the start of project construction. Consideration should be given to reactivation of the remaining stations (Dover River, Joslyn Creek, Pierre River, Asphalt Creek and Unnamed Creek) to allow collection of long-term data in advance of project developments in the area.

3.5.2 Detecting and Assessing Regional Trends

Long-term climatic and hydrologic data from the Oil Sands Region north of Fort McMurray were used to identify temporal trends in climate and hydrology. The available data sets were subjected to statistical tests for trend, independence and randomness.

Annual precipitation data from Fort McMurray Airport did not display any significant trend. However, they did display some degree of serial dependence, which may be related to the El Nino/La Nina phases of the Southern Oscillation.

Mean annual temperature data exhibited a warming trend over the monitoring period of 1944 to 2001. The data also displayed some degree of serial dependence, which again may be related to the Southern Oscillation.

Water yield data did not display any significant temporal trend for any of the streams examined, as would be expected since water yield is highly correlated to annual precipitation. Data from the Beaver River, Mackay River and Jackpine Creek displayed a high degree of serial dependence at a 1% level of significance, while water yield data for the Athabasca and Muskeg rivers displayed serial dependence at a 5% level of significance. This is attributable to the dependence of water yield on precipitation, which was also found to be serially dependent. However, the Steepbank and Firebag rivers did not exhibit serial dependence, likely due to masking by non-climatic factors.

Flood data for all long-term regional stations were without trend. Only maximum mean daily discharge data for the MacKay River displayed serial dependence at a 5% level of significance.

Low flow data did not display any significant temporal trend, except for the Beaver River, where an upward trend in low flows may be affected by the observed warming trend. The data for the Beaver and Steepbank rivers displayed a high degree of serial dependence at a 1% level of significance, while low flow data for the Athabasca and Muskeg rivers and Jackpine Creek displayed serial dependence at a 5% level of significance. This is attributable to the dependence of water yield on precipitation, which was also found to be serially dependent. However, the MacKay and Firebag rivers did not exhibit serial dependence, likely due to masking by non-climatic factors.

Spatial trends in precipitation and temperature are subtle and are influenced by geographic factors. They should not be affected by the activities of local industry.

Spatial trends in annual water yields, flood discharges and low flows are dependent on climatic conditions and physical characteristics of the tributary watershed. The hydrologic characteristics at any location on a stream are a function of precipitation, evaporation and temperature regimes, as well as watershed area, terrain, surficial geology, and lake and wetlands storage. The hydrologic characteristics for long-term regional monitoring stations and selected short-term RAMP stations are presented in this report, and hydrologic characteristics of other nodes within the region have been calculated by hydrologic modelling undertaken during recent EIAs (CNRL 2002; Shell 2002).

Data from the long-term climatic and hydrologic stations in the Oil Sands Region have been used to calibrate a regional hydrologic model that provides predicted baseline characteristics for selected nodes in the region. Ongoing data collection at existing long-term and short-term stations will better define natural variability and variation due to local geographic and geologic conditions. If required to assess the hydrologic changes at a particular location, measured stream discharge and precipitation data could be used in a calibrated water balance model to estimate changes to stream discharge attributable to developments within the watershed. Accurate model results would be highly dependent on accurately quantifying the temporal and areal variation of precipitation in the modelled watershed.

3.5.3 Monitoring to Verify EIA Predictions

All of the RAMP Climatic and Hydrologic Monitoring Stations examined in this report are located in appropriate locations. The existing year-round monitoring at many stations should continue. Additional continuous monitoring is recommended at RAMP Hydrologic Monitoring Stations S1 and S6, and periodic manual discharge measurements are recommended at RAMP Hydrologic Monitoring Stations S2, S9, S10 and S11.

Continued purchase and compilation of long-term regional climatic and hydrologic data from Environment Canada stations, as discussed in Sections 3.2 and 3.3, is recommended. These data will be required in any analysis that attempts to differentiate natural variability from the effects of on-site activities.

Data from the Aurora Climate Station were used to examine precipitation and temperature in the Muskeg River basin. The measured annual precipitation, including rainfall and snowfall components, at the Aurora Climate Station compares well to that measured at Fort McMurray Airport. The measured temperature data show that annual mean, winter mean and summer mean temperatures measured at the Aurora Climate Station compare well to those recorded at Fort McMurray Airport. The Aurora Climate Station is the best station available for measuring local temperature and precipitation in the Muskeg River basin. Continued operation of this station by RAMP is recommended for the duration of mining and reclamation activities in the region. Operation of tipping bucket rainfall gauges at RAMP hydrologic monitoring stations, where possible, is recommended to supplement data from the Aurora Climate Station and provide more information on the areal extent and variation of precipitation events.

Furthermore, it is recommended that intensive precipitation monitoring be undertaken on small natural and reclaimed watersheds to measure the temporal and areal variation of precipitation inputs. This monitoring would include a network of rainfall and snowfall gauges as well as regular snowcourse surveys along a defined traverse within each watershed. These precipitation measurements would be more detailed than any previously undertaken within RAMP, and would be used, in conjunction with stream gauging data from the watershed outlet, to allow more detailed analysis of watershed response to rainfall and snowfall, in support of future reclamation drainage designs.

Data from nine RAMP Hydrologic Stations, including those on the Alsands Drain, Iyinimin Creek, Blackfly Creek, Muskeg River Aurora, Mills Creek, Kearl Lake Outlet, Wapasu Creek, Poplar Creek and McClelland Lake Outlet were used to assess whether the existing monitoring program will be effective in verifying EIA predictions. Measurements at these short-term stations are generally consistent with the record provided by long-term Environment Canada stations. Where measurements do not reflect natural conditions, the differences can be explained by mining activities, including closed-circuiting of mine areas and discharges from muskeg drainage and overburden dewatering.

Though this report makes no attempt to assess artificial changes to stream discharges or lake levels based on measured data, it appears that it would be possible to undertake this type of assessment, based on measured climatic and hydrologic data. The short-term hydrologic stations operated by RAMP were generally installed to provide baseline data for EIAs and/or to meet regulatory reporting requirements during mine operations. These stations should continue to gather baseline data for as long as possible to provide data for characterizing the natural behaviour. When developments are initiated, the stations should be used to collect data to quantify the impact of developments on the stream. If required, stream discharge data would be combined with precipitation data, hydrologic models and knowledge of mine layout and activities to construct a water balance used to assess water quantity impacts at the station and on downstream waterbodies. Station deactivation should only be considered if the upstream watershed is closed-circuited or diverted to the extent that discharges at the station become negligible. More detailed winter flow measurements, including periodic manual stream discharge measurements where continuous monitoring is not possible, should also be undertaken.

Additional data collection and analysis to characterize the geomorphology of natural streams in the Oil Sands Region is also recommended to develop an understanding of the physical nature of these streams. This is essential to developing sustainable stream diversions and reclamation drainage channels that replicate the features of natural channels with similar hydrologic characteristics. Further studies should specifically address the low flow hydraulics of streams and the collection of a greater body of geomorphology data for regional streams.

Data from long-term regional and short-term RAMP hydrologic monitoring stations were used in 2002 to recalibrate a regional hydrologic model that was the basis for the hydrologic impact assessments in the CNRL Horizon and Shell Jackpine EIAs. Update and recalibration of this model is recommended at such time as justified by a larger data set. This would provide a basis for future EIAs, operational water management plans and reclamation drainage designs. The recalibration would, in particular, use larger data sets from RAMP stations and ideally be undertaken after a broader range of data have been collected, since most RAMP hydrologic data have been collected under dry conditions and are not representative of average or wet conditions.

4 WATER QUALITY

4.1 INTRODUCTION

4.1.1 Program Overview

Since its inception in 1997, the water quality monitoring program has increased in scope with the addition of new parties to RAMP and the expansion of oil sands development in the lower Athabasca River watershed. Initially, in 1997, sampling was restricted to three-season sampling at four locations. In 2001, water quality samples were collected from over 32 sites during various times of the year (Table 4.1). The water quality program will likely continue to expand in response to further development proposed within the Oil Sands Region, including the Shell Canada Limited Jackpine Mine – Phase 1 and the Canadian Natural Resources Ltd. Horizon Project. Locations of existing sampling sites included in the RAMP water quality monitoring program are shown in Figure 4.1.

The rationale upon which the program is based has also evolved over time in response to expanded development and annual findings[1]. As a result of both expansion in the program and alteration of the program's underlying rationale, few locations have been sampled continuously over the five year history of RAMP, as illustrated in Table 4.1. However, consistent sampling techniques have been used throughout the program's history, and water samples collected by RAMP have typically been analyzed for all of the parameters listed in Table 4.2, with the possible exception of some of the non-core work completed to date. Occasional polycyclic aromatic hydrocarbon (PAH) and toxicity testing have also been included in the water quality monitoring program, as outlined in Table 4.1. Individual compounds included in the PAH analysis are listed in Table 4.3. Toxicity testing has involved definitive testing with algae (*Selenastrum capricornutum*), the water flea (*Ceriodaphnia dubia*) and fathead minnows (*Pimephales promelas*).

[1] A summary of the current program rationale is presented in Golder (2002f).

Table 4.1 RAMP Water Quality Monitoring Program, 1997 to 2001

Location		1997				1998				1999				2000				2001			
		W	S	S	F	W	S	S	F	W	S	S	F	W	S	S	F	W	S	S	F
Athabasca River																					
upstream of Fort McMurray	- grab[a]	♌	♋	♌	♋	♌	♋	♌	♋	♌	♋	♌	♋	♌	♋	♌	♋	♌	♋	♌	♋
upstream of Donald Creek	- cross channel		●	☒	●																
	- middle																●				
	- west bank								●								●	❍			
	- east bank								●								●	❍			
upstream of the Steepbank River	- middle																●				
	- west bank																●	●			
	- east bank																●	●			
upstream of the Muskeg River	- middle																●				
	- west bank[b]								●								●	●			
	- east bank[b]								●								●	●			
upstream of Fort Creek	- cross channel		●	☒	●					●											
	- middle																●				
	- west bank[b]								●								●				❍
	- east bank[b]								●								●				❍
upstream of the Embarras River	- cross channel									●							●				❍
at Old Fort	- grab[c]													♋	♋	♋	♋	♋	♋	♋	♋
Athabasca River Delta																					
Big Point Channel[d]												●					●				●
Athabasca River Tributaries (South of Fort McMurray)																					
Clearwater River	- upstream of Fort McMurray																	❍	◆	◆	◆
	- upstream of the Christina River																	❍	◆	◆	◆

Table 4.1 RAMP Water Quality Monitoring Program, 1997 to 2001 (continued)

Location	1997				1998				1999				2000				2001			
	W	S	S	F	W	S	S	F	W	S	S	F	W	S	S	F	W	S	S	F
Athabasca River Tributaries (North of Fort McMurray)																				
McLean Creek - mouth											❖	□		❖	❖	■		❖	❖	■
Poplar Creek - mouth																●				●
Steepbank River - mouth	❍	●	●	●		●	●	●	●							●				●
MacKay River - mouth								●								●				●
Ells River - mouth						●	●	●						♋	♋	♋	♋			
Tar River - mouth						●	●	●												
Fort Creek - mouth														□		□■		❖	❖	□
Muskeg River																				
Mouth[e]			●	●	♌	♌●	♌●	♋●	♌	♌❖	♌❖	♋□				●				●
Environment Canada gauge station[e]					♌	♌	♌	♋	♌	♌	♌	♋	♍	♍	♍	♒	♍	♍	♍	♒
upstream of Canterra Road Crossing[f]		●							♓	■	■	■	⌘	⌘	⌘	⌘	⌘	⌘	⌘	⌘
upstream of Jackpine Creek[e,f,g]					♌	♌	♌	♋	♌	♌❖	♌❖	♋□	♎	⌘	⌘	⌘	♎	⌘	⌘	⌘
upstream of Muskeg Creek[e,f]					♌	♌	♌	♋	♌♓	♌■	♌■	♋■	⌘	⌘	⌘	⌘	⌘	⌘	⌘	⌘
upstream of Wapasu Creek					♓			♓		■	■	■		❖	❖	■		❖	❖	■
Muskeg River Tributaries																				
Alsands Drain - mouth[e,f]				●	♌	♌	♌	♋	♌	♌❖	♌❖	♋□	♎	⌘	⌘	⌘	♎	⌘	⌘	⌘
Jackpine Creek - mouth[e]					♌	♌	♌	♋	♌	♌	♌	♋●				●				●
Shelley Creek - mouth								♋				♋●								
Muskeg Creek - mouth								♋♓				♋●				●				●
Stanley Creek - mouth								♋				♋●								●
Wapasu Creek - Canterra Road Crossing					♓			♋	♓			♋●								
Wetlands																				
Kearl Lake							●	●								●			●	●

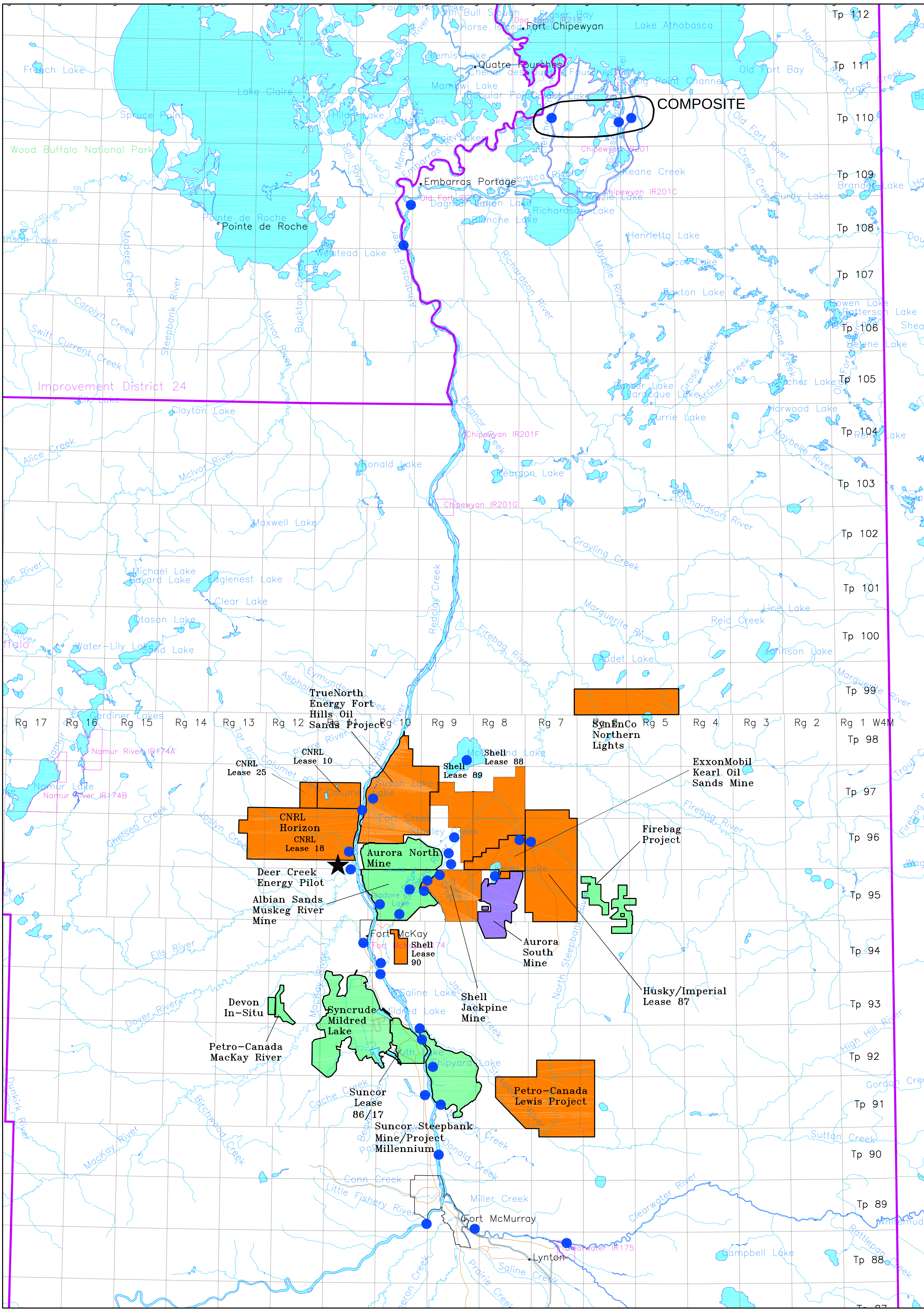
Table 4.1 RAMP Water Quality Monitoring Program, 1997 to 2001 (continued)

Location	1997				1998				1999				2000				2001			
	W	S	S	F	W	S	S	F	W	S	S	F	W	S	S	F	W	S	S	F
Isadore's Lake							●									●			●	●
Shipyard Lake							●			●	●	●			●	●			●	●
McClelland Lake																●			●	●
Additional Sampling (Non-Core Programs)																				
unnamed Creek - north of Ft. Creek - mouth																●●				
OPTI lakes																		♐		♐

Legend:
● = standard water quality parameters
♓ = standard water quality + chronic toxicity testing
❍ = standard water quality + polycyclic aromatic hydrocarbons (PAHs)
♎ = standard water quality + chronic toxicity testing + PAHs
♐ = standard water quality for OPTI lakes
❖ = thermograph
❑ = thermograph + standard water quality
⬥ = thermograph + standard water quality + PAHs
■ = thermograph + standard water quality + chronic toxicity testing
⌘ = thermograph + standard water quality + chronic toxicity testing + PAHs
♋ = AENV routine parameters (conventional parameters, major ions, nutrients and total metals)
♌ = AENV routine parameters + PAHs
♒ = AENV routine parameters + DataSonde
♍ = AENV routine parameters + PAHs + DataSonde
⌧ = Field Parameters + Dissolved Metals

Footnotes:
(a) Two samples collected in winter, but PAHs and several other parameters only measured once
(b) Samples were collected downstream of the named tributary in 1997 +/or 1998
(c) Monthly sampling for nutrients and conventional parameters; quarterly sampling for total and dissolved metals
(d) In 1999, one composite samples was prepared with water from Big Point, Goose Island and Fletcher channels
(e) AENV collected nine samples throughout the year, although only three were analyzed for PAHs
(f) After 1999, all sampling, with the exception of the thermographs, was conducted by individual industries
(g) In 1999, this sampling site was located upstream of Shelley Creek

Note: The heading symbols W,S,S,F = winter, spring, summer, fall symbols



LEGEND

- WATER SAMPLING LOCATION
- EXISTING and APPROVED DEVELOPMENTS
- PLANNED DEVELOPMENTS
- EUB APPROVED DEVELOPMENT

NOTE

INCLUDES ONLY THOSE SITES MONITORED AS PART OF THE CORE PROGRAM.

REFERENCE

ALBERTA NTDB DIGITAL DATA OBTAINED FROM GEOMATICS CANADA, AUGUST 2001. SASKATCHEWAN NTDB DATA OBTAINED FROM ISC, AUGUST 2001. DATUM: NAD 83 PROJECTION: UTM ZONE 13

PROJECT

RAMP FIVE YEAR REPORT

TITLE

RAMP WATER QUALITY SAMPLING SITES, 1997 TO 2001

Golder Associates
Calgary, Alberta

PROJECT	No. 022-2301.6150		FILE No.	Water Sampling
DESIGN	JPB	06/01/03	SCALE AS SHOWN	REV. 1
CADD	AS	06/03/03		
CHECK				
REVIEW				

FIGURE: 4.1

Table 4.2 Standard RAMP Water Quality Parameter List

Group Name	Individual Parameters
conventional parameters	colour
	dissolved organic carbon
	pH
	specific conductance
	total alkalinity
	total dissolved solids
	total hardness
	total organic carbon
	total suspended solids
major ions	bicarbonate
	calcium
	carbonate
	chloride
	magnesium
	potassium
	sodium
	sulphate
	sulphide
nutrients	nitrate + nitrite
	nitrogen - ammonia
	nitrogen - kjeldahl
	phosphorus - dissolved
	phosphorus - total
	chlorophyll *a*
biological oxygen demand	biological oxygen demand
organics	naphthenic acids
	total phenolics
	total recoverable hydrocarbons
metals (total and dissolved)	aluminum (Al)
	antimony (Sb)
	arsenic (As)
	barium (Ba)
	beryllium (Be)
	boron (B)
	cadmium (Cd)
	chromium (Cr)
	cobalt (Co)
	copper (Cu)
	iron (Fe)
	lead (Pb)
	lithium (Li)
	manganese (Mn)
	mercury (Hg)
	molybdenum (Mo)
	nickel (Ni)
	selenium (Se)
	silver (Ag)
	strontium (Sr)
	thallium (Tl)
	titanium (Ti)
	uranium (U)
	vanadium (V)
	zinc (Zn)

Table 4.3 Compounds Included in RAMP's Polycyclic Aromatic Hydrocarbon (PAH) and Alkylated PAH Target List

Group Name	Individual Parameters
target PAHs	acenaphthene
	acenaphthylene
	anthracene
	benzo(a)anthracene/chrysene
	benzo(a)pyrene
	benzo(b&k)fluoranthene
	benzo(g,h,i)perylene
	biphenyl
	dibenzo(a,h)anthracene
	dibenzothiophene
	fluoranthene
	fluorene
	indeno(c,d-123)pyrene
	naphthalene
	phenanthrene
	pyrene
alkylated PAHs	C1 substituted acenaphthene
	C1 substituted benzo(a)anthracene/chrysene
	C2 substituted benzo(a)anthracene/chrysene
	C1 substituted biphenyl
	C2 substituted biphenyl
	C1 substituted benzo(b or k)fluoranthene/methyl benzo(a)pyrene
	C2 substituted benzo(b or k)fluoranthene/benzo(a)pyrene
	C1 substituted dibenzothiophene
	C2 substituted dibenzothiophene
	C3 substituted dibenzothiophene
	C4 substituted dibenzothiophene
	C1 substituted fluoranthene/pyrene
	C1 substituted fluorene
	C2 substituted fluorene
	C1 substituted naphthalenes
	C2 substituted naphthalenes
	C3 substituted naphthalenes
	C4 substituted naphthalenes
	C1 substituted phenanthrene/anthracene
	C2 substituted phenanthrene/anthracene
	C3 substituted phenanthrene/anthracene
	C4 substituted phenanthrene/anthracene
	1-methyl-7-isopropyl-phenanthrene (retene)

The design of the annual monitoring is determined by committee using a consensus process; thus, committee changes result in design changes as a new consensus is achieved. The structure of subcommittees, committee membership, program funding and RAMP objectives have varied since the program's inception. Therefore, the Five Year Report provides an opportunity to assess whether the results of the first five years of RAMP monitoring meet the current RAMP objectives.

The RAMP water quality monitoring program currently consists of four components:

- the core RAMP water quality monitoring program that is consistently implemented year after year;
- non-core RAMP water quality monitoring, which tends to include either short term investigations, samples collected to supplement data collected as part of the core program or industry commitments (e.g., the OPTI lakes sampling program);
- monitoring completed by individual company(ies) in accordance with approval conditions; and
- monitoring conducted by Alberta Environment (AENV) at selected locations within the lower Athabasca River watershed.

4.1.2 Objectives

RAMP was designed around eight overall objectives, as outlined in Chapter 1, Sections 1.2.1 and 1.3.1. Three of these eight objectives are relevant for defining the scope of the water quality component of the Five Year Report:

- collecting scientifically defensible baseline and historical data to characterize variability in the oil sands area;
- monitoring aquatic environments in the oil sands area to detect and assess cumulative effects and regional trends; and
- collecting data against which predictions contained in environmental impact assessments (EIAs) can be verified.

In addition to the above, the RAMP Water and Sediment Subgroup of the Technical Subcommittee identified the following issues for consideration in the water quality section of the Five Year Report:

- influence of instream flow conditions on water quality sampling results and subsequent interpretation of apparent trends;

- comparison of fall and winter water quality with reference to the merits of switching from fall to winter water sampling;
- presence of spatial trends within the lower Athabasca River watershed;
- correlation between monitored parameters, including, for example:
  - total metal and total suspended solids (TSS) concentrations; and
  - total phosphorus and TSS concentrations; and
- use of three years of data to describe baseline variability in a previously unsampled waterbody.

To address both the broad objectives of RAMP and the specific issues raised by the Water and Sediment Technical Subgroup of the Technical Subcommittee, the specific objectives of the water quality component were established to determine the following:

1. which water quality parameters may be correlated to each other, and if these correlations are common to all waterbodies sampled by RAMP;
2. which water quality parameters may be influenced by water flow;
3. if there are significant seasonal variations between fall and winter water quality in the lower Athabasca River watershed that may favour winter water sampling over fall water sampling;
4. if there are temporal or spatial trends in the existing water quality data set;
5. given existing levels of variability and sampling frequency, how effective is the current water quality monitoring program at detecting change, and if three years of data are sufficient to assess baseline variability;
6. if the information being collected by RAMP can be used to verify EIA predictions; and
7. if and how the water component of RAMP program may be improved.

The first six specific water quality objectives relate back to the three broad program objectives as outlined in Table 4.4. The seventh objective (i.e., developing recommendations for program improvement) applies to all three broad program objectives.

Table 4.4 Relationship of the Specific Water Quality Study Objectives to RAMP's Overall Objectives

Overall Program Objectives	Relevant Component-Specific Objectives
characterize existing variability	examine potential parameter correlations
	examine the potential influence of instream flow on receiving water quality
	identify significant variation(s) between winter and fall water quality
detect and assess cumulative effects and regional trends	identify temporal and/or spatial trends in the existing water quality data set
	examine the power of the existing sampling program to detect change
collect data that can be used to verify EIA predictions	determine if the information collected by RAMP can be used to verify EIA predictions

4.1.3 Scope

The following section outlines the work undertaken to address each of the specific objectives listed in Section 4.1.2, as well as providing a brief description of the data used in this study and which parameters were considered. For each objective, the scope represents a balance between budget limitations, time constraints and scientific possibility.

4.1.3.1 Characterizing Existing Variability

Parameter Correlations

As outlined in Table 4.4, existing variability in the RAMP study area was examined, in part, by looking at general correlations among parameters included in the standard RAMP parameter list (Table 4.2), with noted exceptions[2]. Specific attention was focused on resolving the degree to which total metal and total phosphorus levels are influenced by TSS concentrations through the use of Pearson correlations and linear regression analysis. In addition, Principal Component Analysis (PCA) was used to reduce the standard parameter list to a small number of key variables to be carried forward into subsequent analyses described below.

[2] Parameters where more than 70% of the available data were non-detectable results were excluded from this study. These parameters comprised carbonate, sulphide, naphthenic acids, total phenolics, total recoverable hydrocarbons, total and dissolved beryllium, cadmium, mercury, selenium, silver and thallium, and dissolved antimony.

The input data set was limited to those waterbodies sampled as part of the core RAMP water quality program (see Table 4.1). It included comparable, discrete data (i.e., grab or composite samples) collected by AENV (2001), Albian (2000, 2002), Syncrude (2002), Komex (1997a), RL&L (1982, 1989), Shell (1975), TrueNorth (2001) and Golder (1996a, 1997b, 2002g), in addition to those collected by RAMP between 1997 and 2001. Continuous monitoring information was excluded from this study, as it has been discussed in previous reports (i.e., Golder 2002c; AENV 2002a).

The examination of parameter correlations using PCA was completed using the entire data set, as well as two subsets focusing on the Athabasca River and tributaries to the Athabasca River. A separate wetlands PCA was not included in this study, as there is not yet enough data available from Shipyard, Isadore's, Kearl and McClelland lakes to satisfy the input requirements of this statistical procedure. With respect to the investigation into the influence of TSS on total metal and total phosphorus levels, data from the Athabasca River, tributaries to the Athabasca River and the four wetlands sampled by RAMP were examined separately.

Influence of Instream Flow

The potential influence of instream flow on water quality was examined first by using flow and corresponding water quality data from the Athabasca River in a regression analysis. This analysis was then repeated using similar information from tributaries of the Athabasca River sampled by RAMP to determine if common relationships were present in the two data sets. Wetlands were excluded from this analysis, since these waterbodies are lentic (i.e., non-flowing) systems.

Parameters considered in this investigation included key Principal Components (PCs) derived from the relevant PCAs described above, as well as the following substances:

- dissolved organic carbon (DOC)
- pH
- total alkalinity
- total dissolved solids (TDS)
- TSS
- sulphate
- total Kjeldahl nitrogen (TKN)
- total phosphorus
- total aluminum
- total boron
- total chromium

DOC, total phosphorus and TKN were selected to provide a general indication of nutrient status. Total alkalinity and pH were selected as key variables for monitoring potential acidification. TDS, sulphate, total aluminum, total boron and total chromium were chosen, because recent EIAs (e.g., Shell 1997; Golder and Cantox 2002) indicate that concentrations of these substances may increase as a result of development. Finally, TSS was included, due to its likely influence on total metal levels.

Winter Versus Fall Water Quality

A statistical comparison of fall and winter water flow and water quality was completed using data collected from the long-term monitoring stations positioned in the Athabasca River upstream of Fort McMurray and near Old Fort, as well as monitoring sites situated in the lower Muskeg River between Jackpine Creek and the river mouth. Parameters considered in the analysis were the same as those discussed with reference to the influence of instream flow.

The purpose of this comparison was to determine if statistically significant seasonal variations could be detected between fall and winter. The discussion presented herein is limited to a description of seasonal variations observed at the above-named locations, a review of the rationale used originally to select the current fall sampling schedule and recommendations on how the RAMP Water and Sediment Subgroup of the Technical Subcommittee may proceed towards resolving the issue of a winter versus fall sampling schedule.

4.1.3.2 Detecting and Assessing Regional Trends

Temporal Trends

The investigation into temporal trends in the water quality data set was limited to an examination of long-term (i.e., 1976 to 2001) and short-term (i.e., 1997 to 2001) temporal variability observed at several locations within the Athabasca and Muskeg rivers, respectively. The two long-term Athabasca River sites are situated upstream of Fort McMurray and near Old Fort. The two short-term Muskeg River sites are located upstream of Muskeg Creek and in the lower section of the Muskeg River between of Jackpine Creek and the river mouth.

The short-term locations within the Muskeg River were selected because they are upstream and downstream, respectively, of current oil sands development in this basin. Similarly, the two long-term locations situated in the Athabasca River are positioned upstream and downstream of current oil sands development in that basin. Parameters considered in both the long-term and short-term temporal analyses were the same as those discussed with reference to the investigation into the influence of instream flow.

Spatial Trends

The investigation into spatial trends in the water quality data set included a discussion of general patterns within the lower Athabasca River watershed as a whole, as well as an examination of potentially significant variations along the length of the Athabasca River and within the Muskeg River watershed. Specific attention was focused on comparing water quality observed upstream and downstream of existing oil sands development along the Muskeg and Athabasca rivers. Parameters considered in this analysis were the same as those discussed with reference to the investigation into the influence of instream flow.

Ability to Detect Change

The ability of the current RAMP sampling program to detect significant temporal variations in water quality at a given location was evaluated based on the minimum data requirements of the chosen statistical test procedure. The ability of the current sampling program to detect significant spatial variations was examined using power analysis. The focus of the power analysis was to resolve the power associated with the statistical tests used to examine potentially significant differences in water quality in the Athabasca River upstream and downstream of development.

The Muskeg River was not included in the power analysis, because, as outlined in Section 4.3.2.2, significant variations that may be caused by oil sands development in the basin were identified by the interaction term included in the ANOVA. Based on Zar (1984), power analysis on an interaction term is limited to looking at the power of a performed test. One cannot calculate minimum detectable differences or other useful statistics from this type of retrospective analysis, as outlined by Steidl et al. (1997).

4.1.3.3 Monitoring to Verify EIA Predictions

Whether the information collected by RAMP can be used to verify EIA predictions was addressed through an examination of the following questions:

- Are RAMP water quality sites situated in appropriate locations (e.g., at or near EIA water quality assessment nodes or other relevant areas)?
- Are water samples collected by RAMP being analyzed for all of the water quality assessment parameters discussed in recent EIAs?

- Is RAMP collecting or otherwise obtaining the type of water quality information required to differentiate natural variability from change associated with human activities?

4.2 CHARACTERIZING EXISTING VARIABILITY

4.2.1 Parameter Correlations

Correlations among parameters included in the standard RAMP water quality parameter list (Table 4.1) were examined to determine the following:

- which substances are typically found together and/or follow consistent patterns with respect to other similar substances (e.g., do water quality samples with high colour levels typically contain high concentrations of dissolved iron);
- how TSS concentrations influence total metal and total phosphorus levels; and
- whether a small number of key parameters could be identified to reduce statistical testing requirements and to simplify subsequent analyses.

4.2.1.1 Methods

Data Origin and Initial Processing

Water quality data collected by RAMP between 1997 and 2001 were combined with comparable information collected by AENV (2001), Albian (2000, 2002), Syncrude (2002), Komex (1997a), RL&L (1982, 1989), Shell (1975), TrueNorth (2001) and Golder (1996a, 1997b, 2002g) to form one large water quality data set. Split and duplicate samples were reduced to single samples to guarantee data independence. This process was completed through either random selection or, in cases of unequal analysis, by choosing the sample that had been submitted for the more complete analysis.

Across the entire data set, values recorded as zeros were eliminated. Parameters where more than 70% of the available results were non-detectable were also eliminated, including carbonate, sulphide, naphthenic acids, total phenolics, total recoverable hydrocarbons, total and dissolved beryllium, cadmium, mercury, selenium, silver and thallium, and dissolved antimony. Remaining non-detectable results were replaced with half of the corresponding method detection limit.

To avoid duplication of effort, parameters providing similar levels of information were reduced to single variables. Bicarbonate was dropped, as it is represented as part of total alkalinity. Lab pH was used in place of field measured pH. Specific conductance, field and lab measured, were eliminated, as they are similar to TDS. Hardness was excluded, since it is an indirect measure of calcium and magnesium levels. All remaining data, with the exception of pH, were $\log_{10}$-transformed.

Principal Components Analysis

Principal Components Analysis (PCA) is a statistical procedure that can be used to transform a data set containing multiple parameters that may be inter-correlated into one with completely independent variables, called Principal Components (PCs) (Tabachnick and Fidell 1996; Walder and Mayhood 1985; SPSS 2000). Each sample included in the input data set is positioned in multi-dimensional space according to its "coordinates", or the values associated with that sample for each of the parameters considered in the PCA. In combination, all of the samples form a cloud. The first PC runs along the main axis of the cloud. The second PC is positioned perpendicular to the first and runs along the next main axis of the cloud. Subsequent PCs are added in a similar fashion, with each one running perpendicular to the rest and stretching along the largest part of the yet unexamined portions of the data cloud.

A simplified version of a PCA would be to consider, for example, a three-dimensional scatter plot of iron, lead and aluminum. Each sample is positioned on the scatter plot according to the iron, lead and aluminum concentrations measured in that sample. After dozens of samples have been positioned on the plot, a three-dimensional cloud develops. For the purposes of this example, the cloud is assumed to be longer than it is wide, and wider than it is tall. Under these conditions, the first PC would run along the length of the cloud, with the second PC positioned along its width and third PC describing the height of the cloud.

Although the total number of PCs that can be developed in a PCA will equal the total number of variables included in the input data set, the first few PCs will generally account for a large proportion of the total variance contained in the original data set. These first few PCs can then be used in subsequent analyses with minimal loss of information. Interpretation of the results of these subsequent analyses is done with reference to which of the original parameters are correlated to, and thus represented by, each PC. Parameters highly correlated to the same PC are also often highly correlated to one another (Walder and Mayhood 1985). Further detail concerning PCA can be found in Tabachnick and Fidell (1996).

In this study, three PCAs were performed. One PCA included the entire water quality data set, the second PCA was restricted to samples collected from the Athabasca River, and the final PCA was performed using samples collected from tributaries to the Athabasca River and the Muskeg River watershed. Three PCAs were used to determine if the parameter correlations observed in the overall data set were common to both the Athabasca River and its tributaries. A fourth PCA considering only the four wetlands sampled by RAMP (i.e., Shipyard, Kearl, Isadore's and McClelland lakes) was not completed, because enough data are not available from these four waterbodies to satisfy the input requirements of this statistical procedure. The distribution of samples included in each of the three PCAs is outlined in Table 4.5.

As outlined in Walder and Mayhood (1985), PCA requires a complete two-dimensional input table, wherein every sample included in the analysis has data for all of the corresponding parameters included in the PCA. This prerequisite resulted in a compromise between maximizing the number of parameters and the number of samples included in each PCA. As a general guideline, PCA input tables were set-up to maintain an approximate sample to parameter ratio of 3:1. The resulting list of parameters included in each of the three PCAs is provided in Table 4.6.

All three PCAs were performed without rotation in SYSTAT 10 (SPSS 2000), using pairwise correlations. Given the available sample sizes, correlation coefficients of ≥ 0.35 were used to identify a significant correlation between a water quality parameter and a PC. This threshold was selected based on the results of the explicit Pearson correlations completed as part of this study (i.e., 0.35 was generally the level at which the corresponding Bonferroni adjusted probabilities were less than 0.05 when samples sizes were between 70 and 140). In cases where correlation coefficients were greater than 0.35 on several PCs, the PC containing the highest coefficient was considered the most representative of that parameter.

Table 4.5 Distribution of Water Quality Samples Included in Each of the Three Water Quality Principal Component Analyses

Waterbody	Location[a]	Sample Size[b]		
		Overall PCA	Athabasca River PCA	Tributary PCA
Athabasca River	u/s of Fort McMurray	- [c]	31	-
	u/s of Donald Creek	7	8	-
	u/s of the Steepbank River	5	5	-
	u/s of the Muskeg River	8	8	-
	u/s of Fort Creek	9	9	-
	u/s of Embarras	6	21	-
	Delta	3	8	-
Athabasca River tributaries	Clearwater River	7	-	8
	McLean Creek	4	-	4
	Poplar Creek	2	-	2
	Steepbank River	9	-	9
	MacKay River	3	-	3
	Fort Creek	6	-	6
	Ells River	3	-	5
	Tar River	3	-	5
Muskeg River watershed	Muskeg River	25	-	66
	Alsands Drain	1	-	9
	Jackpine Creek	7	-	16
	Shelley Creek	5	-	9
	Muskeg Creek	7	-	11
	Stanley Creek	1	-	2
	Wapasu Creek	3	-	7
wetlands	Shipyard Lake	9	-	-
	McClelland Lake	5	-	-
	Isadore's Lake	5	-	-
	Kearl Lake	5	-	-
Total		**148**	**90**	**162**

[a] u/s = upstream.

[b] PCA = Principal Components Analysis; - = not included.

[c] None of the samples taken upstream of Fort McMurray have been analyzed for all of the parameters included in the Overall PCA. As a result, this sample site was excluded from the Overall PCA.

Table 4.6 Parameters Included in Each Water Quality Principal Component Analysis (PCA)

Parameter [(a)]		Overall PCA	Athabasca River PCA	Tributary PCA
conventional parameters	colour	x	x	x
	dissolved organic carbon	x	x	x
	pH	x	x	x
	total alkalinity	x	x	x
	total dissolved solids	x	x	x
	total suspended solids	x	x	x
major ions	calcium	x	x	
	chloride	x	x	x
	magnesium	x	x	x
	potassium	x	x	x
	sodium	x	x	x
	sulphate	x	x	x
nutrients	ammonia	x	x	
	dissolved phosphorus	x	x	
	nitrate + nitrite	x		
	total Kjeldahl nitrogen	x	x	
	total phosphorus	x	x	x
total metals	aluminum (Al)	x		x
	antimony (Sb)	x		x
	arsenic (As)	x	x	x
	barium (Ba)	x	x	x
	boron (B)	x		x
	chromium (Cr)	x	x	x
	cobalt (Co)	x	x	x
	copper (Cu)	x	x	x
	iron (Fe)	x	x	x
	lead (Pb)	x		x
	lithium (Li)	x		
	manganese (Mn)	x	x	x
	molybdenum (Mo)	x	x	x
	nickel (Ni)	x	x	x
	strontium (Sr)	x		x
	titanium (Ti)	x		
	uranium (U)	x		x
	vanadium (V)	x	x	x
	zinc (Zn)	x	x	x

Table 4.6 Parameters Included in Each Water Quality Principal Component Analysis (PCA) (continued)

Parameter [(a)]		Overall PCA	Athabasca River PCA	Tributary PCA
dissolved metals	aluminum (Al)	x		
	arsenic (As)	x		
	barium (Ba)	x		
	boron (B)	x		
	chromium (Cr)	x		
	cobalt (Co)	x		
	copper (Cu)	x		
	iron (Fe)	x		
	lead (Pb)	x		
	manganese (Mn)	x		
	molybdenum (Mo)	x		
	nickel (Ni)	x		
	titanium (Ti)	x		
	uranium (U)	x		
	vanadium (V)	x		
	zinc (Zn)	x		
Total		**52**	**27**	**29**

(a) PCA requires a complete two-dimensional input table. Selected parameters were, therefore, excluded from each PCA in order to construct complete input tables with approximate sample to parameter ratios of 3:1.

Explicit TSS Relationships

To directly examine how total metal concentrations may be influenced by TSS levels, pairwise Pearson correlations with Bonferroni adjustments were used to determine which total metals were significantly correlated to TSS concentrations. Data from the Athabasca River, Athabasca River tributaries including the Muskeg River watershed and the four wetlands sampled by RAMP were analyzed separately. Where significant correlations between TSS levels and total metal concentrations were observed, linear regression analysis was performed to characterize the relationship. Discussion of the resulting linear regression relationships focused on those parameters where the proportion of observed variation explained by TSS was equal to or greater than 50% (i.e., R^2 of the linear regression model was ≥ 0.50).

Potential relationships between total phosphorus (TP) concentrations and TSS levels were examined in a similar fashion using linear regression analysis with the three separate data sets discussed above (i.e., the Athabasca River, the four wetlands and tributaries to the Athabasca River including the Muskeg River watershed). For both the metals and TP, outliers identified during the regression analyses were removed iteratively until either no outliers remained or until 10% of the data had been excluded. All statistical tests were completed using SYSTAT 10 (SPSS 2000).

4.2.1.2 Results and Discussion

Principal Components Analysis

Lower Athabasca River Watershed

The first three PCs produced from the overall water quality PCA accounted for approximately 42.1% of the total variance contained within the two dimensional input table, with Overall PC1, 2 and 3 accounting for 20, 12 and 10.1% of the total variance, respectively (Table 4.7). As all but four of the input parameters (i.e., total and dissolved boron, dissolved chromium and nitrate+nitrite) were correlated with one or more of the first three PCs, only these three PCs are described herein.

Patterns observed in the Overall PCA followed expected trends. Total metals, TSS and dissolved metals were all generally positively correlated with Overall PC1 (i.e., correlation coefficients ≥ 0.35 - Table 4.7). These results reflect the fact that total metal concentrations include both the dissolved metal fraction and the fraction associated with suspended materials. These results also indicate that samples that contained high levels of one metal often contained high levels of other metals as well. Possible exceptions to this overall pattern included, among others, total and dissolved boron, iron, manganese and barium.

Total and dissolved boron did not exhibit a strong correlation to Overall PC1 or to either of the other PCs (Table 4.7). This observation suggests that boron was largely present in the dissolved phase within the RAMP study area. A review of the data presented in recent RAMP reports (e.g., Golder 2002c) substantiates this conclusion, with dissolved to total ratios for boron often approaching 1. The absence of significant correlations between total and dissolved boron and the three PCs also suggests that boron levels may be controlled by environmental factors different from those controlling the concentrations of other metals.

In contrast, manganese and iron were positively correlated, along with colour and DOC, to Overall PC3, reflective of the fact that iron, manganese and DOC tend to impart colour to water. The strong positive correlations of total iron to Overall PC2 and Overall PC3 also indicate that, when looking across all of the waterbodies sampled by RAMP, total iron levels in the study area tended to be more strongly influenced by groundwater inflow than by TSS inputs.

Although dissolved manganese was correlated to PC3, it exhibited a slightly stronger correlation to Overall PC2. Major ions and TDS were also positively correlated to PC2, as were total and dissolved barium, total strontium, lithium and dissolved titanium (Table 4.7). The association of total barium, strontium and lithium with PC2 indicates that these metals were typically present in the dissolved form, with minor suspended fractions. A pattern reflected in recent RAMP reports (e.g., Golder 2002c).

Table 4.7 Correlation of Individual Water Quality Parameters to Each of the Three Key Principal Components Derived from the Overall Principal Components Analysis

Parameter	Overall PC1[(a)]	Overall PC2[(a)]	Overall PC3[(a)]
total molybdenum (Mo)	**0.79**	0.08	-0.24
total aluminum (Al)	**0.74**	0.06	0.13
dissolved molybdenum (Mo)	**0.72**	0.10	-0.32
total vanadium (V)	**0.71**	0.12	0.04
total cobalt (Co)	**0.69**	0.09	0.25
total nickel (Ni)	**0.69**	0.03	0.04
total copper (Cu)	**0.67**	0.00	-0.04
dissolved nickel (Ni)	**0.67**	0.29	0.13
total lead (Pb)	**0.66**	-0.07	0.08
dissolved uranium (U)	**0.61**	**0.44**	**-0.48**
total chromium (Cr)	**0.60**	0.09	0.04
total arsenic (As)	**0.59**	0.01	0.21
dissolved copper (Cu)	**0.59**	0.07	-0.12
total titanium (Ti)	**0.58**	0.25	0.09
total suspended solids	**0.58**	0.01	0.30
total uranium (U)	**0.56**	0.23	**-0.39**
dissolved aluminum (Al)	**0.55**	-0.04	0.19
dissolved lead (Pb)	**0.55**	-0.06	0.16
total zinc (Zn)	**0.54**	-0.03	0.16
dissolved cobalt (Co)	**0.48**	**0.40**	0.27
dissolved vanadium (V)	**0.42**	0.13	-0.06
total antimony (Sb)	**0.40**	-0.30	0.00
dissolved arsenic (As)	**0.38**	0.08	0.08
dissolved zinc (Zn)	**0.35**	-0.08	-0.05
total dissolved solids	**-0.38**	**0.82**	-0.17
total alkalinity	**-0.53**	**0.74**	-0.02
calcium	**-0.41**	**0.70**	-0.12
magnesium	**-0.48**	**0.68**	-0.17
sodium	0.02	**0.59**	-0.19

Table 4.7 Correlation of Individual Water Quality Parameters to Each of the Three Key Principal Components Derived from the Overall Principal Components Analysis (continued)

Parameter	Overall PC1[(a)]	Overall PC2[(a)]	Overall PC3[(a)]
total lithium (Li)	-0.11	**0.59**	0.10
dissolved barium (Ba)	0.03	**0.57**	-0.20
dissolved manganese (Mn)	**-0.35**	**0.52**	**0.43**
total strontium (Sr)	0.24	**0.50**	-0.08
total barium (Ba)	0.01	**0.50**	-0.20
chloride	0.15	**0.45**	-0.30
potassium	-0.04	**0.44**	-0.11
ammonia	-0.26	**0.38**	**0.36**
dissolved titanium (Ti)	0.15	**0.36**	-0.07
colour	-0.04	-0.05	**0.75**
total manganese (Mn)	-0.01	**0.45**	**0.67**
total iron (Fe)	0.25	**0.36**	**0.67**
dissolved organic carbon	-0.31	0.12	**0.65**
dissolved iron (Fe)	-0.04	0.11	**0.63**
total Kjeldahl nitrogen	-0.17	0.24	**0.58**
sulphate	0.32	**0.38**	**-0.54**
total phosphorus	**0.46**	0.12	**0.53**
dissolved phosphorus	0.16	-0.13	**0.49**
pH	-0.02	0.02	**-0.43**
total boron (B)	0.08	0.26	0.17
dissolved boron (B)	-0.11	0.27	0.16
nitrate + nitrite	-0.07	0.30	0.06
dissolved chromium (Cr)	0.26	0.23	-0.05
Eigenvalue	10. 4	6.2	5.3
percent of variance explained	20.0	12.0	10.1

(a) PC = principal component; correlation coefficients ≥ | 0.35 | are bolded, and shading is used to identify PC that best represents the parameter in question. Samples included in this analysis are summarized in Table 4.5.

Athabasca River

All 27 parameters included in Athabasca River PCA were correlated to one or more of the first three PCs produced as part of the analysis (i.e., correlation coefficient ≥ 0.35 - Table 4.8). As such, only these first three PCs are discussed herein. They accounted for 56% of the total variance contained within the two dimensional input table, with Athabasca PC1, 2 and 3 accounting for 33.3, 15.7 and 7% of the total variance, respectively.

As expected, patterns observed in the Overall PCA were repeated to some degree within the Athabasca River PCA. Total metals were generally positively correlated to one another and to Athabasca PC1, with the possible exception of total molybdenum and total barium (Table 4.8). TSS was also positively correlated with Athabasca PC1. TDS and major ions were positively correlated to one another, expressed through joint negative correlations on Athabasca PC1 and joint positive correlations on Athabasca PC2.

Table 4.8 Correlation of Individual Water Quality Parameters to Each of the Three Key Principal Components Derived from the Athabasca River Principal Components Analysis

Parameter	Athabasca PC1[a]	Athabasca PC2[a]	Athabasca PC3[a]
total suspended solids	**0.86**	-0.12	0.04
total arsenic (As)	**0.84**	0.21	0.05
total phosphorus	**0.79**	0.15	-0.13
total iron (Fe)	**0.78**	**0.42**	-0.04
total manganese (Mn)	**0.75**	0.32	0.02
sodium	**-0.70**	**0.52**	-0.05
colour	**0.67**	0.23	-0.32
magnesium	**-0.66**	**0.57**	0.06
total dissolved solids	**-0.66**	**0.59**	0.03
total cobalt (Co)	**0.64**	0.33	0.34
sulphate	**-0.64**	**0.44**	0.19
chloride	**-0.61**	0.34	-0.06
total copper (Cu)	**0.60**	0.29	0.16
total vanadium (V)	**0.58**	**0.38**	**0.57**
dissolved organic carbon	**0.53**	**0.42**	**-0.45**
total zinc (Zn)	**0.51**	0.21	-0.15
total chromium (Cr)	**0.50**	0.32	**0.42**
total Kjeldahl nitrogen	**0.49**	0.32	**-0.35**
total alkalinity	**-0.58**	**0.65**	0.04
calcium	**-0.57**	**0.64**	0.13
total molybdenum (Mo)	0.24	**0.45**	-0.05
total barium (Ba)	-0.05	**0.41**	-0.11
potassium	-0.14	**0.41**	-0.23
ammonia	-0.24	**0.36**	-0.12
dissolved phosphorus	0.20	**0.40**	**-0.50**
total nickel (Ni)	**0.42**	**0.37**	**0.43**
pH	-0.13	-0.09	**0.44**
Eigenvalue	9.0	4.2	2.0
Percent of variance explained	33.3	15.7	7.0

[a] PC = principal component; correlation coefficients ≥ | 0.35 | are bolded, and shading is used to identify PC that best represents the parameter in question. Samples included in this analysis are summarized in Table 4.5.

Within the Athabasca River, total iron, total manganese and colour were all correlated with the same PC as TSS (i.e., Athabasca PC1 - Table 4.8). In the Overall PCA, these three parameters were not correlated with the same PC as TSS (Table 4.7). This contrast suggests that total iron and total manganese concentrations in the Athabasca River may be more strongly influenced by TSS levels than observed in other waterbodies in the RAMP study area. This contrast is also reflective of the fact that the brown, opaque colour of the Athabasca River results from suspended particles, whereas the deep, translucent, tea stained colour common to Athabasca River tributaries, the Muskeg River and other waterbodies within the RAMP study area results from DOC, dissolved iron and other dissolved ions (as discussed in Golder 2002g and AENV 2002a).

Athabasca River Tributaries

As previously discussed, the Tributary PCA was based on 162 samples from tributaries to the Athabasca River including streams and creeks within the Muskeg River watershed. Of the 29 parameters included in this PCA, all but one, total arsenic, were correlated with one of the first three PCs (i.e., correlation coefficient ≥ 0.35 - Table 4.9). As such, only the first three Tributary PCs are discussed herein. Together, these three PCs accounted for 46.4% of the total variance contained within the input table, with Tributary PC1, 2 and 3 accounting for 20.7, 15.7 and 10.0 % of the total variance, respectively.

Patterns present in the Tributary PCA that were also observed in the Overall PCA included the following (Table 4.9):

- Total metal concentrations, with the possible exception of iron, manganese, strontium, boron and arsenic, were highly correlated with Tributary PC1, suggesting that samples containing high levels of one metal generally contained high levels of other metals.
- Major ions, total strontium, total boron and TDS were all correlated with Tributary PC2. The positive correlation of total strontium and total boron to TDS and other dissolved constituents indicates that, as previously discussed, these metals were typically present in the dissolved form, with minor suspended fractions.
- As in the Overall PCA, total iron and manganese were most strongly correlated to PC3, along with colour and DOC. An observation that further supports the statement that the deep, tea stained colour common to Athabasca River tributaries results from DOC, dissolved iron and other dissolved ions.

Table 4.9 Correlation of Individual Water Quality Parameters to Each of the Three Key Principal Components Derived from the Athabasca River Tributary Principal Components Analysis

Parameter	Tributary PC1[(a)]	Tributary PC2[(a)]	Tributary PC3[(a)]
total molybdenum (Mo)	**0.78**	0.16	**0.35**
total cobalt (Co)	**0.78**	0.23	-0.15
total nickel (Ni)	**0.74**	0.12	0.05
total lead (Pb)	**0.69**	0.03	-0.03
total vanadium (V)	**0.64**	0.29	-0.05
total chromium (Cr)	**0.62**	0.24	-0.05
total zinc (Zn)	**0.59**	0.03	0.02
total copper (Cu)	**0.58**	0.05	0.18
total antimony (Sb)	**0.55**	-0.25	0.10
total aluminum (Al)	**0.48**	0.16	0.00
total barium (Ba)	**-0.45**	0.29	0.08
total dissolved solids	**-0.46**	**0.82**	0.11
magnesium	**-0.53**	**0.71**	-0.02
sodium	0.12	**0.67**	0.27
total alkalinity	**-0.56**	**0.65**	-0.07
chloride	0.09	**0.60**	0.26
potassium	-0.08	**0.55**	0.06
total strontium (Sr)	0.07	**0.51**	0.02
sulphate	0.03	**0.49**	**0.45**
total boron (B)	0.33	**0.38**	0.06
total iron (Fe)	0.13	**0.39**	**-0.76**
total manganese (Mn)	-0.11	**0.54**	**-0.62**
colour	0.18	-0.23	**-0.55**
total phosphorus	**0.36**	0.29	**-0.51**
total uranium (U)	**0.43**	0.30	**0.49**
pH	-0.20	0.05	**0.48**
total suspended solids	0.25	0.27	**-0.46**
dissolved organic carbon	-0.03	0.14	**-0.36**
total arsenic (As)	0.34	0.03	-0.09
Eigenvalue	6.0	4.5	2.9
percent of variance explained	20.7	15.7	10.0

[(a)] PC = principal component; correlation coefficients ≥ | 0.35 | are bolded, and shading is used to identify PC that best represents the parameter in question. Samples included in this analysis are summarized in Table 4.5.

In the Tributary PCA, TSS was most strongly correlated with Tributary PC3, whereas the majority of total metals included in the PCA were most strongly correlated to Tributary PC1. This pattern is in contrast to that observed in the Athabasca PCA, where TSS and the majority of total metals included in the analysis were all strongly correlated to the same PC (see Table 4.8). This difference between the two PCAs suggests that TSS levels exhibited a stronger influence on total metal concentrations in the Athabasca River than in the Athabasca River tributaries. This issue is explored further below as part of the discussion of explicit TSS-total metal relationships in the Athabasca River tributaries.

Explicit TSS Relationships

As previously stated in Section 4.2.1.1, PCA requires a complete two-dimensional input table, wherein every sample included in the analysis has data for all of the corresponding parameters included in the PCA input. Using explicit Pearson correlations and subsequent linear regression analyses alleviates this input restriction and allows for the inclusion of a greater number of samples in the analysis of potential TSS-total metal or TSS-TP relationships within the Athabasca River, wetlands or Athabasca River tributaries including the Muskeg River watershed.

In the Athabasca River, 12 of the 19 total metals included in the analysis exhibited statistically significant correlations with TSS (Table 4.10), as did TP (Table 4.11). All of the significant correlations were positive, indicating that total metal levels were high in samples containing high TSS concentrations. The proportion of the variation explained by the regression models (represented by R^2) was equal to or greater than 0.50 for total aluminum, arsenic, iron, manganese and TP (Table 4.11). For other parameters, the proportion of variation explained by TSS varied between 0.06 and 0.22.

Graphical illustrations of the types of relationships observed are presented in Figures 4.2 to 4.5 using total aluminum, iron, phosphorus and chromium, respectively. Total aluminum, phosphorus and iron had relatively high R^2 values (i.e., $R^2 \geq 0.63$) and little scatter around the respective regression lines. Total chromium had a relatively low R^2 value (i.e., 0.11), and considerable scatter was observed about the regression line. These results are indicative of TSS levels having limited influence on total chromium concentrations in the Athabasca River, while strongly influencing concentrations of total aluminum, iron, phosphorus and other metals with R^2 values greater than 0.50 (i.e., total arsenic and total manganese). The non-linearity observed in Figures 4.3 and 4.4, which contain plots of TP and total iron concentrations against TSS levels, also suggests that alternative transformation techniques or the use of non-linear regressions would likely yield higher R^2 values for these two parameters.

Table 4.10 Correlation Between Total Metal Concentrations and Total Suspended Solids Levels

Parameter	Athabasca River(a)		Athabasca River Tributaries(a)		Wetlands	
	Correlation Coefficient	Sample size	Correlation Coefficient	Sample size	Correlation Coefficient	Sample size
total aluminum (Al)	**0.81*****	133	**0.42*****	303	0.23	37
total antimony (Sb)	-0.17	61	0.12	211	-0.28	28
total arsenic (As)	**0.72*****	261	**0.32*****	364	-0.22	36
total barium (Ba)	-0.01	213	-0.02	277	0.12	31
total boron (B)	0.17	78	0.12	292	-0.12	37
total chromium (Cr)	**0.33*****	270	0.05	343	0.15	38
total cobalt (Co)	**0.48*****	231	0.16	280	0.23	32
total copper (Cu)	**0.43*****	281	**0.21***	328	0.12	36
total iron (Fe)	**0.76*****	168	**0.39*****	331	0.31	38
total lead (Pb)	**0.32***	138	0.07	308	-0.04	38
total lithium (Li)	0.32	72	0.10	234	-0.16	31
total manganese (Mn)	**0.71*****	278	**0.38*****	342	0.31	38
total molybdenum (Mo)	0.14	231	-0.03	288	0.19	31
total nickel (Ni)	**0.27*****	236	0.10	346	0.32	38
total strontium (Sr)	0.09	72	0.11	243	0.12	31
total thallium (Tl)	**0.39*****	101	**0.20***	284	0.38	31
total uranium (U)	0.07	66	**-0.24***	204	0.28	29
total vanadium (V)	**0.33*****	608	**0.25*****	789	0.03	37
total zinc (Zn)	**0.40*****	264	0.11	322	0.09	38

(a) Significant correlation coefficients are bolded; * = $p < 0.05$, *** = $p < 0.001$.

Table 4.11 Linear Regression Models Developed to Describe Significant Total Suspended Solids (TSS) - Total Metal and TSS - TP Correlations in the Athabasca River

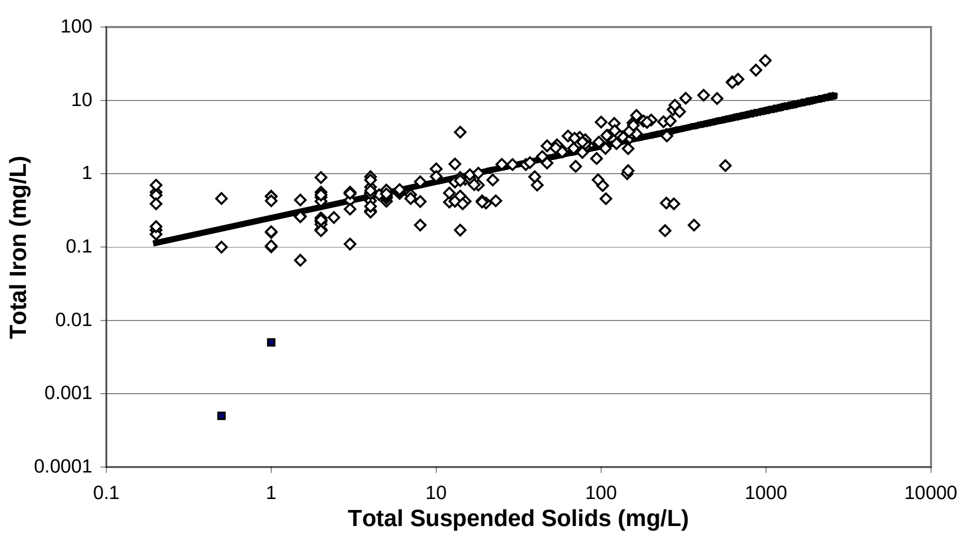
Parameter(a)	Slope	Constant	R^{2}(b)	Sample size
total aluminum (Al)	0.70	-1.37	**0.69**	132
total arsenic (As)	0.36	-3.53	**0.58**	258
total chromium (Cr)	0.17	-2.81	0.11	270
total cobalt (Co)	0.26	-3.45	0.22	230
total copper (Cu)	0.23	-2.94	0.19	281
total iron (Fe)	0.49	-0.60	**0.69**	164
total lead (Pb)	0.21	-3.18	0.10	138
total manganese (Mn)	0.38	-1.89	**0.50**	277
total nickel (Ni)	0.16	-2.64	0.06	235
total phosphorus (c)	0.41	-1.78	**0.63**	810
total thallium (Tl)	0.26	-2.32	0.15	101
total vanadium (V)	0.20	-3.13	0.11	608
total zinc (Zn)	0.25	-2.37	0.16	264

(a) Regression model has the form $\log_{10}$(parameter concentration) = constant + slope * $\log_{10}$(TSS level).
(b) R^2 values ≥ 0.5 are bolded
(c) Regression model was significant with $p < 0.001$.

Figure 4.2 Relationship Between Total Suspended Solids Levels and Total Aluminum Concentrations in the Athabasca River

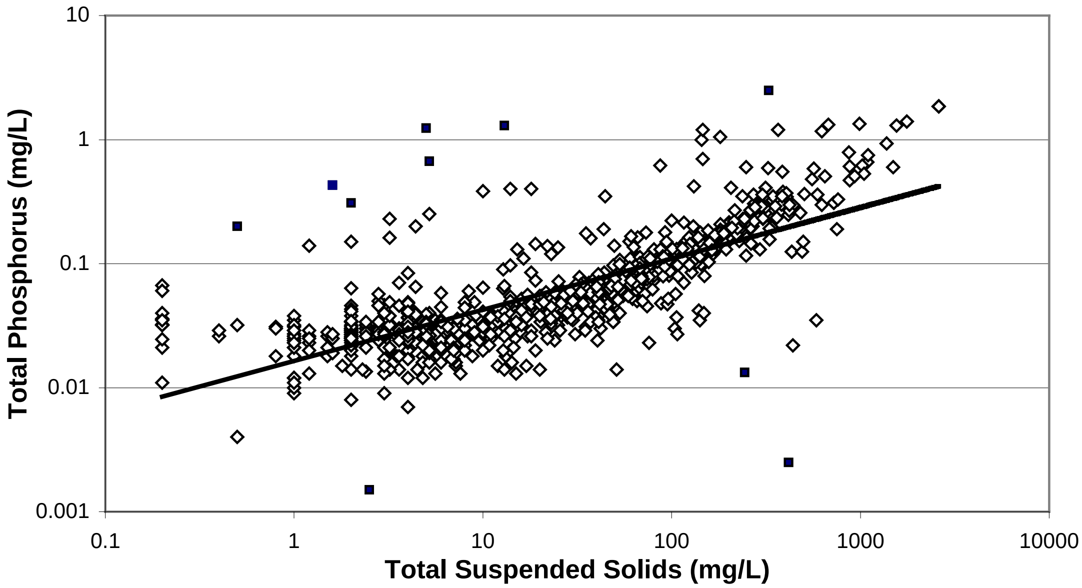
Note: Solid square points are outliers that were excluded from the analysis.

Figure 4.3 Relationship Between Total Suspended Solids Levels and Total Iron Concentrations in the Athabasca River



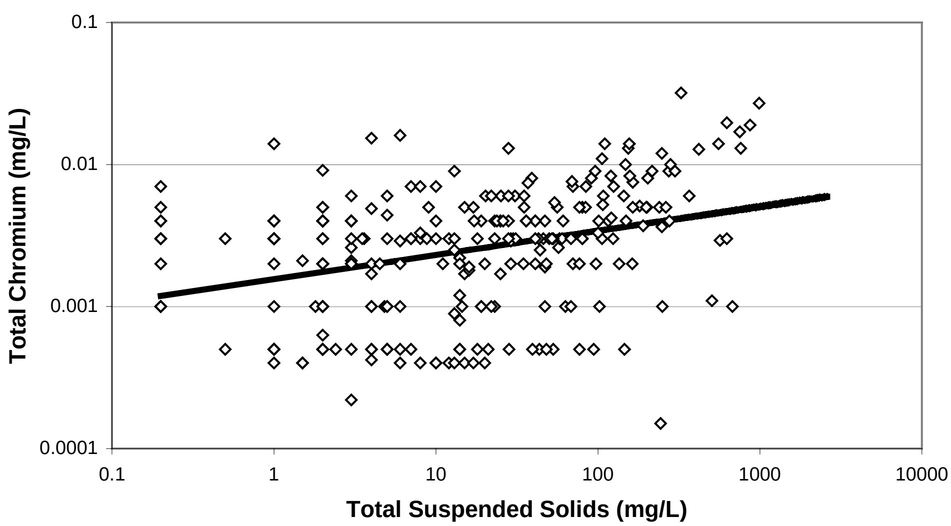
Note: Solid square points are outliers that were excluded from the analysis.

Figure 4.4 Relationship Between Total Suspended Solids Levels and Total Phosphorus Concentrations in the Athabasca River



Note: Solid square points are outliers that were excluded from the analysis.

Figure 4.5 Relationship Between Total Suspended Solids Levels and Total Chromium Concentrations in the Athabasca River



In the Athabasca River tributaries, nine of the 20 parameters included in the analysis demonstrated significant correlations with TSS: eight metals and TP (Tables 4.10 and 4.12). With the exception of total uranium, all significant correlations were positive, although they were not as strong as those observed in the Athabasca River. Uranium was initially negatively correlated to TSS. However, following the removal of outliers, this relationship was no longer significant. For the remaining total metals found to be significantly correlated to TSS, the proportion of variance explained by the regression models was less that 0.50 in all cases (Table 4.12). An example of the degree of scatter observed around the tributary regression lines is presented in Figures 4.6 and 4.7.

The principal water source for many of the Athabasca River tributaries is groundwater flow that passes through shallow aquifers or muskeg soils (Swartz 1980). These waters typically contain only dissolved metals, because the media through which they flow naturally filter out the suspended fraction. Consequently, TSS concentrations in the Athabasca River tributaries are typically lower than those observed in the Athabasca River (e.g., Figure 4.2 versus Figure 4.5). In the tributaries, a larger proportion of the total metal and/or TP content in the water column would, therefore, exist in the dissolved phase. Hence, the absence of strong linear relationships between TSS levels and corresponding total metal or TP concentrations in the Athabasca River tributaries, in comparison to those observed in the Athabasca River.

Table 4.12 Linear Regression Models Developed to Describe Significant Total Suspended Solids (TSS) - Total Metal and TSS - TP Correlations in the Athabasca River Tributaries

Parameter [(a)]	Slope	Constant	R^2	Sample Size
total aluminum (Al)	0.42	-1.54	0.19	302
total arsenic (As)	0.24	-3.55	0.13	359
total copper (Cu)	0.16	-3.18	0.05	327
total iron (Fe)	0.31	-0.18	0.21	327
total manganese (Mn)	0.35	-1.39	0.15	341
total phosphorus [(b)]	0.29	-1.57	0.25	852
total thallium (Tl)	0.19	-2.53	0.05	283
total uranium (U)	-0.02	-4.01	0.00	188
total vanadium (V)	0.16	-3.31	0.07	788

(a) Regression model has the form $\log_{10}$(parameter concentration) = constant + slope * $\log_{10}$(TSS level).

(b) Regression model was significant with $p < 0.001$.

Figure 4.6 Relationship Between Total Suspended Solids Levels and Total Aluminum Concentrations in the Athabasca River Tributaries

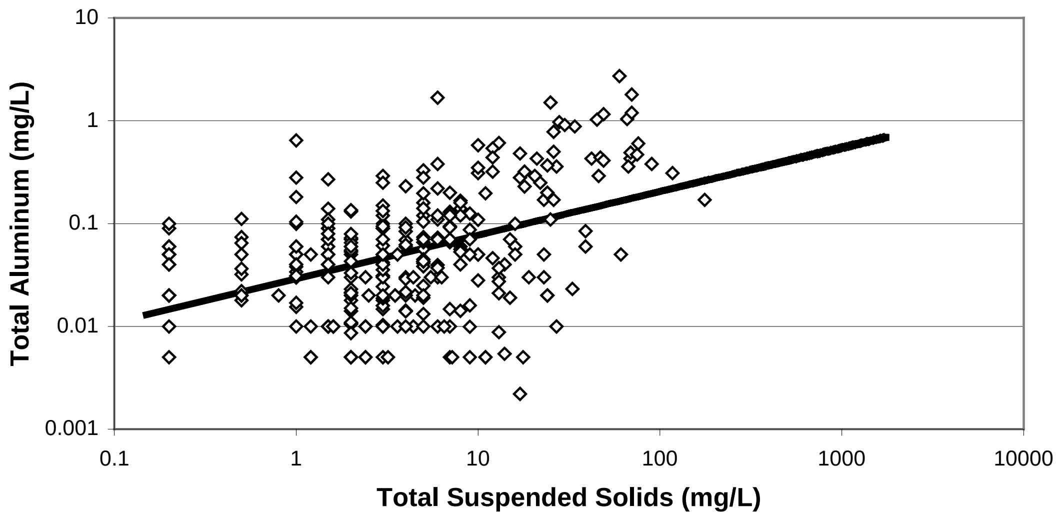
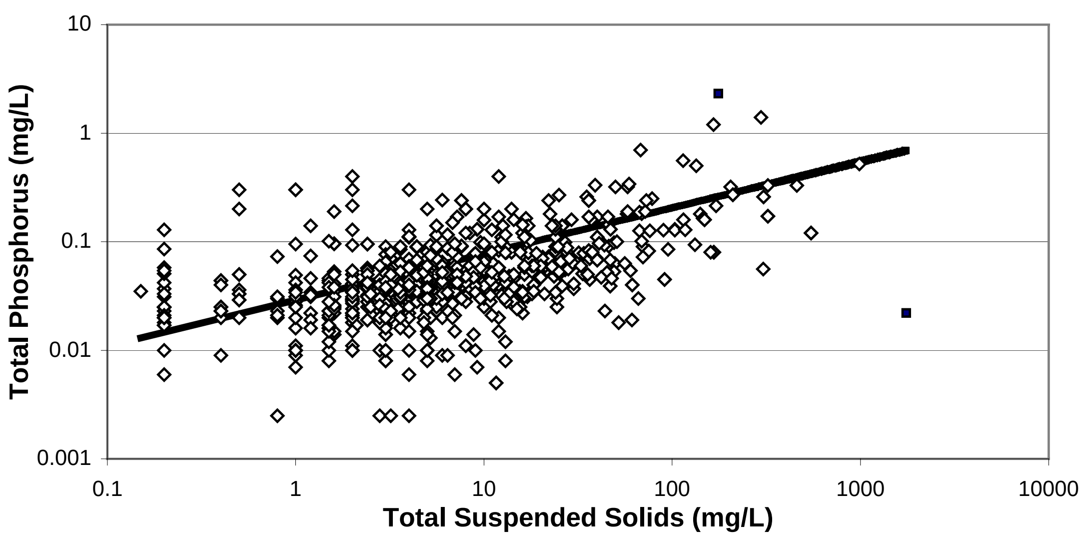


Figure 4.7 Relationship Between Total Suspended Solids Levels and Total Phosphorus Concentrations in the Athabasca River Tributaries



Note: Solid square points are outliers that were excluded from the analysis.

With respect to the four wetlands sampled by RAMP (i.e., Shipyard, Isadore's, Kearl and McClelland lakes), no significant correlations between total metal concentrations and TSS levels were observed (Table 4.10). TP concentrations in the four wetlands were also not significantly related to TSS levels ($R^2 = 0.08$, $p > 0.05$). Because each wetland effectively acts as a settling basin, the lack of significant TSS - total metal or TSS - TP relationships was expected.

4.2.1.3 Conclusions and Recommendations

Analysis of available data from the lower Athabasca River watershed revealed that water quality characteristics in the area follow expected patterns. These patterns included the following:

- Total metals, TSS and dissolved metals were all generally positively correlated with the same Overall PC, reflective of the fact that total metal concentrations include both the dissolved metal fraction and that associated with suspended materials.
- Total metal concentrations tended to follow consistent, positively correlated trends, whereby samples containing high levels of one metal (e.g., total aluminum) also generally contained high levels of other total metals (e.g., cobalt, nickel and vanadium).
- Manganese and iron were positively correlated, along with colour and DOC, to Overall PC3, reflective of the fact that iron, manganese and DOC tend to impart colour to water.
- High TDS and total alkalinity measurements were recorded for samples containing high levels of calcium, magnesium, chloride and other major ions.
- Barium, strontium, lithium and boron were typically present in the dissolved form, with minor suspended fractions.

Within the Athabasca River, similar correlations among parameters were observed. Conclusions specific to Athabasca River water quality that extend beyond those discussed above include the following:

- The brown, opaque colour of the Athabasca River results from suspended particles, as reflected by the common correlation of total metals, including iron and manganese, TSS and colour to the same principal component.
- Although 12 of the 19 total metals included in this study exhibited statistically significant correlations with TSS, only total aluminum, arsenic, iron and manganese concentrations appear to be strongly influenced by TSS levels (i.e., $R^2 > 0.50$).

- TP concentrations also tend to be strongly influenced by TSS levels in the Athabasca River.

Other conclusions that can be drawn from the results discussed in Section 4.2.1.2 include the following:

- The deep, translucent, tea-stained colour common to Athabasca River tributaries, the Muskeg River and other waterbodies within the RAMP study area results from DOC, dissolved iron and other dissolved ions (Golder 2002g; AENV 2002a). Hence, the common correlation of these parameters to the same principal component.
- Total metal and TP concentrations in the Athabasca River tributaries are generally less influenced by TSS levels than those in the Athabasca River, with only nine of the 20 parameters examined in this study demonstrating significant TSS correlations and corresponding regression equations explaining less than 50% of the observed variation.
- Total metal and TP concentrations in Shipyard, Isadore's, McClelland and Kearl lakes are largely independent of TSS levels.

4.2.2 Influence of Instream Flow

Parameter concentrations may vary in relation to flow as a result of increased dilution during heavy storm events or the increased contribution of saline groundwater during periods of low overland flow. Characterization of the relationship between parameter concentrations and flow in the lower Athabasca River watershed can help in the analysis and interpretation of potential variations in parameter concentrations observed over time and/or among locations.

4.2.2.1 Methods

The potential influence of instream flow on water quality was examined first by using flow and corresponding water quality data from the Athabasca River in a linear regression analysis. This analysis was then repeated using similar information from tributaries of the Athabasca River sampled by RAMP to determine if common relationships were present in the two data sets. Wetlands were excluded from this analysis, since these waterbodies are lentic (i.e., non-flowing) systems. Similar to Section 4.2.1, discussion of the resulting linear regression relationships focused on those parameters where the proportion of observed variation explained by instream flow was equal to or greater than 50% (i.e., R^2 of the linear regression model was ≥ 0.50).

Parameters considered in this investigation included the first two PCs from the Athabasca River and Athabasca River tributary PCAs[3], as well as the following individual substances[4]:

- DOC
- pH
- total alkalinity
- TDS
- TSS
- sulphate
- TKN
- total phosphorus
- total aluminum
- total boron
- total chromium

Both average daily and 14-day average flows were used to determine which is a better predictor of instream concentrations. Flow information originated from Golder (2002d) and AENV (2002b). The corresponding water quality data were taken from the water quality data set described in Section 4.2.1.1 - Data Origin and Initial Processing. The 14-day average flow values were derived using data collected from the day each water quality sample was collected along with the data collected over the preceding 13 days.

Data originating from the Muskeg River downstream of the Alsands Drain after 1997 were excluded from the analysis, because of the potential influence of dewatering operations from Aurora North and the Muskeg River Oil Sands Plant (MROSP) on instream flows. In the analysis of both the Athabasca River and the Athabasca River tributaries, identified outliers were removed iteratively until either no outliers remained or 10% of the data had been excluded. All statistical tests were completed using SYSTAT 10 (SPSS 2000).

4.2.2.2 Results and Discussion

In the Athabasca River, linear regression models were statistically significant for 11 of the 13 tested parameters (Table 4.13). Flow accounted for over 50% of the observed variation in parameter concentrations for seven of the 11 significant relationships, including those developed for Athabasca PC1, total alkalinity, TDS, TSS, sulphate, TP and total aluminum. Results derived using average daily and 14-day average flows were similar, with average daily flows tending to produce marginally higher R^2 values.

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[3] The third PCs from the Athabasca River and Athabasca River tributary PCAs were not included, because approximately one third of the parameters correlated with those PCs were already included as individual, indicator parameters.

[4] Individual, indicator parameters were selected based on the rationale presented in Section 4.1.3.1.

Table 4.13 Linear Regression Models Developed to Describe Flow Relationships in the Athabasca River

Parameter[a]	Average Daily Flow				14-Day Averaged Flow			
	Slope[b]	Constant	$R^{2(c)}$	n[d]	Slope[b]	Constant	$R^{2(c)}$	n[d]
Athabasca PC1	2.07*	-5.47	**0.80**	58	2.01*	-5.35	**0.81**	58
Athabasca PC2	-0.61*	1.85	0.11	58	-0.61*	1.84	0.12	58
pH	-0.06	7.94	0.01	364	-0.06	7.94	0.01	364
dissolved organic carbon	0.14*	0.56	0.10	321	0.14*	0.56	0.10	321
sulphate	-0.40*	2.43	**0.77**	358	-0.41*	2.46	**0.79**	359
total alkalinity	-0.25*	2.72	**0.78**	369	-0.25*	2.73	**0.78**	369
total dissolved solids	-0.31*	3.06	**0.73**	371	-0.31*	3.07	**0.73**	371
total suspended solids	1.78*	-3.34	**0.70**	380	1.72*	-3.20	**0.65**	381
total Kjeldahl nitrogen	0.29*	-1.01	0.16	321	0.26*	-0.96	0.14	321
total phosphorus	0.79*	-3.32	**0.53**	368	0.74*	-3.19	0.44	369
total aluminum	1.65*	-4.94	**0.67**	80	1.55*	-4.73	**0.62**	81
total boron	-0.07	-1.42	0.01	33	-0.06	-1.44	0.01	33
total chromium	0.40*	-3.68	0.12	138	0.37*	-3.61	0.11	138

(a) Regression model has the form $\log_{10}$(parameter concentration) = constant + slope * $\log_{10}$(flow).

(b) * = $p < 0.05$.

(c) R^2 values > 0.5 are bolded.

(d) n = sample size.

Athabasca PC1, which represents total metals, TSS and DOC, exhibited a positive relationship with flow (Figure 4.8), as did DOC, TSS, TKN, total chromium and total aluminum concentrations when examined individually (Table 4.13). Athabasca PC2, which is generally representative of major ions, was negatively related to flow, as were total alkalinity, TDS and sulphate concentrations. The inverse relationship observed between flow and TDS concentrations is illustrated in Figure 4.9. The occurrence of increasing major ion concentrations during periods of low flow likely is attributable to increased groundwater inflow into the Athabasca River, relative to surface water inputs. In contrast, the increasing metal and TSS concentrations observed with increasing instream flows likely reflects the increased input of suspended materials during spring runoff and other heavy surface flow events.

Figure 4.8 Relationship Between Instream Water Flow and Athabasca PC1 in the Athabasca River

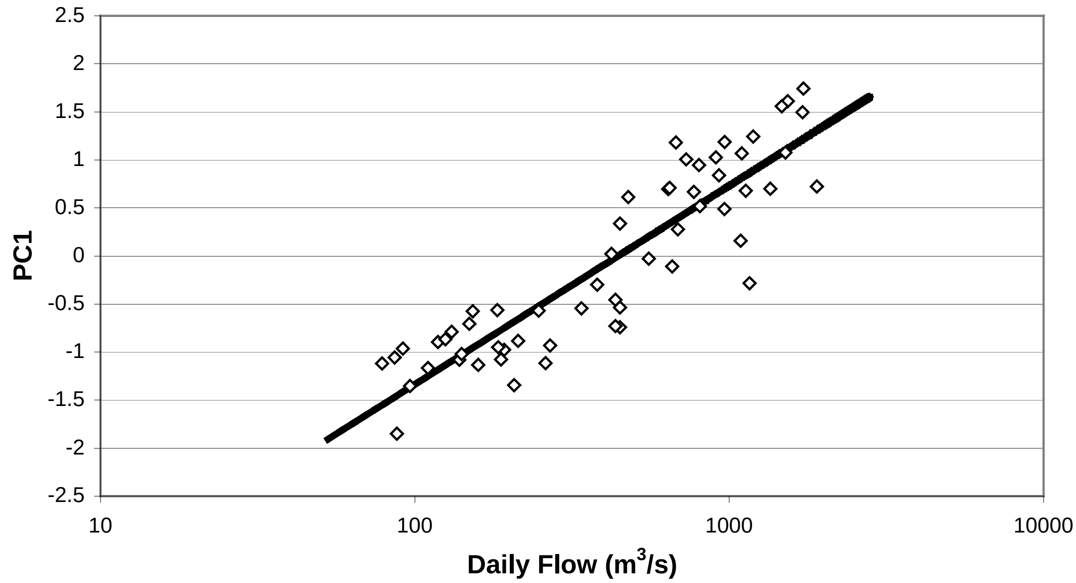
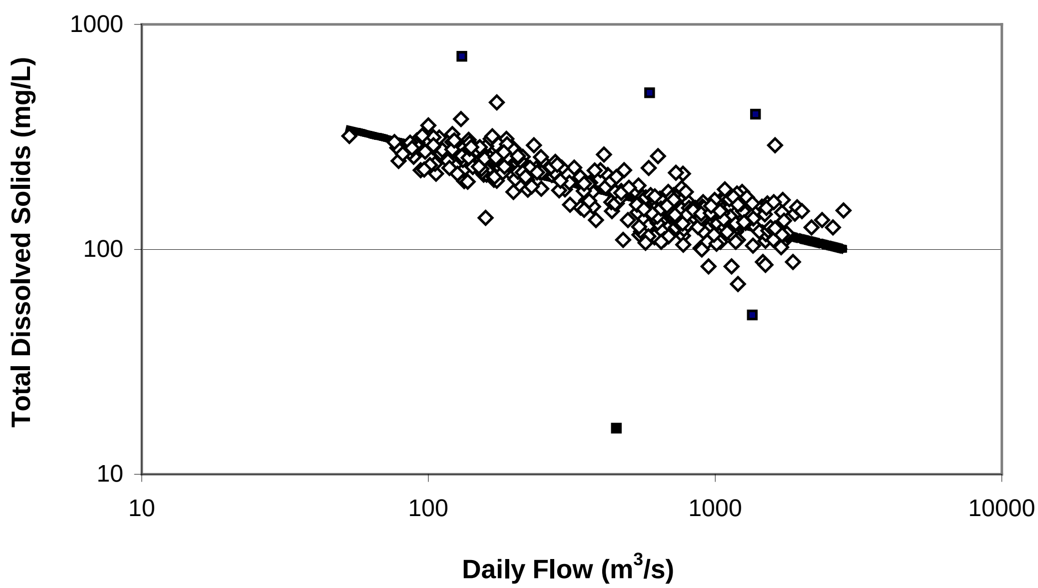


Figure 4.9 Relationship Between Instream Water Flow and Total Dissolved Solids Concentrations in the Athabasca River



Note: Solid square points are outliers that were excluded from the analysis.

In the Athabasca River tributaries, linear regression models were statistically significant for 12 of the 13 tested parameters (Table 4.14). However, the amount of variation explained by the resulting regression equations was greater than 50% for only two parameters: Tributary PC1 and total alkalinity. Similar to the Athabasca River,

- average daily flow was generally a slightly better predictor of concentration than the 14-day averaged flow;
- TSS, TP, total aluminum and total chromium concentrations exhibited a positive relationship with flow, as did Tributary PC1; and
- Tributary PC2, sulphate, total alkalinity and TDS concentrations were negatively related to flow.

DOC, pH and TKN concentrations were also significantly, inversely related to flow.

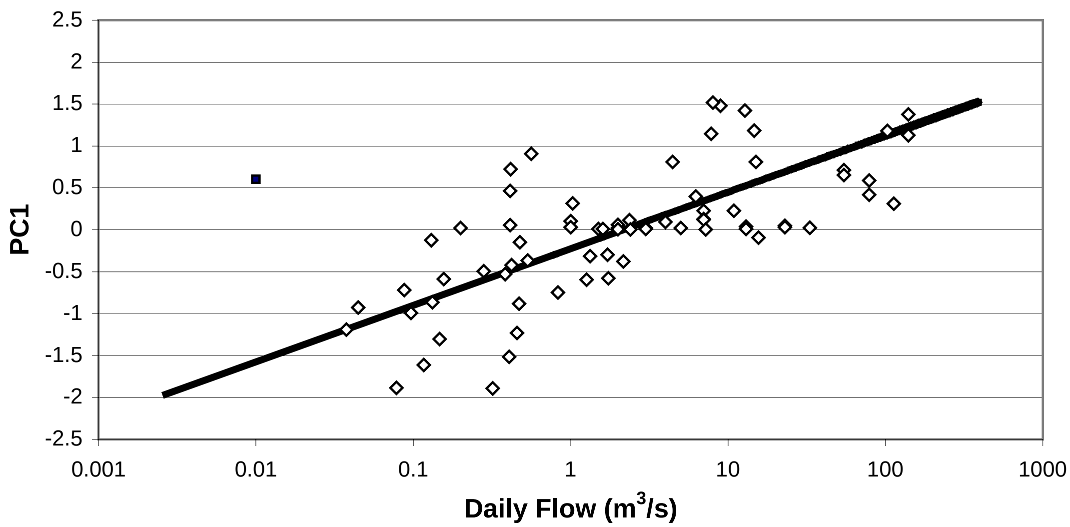
Table 4.14 Linear Regression Models Developed to Describe Flow Relationships in the Athabasca River Tributaries

Parameter[a]	Average Daily Flow				14-Day Averaged Flow			
	Slope[b]	Constant	$R^{2(c)}$	n[d]	Slope[b]	Constant	$R^{2(c)}$	n[d]
Tributary PC1	0.67*	-0.23	**0.58**	53	0.66*	-0.23	**0.57**	54
Tributary PC2	-0.40*	-0.35	0.19	54	-0.39*	-0.39	0.18	55
pH	-0.11*	7.80	0.14	527	-0.10*	7.80	0.12	532
dissolved organic carbon	-0.06*	1.30	0.10	475	-0.06*	1.30	0.10	480
sulphate	-0.09*	1.02	0.05	530	-0.09*	1.02	0.04	536
total alkalinity	-0.18*	2.17	**0.67**	531	-0.18*	2.17	**0.67**	536
total dissolved solids	-0.15*	2.36	0.47	528	-0.15*	2.36	0.45	532
total suspended solids	0.16*	0.84	0.08	541	0.14*	0.84	0.06	546
total Kjeldahl nitrogen	-0.07*	0.00	0.10	449	-0.07*	0.00	0.10	453
total phosphorus	0.05*	-1.35	0.04	520	0.05*	-1.34	0.03	525
total aluminum	0.24*	-1.08	0.17	82	0.23*	-1.08	0.16	83
total boron	-0.06	-1.27	0.05	77	-0.05	-1.28	0.04	78
total chromium	0.19*	-3.04	0.13	114	0.19*	-3.04	0.14	116

(a) Regression model has the form $\log_{10}$(parameter concentration) = constant + slope * $\log_{10}$(flow).
(b) * = $p < 0.05$.
(c) R^2 values > 0.5 are bolded.
(d) n = sample size.

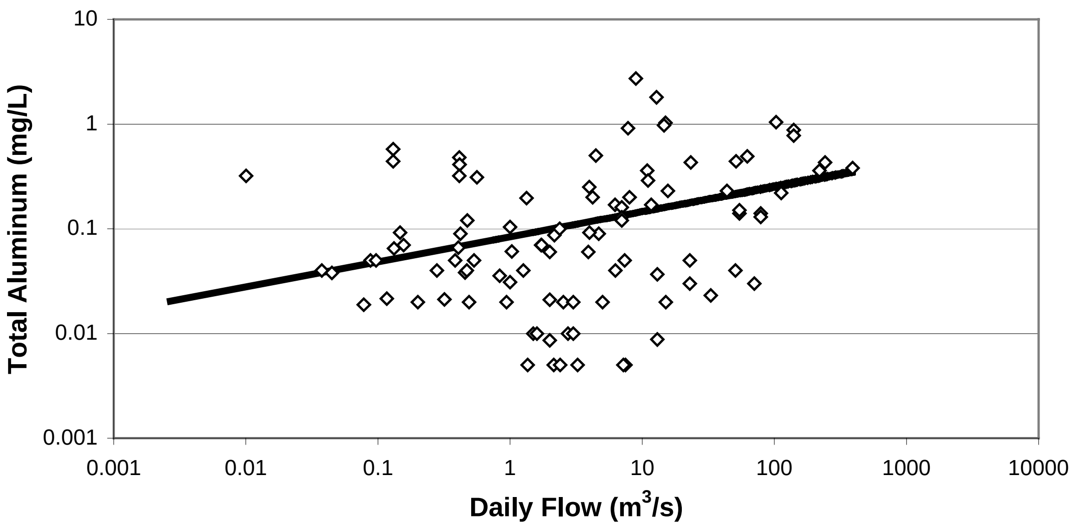
As shown in Figures 4.10 and 4.11, considerable scatter was observed among the tributary data. Hence, the low R^2 values associated with most of the significant regression equations. Tributaries of the Athabasca River included both small creeks (e.g., Fort Creek) and large rivers (e.g., the Clearwater River), with flow rates ranging from 0.05 to > 100 m^3/s (Figure 4.10). As such, high flows recorded in a small creek may have been equivalent to low flows in one of the larger rivers, and the observed scatter may, therefore, be reflective of the individual characteristics of different stream size classes. In future, it may be desirable to develop flow relationships for specific size classes, with tributaries grouped according to flow regime.

Figure 4.10 Relationship Between Instream Water Flow and Tributary PC1 in the Athabasca River Tributaries



Note: Solid square points are outliers that were excluded from the analysis.

Figure 4.11 Relationship Between Instream Water Flow and Total Aluminum Concentrations in the Athabasca River Tributaries



4.2.2.3 Conclusions and Recommendations

Conclusions that can be drawn from the results discussed in Section 4.2.2.2 include the following:

- DOC, TSS, TKN and total metal concentrations in the Athabasca River tend to increase as flow increases.
- In contrast, major ion concentrations in the Athabasca River tend to increase during periods of low flow, as the contribution of groundwater inflow increases relative to surface water inputs.
- Water quality in the Athabasca River tributaries follows similar trends; dissolved ion concentrations tend to peak during periods of low flow, and TP, TSS and total metal concentrations generally increase as flow increases.
- In both the Athabasca River and the Athabasca River tributaries, average daily flow tends to be a slightly better predictor of instream concentrations than 14-day averaged flow.

Based on the amount of scatter observed within the tributary data set, it is recommended that future work concerning flow relationships in Athabasca River tributaries focus on rivers and creeks of similar size that experience similar flow regimes.

4.2.3 Winter Versus Fall Water Quality

As outlined in the RAMP Program Design and Rationale Document (Golder 2002f), the RAMP water quality monitoring program relies on fall sampling to monitor water quality conditions in receiving streams after an initial three-year, seasonal baseline sampling regime. Instream flows, however, are typically lowest in winter. The RAMP Water and Sediment Subgroup of the Technical Subcommittee has discussed switching from fall to winter sampling to capture this low flow period. An action item resulting from these discussions included a comparison of fall and winter water quality at several locations within the lower Athabasca River watershed to determine if seasonal variations in water flow and water quality could be observed.

4.2.3.1 Methods

Variations between fall and winter water quality were evaluated using average daily flow and water quality data available for the following three locations:

- Athabasca River upstream of Fort McMurray (WDS stations 07CC0010/20/30);
- Athabasca River near Old Fort (WDS stations 07DD0010/40/60/80/0250 and RAMP site ATR-ER); and
- Muskeg River between Jackpine Creek and the river mouth (includes RAMP site MUR-2 and WDS station 07DA0610).

Relevant flow information originated from Golder (2002d) and AENV (2002b). Relevant water quality data were taken from the water quality data set described in Section 4.2.1.1 - Data Origin and Initial Processing. In addition to average daily flow, the parameters were the same 13 water quality parameters discussed in Section 4.2.2.

Fall was defined as running from September 1 to October 31. Winter started November 1 and continued to March 31. The assumed start date for each year was set to April 1.

Comparisons between fall and winter water quality were completed using a one-way analysis of variance (ANOVA) model to test for significant seasonal effects. The one-way ANOVA was structured as a randomized block design, with year acting as a blocking variable. The construction of the resulting model was as follows: model = constant + year + season. The F-ratio for each term was calculated using the remainder or error mean sum of squares (MS) as the denominator.

Year was included as a blocking variable in the ANOVA to account for the potential effects of varying year-to-year flow conditions and other environmental variables on water quality. The effects of these environmental variables, including flow, were assumed to consistent across both seasons. Hence, the exclusion of the interaction term from the two-way ANOVA, and the need to shift year starting dates from January 1st to April 1st. The design of the ANOVA described above follows from randomized block design discussed in Zar (1984) and similar block models discussed in Neter et al. (1990) and Sokal and Rohlf (1995).

Discussions of significant and non-significant effects were limited to those associated with season. Significance related to year was not included, since temporal trends were examined separately using different statistical procedures and are discussed in Section 4.3.1. All of the statistical analysis described above was completed using SYSTAT 10 (SPSS 2000), and identified outliers were removed iteratively until either no outliers remained or until 10% of the data had been excluded.

4.2.3.2 Results and Discussion

At both locations in the Athabasca River, average daily flows were significantly lower in winter than in fall (Tables 4.15 and 4.16). Consequently, concentrations of those parameters that have been shown to be influenced by flow (see Section 4.2.2) generally behaved as expected. Athabasca PC1, TSS and TP levels, for example, were significantly higher in fall, whereas TDS, total alkalinity and sulphate concentrations were significantly higher in winter. Although concentrations of other parameters often followed similar expected trends, significant differences between the seasons were not detected at one or both locations. This may be a reflection of limited statistical power (due to small sample size or large within-season variability) or the result of local influences that were not captured in the general flow relationships derived over a broader scale.

Table 4.15 Comparison of Fall and Winter Water Quality Observed in the Athabasca River Upstream of Fort McMurray

Parameter	Fall			Winter			F Statistic[d]
	Mean[a]	CV[b]	n[c]	Mean[a]	CV[b]	n[c]	
average daily flow	478	8	34	119	7	57	404***
athabasca PC1	-0.37	284	5	-1.10	30	10	15.2*
athabasca PC2	-0.13	597	5	0.53	103	10	0.62
pH	7.9	3	28	7.9	4	46	0.50
dissolved organic carbon	8.0	20	21	8.1	12	53	0.22
sulphate	22.9	11	28	41.9	6	46	194***
total alkalinity	111	4	28	166	3	46	182***
total dissolved solids	157	4	29	248	3	53	166***
total suspended solids	19.6	47	30	2.5	162	56	33.8***
total Kjeldahl nitrogen	0.5	94	24	0.4	62	42	0.18
total phosphorus	0.033	23	30	0.023	20	49	4.39*
total aluminum	0.263	87	6	0.025	30	12	10.7*
total boron	0.032	6	3	0.029	18	5	0.04
total chromium	0.0014	20	11	0.0016	14	23	0.17

(a) Units are mg/L, except for flow (m^3/s), pH (unitless), Athabasca PC1 (unitless) and Athabasca PC2 (unitless).

(b) CV = coefficient of variation, expressed as a percentage.

(c) n = sample size.

(d) * = $p < 0.05$; *** = $p < 0.001$.

Table 4.16 Comparison of Fall and Winter Water Quality Observed in the Athabasca River near Old Fort

Parameter	Fall			Winter			F Statistic[d]
	Mean[a]	CV[b]	n[c]	Mean[a]	CV[b]	n[c]	
average daily flow	581	6	41	176	6	78	575***
Athabasca PC1	-0.04	1825	3	-0.94	16	7	289*
Athabasca PC2	-0.1	460	4	1.03	29	7	7.59
pH	7.8	3	41	7.6	4	74	5.53*
dissolved organic carbon	8.2	23	38	7.8	12	65	4.04*
sulphate	20.6	10	41	32.4	5	74	203***
total alkalinity	104	3	41	142	2	74	319***
total dissolved solids	171	3	40	255	2	73	252***
total suspended solids	23.3	32	43	4.2	84	75	56.6***
total Kjeldahl nitrogen	0.5	86	37	0.5	56	64	0.16
total phosphorus	0.043	16	40	0.031	8	75	23.0***
total aluminum	0.296	124	10	0.043	32	11	3.93
total boron	0.025	29	6	-	-	0	-
total chromium	0.0015	16	15	0.0015	14	20	0.01

(a) Units are mg/L, except for flow (m^3/s), pH (unitless), Athabasca PC1 (unitless) and Athabasca PC2 (unitless).

(b) CV = coefficient of variation, expressed as a percentage.

(c) n = sample size.

(d) * = $p < 0.05$; *** = $p < 0.001$.

In the Muskeg River, average daily flows were significantly lower in winter compared to fall (Table 4.17). Major ions, as represented by Tributary PC2, total alkalinity and TDS were significantly higher in winter, as would be expected based on the influence flow exhibits on these parameters (see Section 4.2.2). Sulphate and total boron concentrations were also higher in winter than in fall, although seasonal differences were not significant. Concentrations of the remaining parameters did not behave as would be expected based on their relationship to flow. DOC and pH levels were significantly lower in winter, whereas TSS and TP concentrations were significantly lower in the fall. These non-flow conforming results are likely a reflection of local influences that were not adequately captured in the general flow relationships developed using data from all of the Athabasca River tributaries.

Table 4.17 Comparison of Fall and Winter Water Quality Observed in the Lower Muskeg River Between Jackpine Creek and the River Mouth

Parameter	Fall			Winter			F Statistic[d]
	Mean[a]	CV[b]	n[c]	Mean[a]	CV[b]	n[c]	
average daily flow	2.56	162	28	0.58	164	33	83.3***
Tributary PC1	-1.4	39	5	-0.45	87	4	3.69
Tributary PC2	0.24	92	5	0.86	21	4	13.8*
pH	7.8	3	25	7.6	5	32	5.53*
dissolved organic carbon	22	9	19	19	8	36	8.93*
sulphate	6.2	86	25	6.8	56	32	3.81
total alkalinity	173	7	26	252	4	30	62.1***
total dissolved solids	223	9	26	312	4	31	32.9***
total suspended solids	2.6	59	22	4.6	53	41	16.2***
total Kjeldahl nitrogen	0.8	224	18	1.3	114	25	27.1***
total phosphorus	0.025	13	22	0.038	12	27	15.5***
total aluminum	0.033	22	9	0.066	31	6	0.23
total boron	0.036	16	10	0.05	7	7	1.54
total chromium	0.0006	19	10	0.0015	20	8	2.85

(a) Units are mg/L, except for flow (m^3/s), pH (unitless), Tributary PC1 (unitless) and Tributary PC2 (unitless).
(b) CV = coefficient of variation, expressed as a percentage.
(c) n = sample size.
(d) * = p < 0.05; *** = p < 0.001.

Clearly, significant seasonal variations exist between fall and winter water flows and water quality. The magnitude of change ranges, on average, from < 3 to > 900 %.

In the past, routine water quality monitoring completed by RAMP has been conducted in the fall for the following reasons:

- RAMP benthic and sediment sampling both occur in the fall. Coordination of the three sampling programs is both cost-efficient and allows for a complete water, sediment and benthic data set from the same season.
- Mine water releases, including muskeg and overburden dewatering and end pit lake outflows, are projected to be highest during the open water season, which includes the fall.
- Winter water quality sampling can be more problematic than fall sampling, because of increased health and safety issues related to exposure, travel (e.g., ice roads) and working over ice, as well as increased risk of sample spoilage as a result of freezing during both sample collection and transport.

As detailed in recent EIAs (Shell 1997; TrueNorth 2001; Golder and Cantox 2002), future mine water releases will include seepage from external facilities and in-pit deposits. These waters are expected to flow year-round, and they will day-light, at least in part, in smaller tributaries which may or may not be receiving overland discharge, suggesting that additional winter monitoring by RAMP may be prudent.

4.2.3.3 Conclusions and Recommendations

Statistically significant seasonal variation between fall and winter water quality in the lower Athabasca River watershed was observed. Water flows in winter have historically been significantly lower than those recorded in fall, and potential process-affected mine waters will likely day-light year-round in the smaller streams and rivers sometime in the future. As a result, it is recommended that the RAMP Water and Sediment Subgroup of the Technical Subcommittee consider additional winter sampling in areas experiencing a high level of development. Adding winter sampling to the existing fall sampling will preserve the advantages of the fall sampling identified in Section 4.2.3.3. Additional winter sampling should be considered under the following conditions:

- relevant EIAs have shown that they are or will be receiving seepage input; and
- existing operators are not already collecting sufficient winter data as part of their approval requirements.

An instream loading analysis is also recommended. This modelling would be waterbody specific. It would include an examination of parameter loading rates under winter and fall conditions, with the goal of establishing the season in which the largest changes in instream loading rates and, consequently, instream concentrations are expected to occur.

4.3 DETECTING AND ASSESSING REGIONAL TRENDS

4.3.1 Temporal Trends

As outlined in Section 4.1.3.2, the investigation into temporal trends in the water quality data set included an examination of long-term (i.e., 1976 to 2001) and short-term (i.e., 1997 to 2001) temporal variability observed at several locations within the Athabasca and Muskeg rivers, respectively. The two long-term, Athabasca River sites are situated upstream of Fort McMurray and near Old Fort. The two short-term, Muskeg River sites are located upstream of Muskeg Creek and in the lower section of the Muskeg River between Jackpine Creek and the river mouth.

The short-term locations within the Muskeg River were selected, because they are upstream and downstream, respectively, of current oil sands development in this watershed. Similarly, the two long-term locations situated in the Athabasca River are positioned upstream and downstream of current oil sands development in that basin.

4.3.1.1 Methods

The non-parametric Seasonal-Kendall test for trend was used in combination with Sen's slope estimation procedure (Gilbert 1987) to determine both the magnitude and potential significance of apparent temporal trends observed in the data collected from the four locations listed above. When significant temporal trends were observed, concentrations were adjusted to account for variations in flow over time following the methods outlined by IDT (1998). The analysis was then repeated to determine if changes in water flow were primarily responsible for the observed temporal trend. Both the flow adjustments and the Seasonal-Kendall analyses were completed using WQStat Plus (IDT 1998).

Relevant water quality data were taken from the water quality data set described in Section 4.2.1.1 - Data Origin and Initial Processing and modified as necessary to meet the input requirements of WQStat Plus. These modifications included back-transforming the data from log units to the original measured values and, for the purposes of flow adjustment, limiting the data set to one reading per calendar day per location. In the few instances where more than one sample had been collected on a given day for a given location, data were reduced either through random selection or, in cases of unequal analysis, by choosing the sample that had been submitted for the more complete analysis.

Flow adjustments were made using relevant average daily data from Golder (2002d) and AENV (2002b). Where necessary, available flow information for the Muskeg River was supplemented with modelled flow data developed using the HSPF model described in Shell (2002). Parameters considered in both the long-term and short-term temporal analyses were the same as those discussed in Sections 4.2.2 and 4.2.3. Unfortunately, insufficient samples were available to examine all parameters at all locations, resulting in, among others, the omission of total boron, Athabasca PC1 and Athabasca PC2 from the analysis of temporal variations near Old Fort.

4.3.1.2 Results and Discussion

Athabasca River

Significant temporal variations were observed in the Athabasca River upstream of Fort McMurray (Table 4.18). Total alkalinity, TDS and sulphate concentrations have increased over time, whereas DOC, TSS, TKN and total chromium concentrations have decreased over time. Concentrations of four of the seven parameters continued to follow significant temporal trends after adjusting for variations in flow, including those observed for sulphate, DOC, TKN and total chromium (Table 4.19). Flow adjusted, sulphate and TKN trends are illustrated in Figures 4.12 and 4.13, respectively.

Near Old Fort, the concentrations of three parameters, sulphate, pH and TKN, were found to be significantly increasing or decreasing over time (Table 4.18). After adjusting for variations in flow, only the trends observed in pH and TKN levels were significant, with concentrations of both parameters decreasing over time (Table 4.19). These trends are illustrated in Figures 4.14 and 4.15, respectively.

The rate at which TKN levels declined near Old Fort was slightly less than that observed upstream of Fort McMurray (i.e., -0.014 versus -0.017 mg/L per year - Table 4.19). The rate of decline in pH levels near Old Fort was estimated to be -0.008 pH units/year. As illustrated in Figure 4.14, this represents a slow rate of decline, whereby the difference between pH levels measured in 1977 and 2001 would, on average, differ by < 0.2 pH units.

Table 4.18 Summary of Temporal Trends Observed in the Athabasca River Upstream of Fort McMurray and near Old Fort Prior to Flow Adjustment (1976 to 2001)

Parameter	Upstream of Fort McMurray[a]			Near Old Fort[a]		
	Sen's slope[b]	n[c]	Z Statistic[d]	Sen's slope[b]	n[c]	Z Statistic[d]
Athabasca PC1	-0.052	31	1.76	-	-	-
Athabasca PC2	-0.051	31	-1.52	-	-	-
pH	0	139	0.11	-0.008	182	-2.20*
dissolved organic carbon	-0.100	132	-3.05*	-0.006	163	-0.31
sulphate	0.452	139	6.15*	0.134	184	2.09*
total alkalinity	0.629	143	3.74*	0.052	184	0.43
total dissolved solids	1.80	151	4.20*	0.579	182	1.67
total suspended solids	-0.241	155	-3.50*	-0.012	184	-0.36
total Kjeldahl nitrogen	-0.018	120	-5.12*	-0.013	162	-4.34*
total phosphorus	-0.356	145	-1.21	0	181	0.08
total aluminum	0	35	0.10	-35.4	36	0.57
total boron	-	-	-	-	-	-
total chromium	-0.254	62	-5.09*	-0.020	54	0.93

(a) - = less than four samples were available for one or more of the four seasons included in the analysis.

(b) Units are mg/L per year for DOC, sulphate, total alkalinity, TDS, TSS and TKN;
μg/L per year for TP, total aluminum, boron and chromium; and
units per year for pH, Athabasca PC1 and Athabasca PC2.

(c) n = sample size.

(d) * = $p < 0.05$.

Table 4.19 Summary of Temporal Trends Observed in the Athabasca River Upstream of Fort McMurray and near Old Fort After Adjusting for Variations in Water Flow (1976 to 2001)

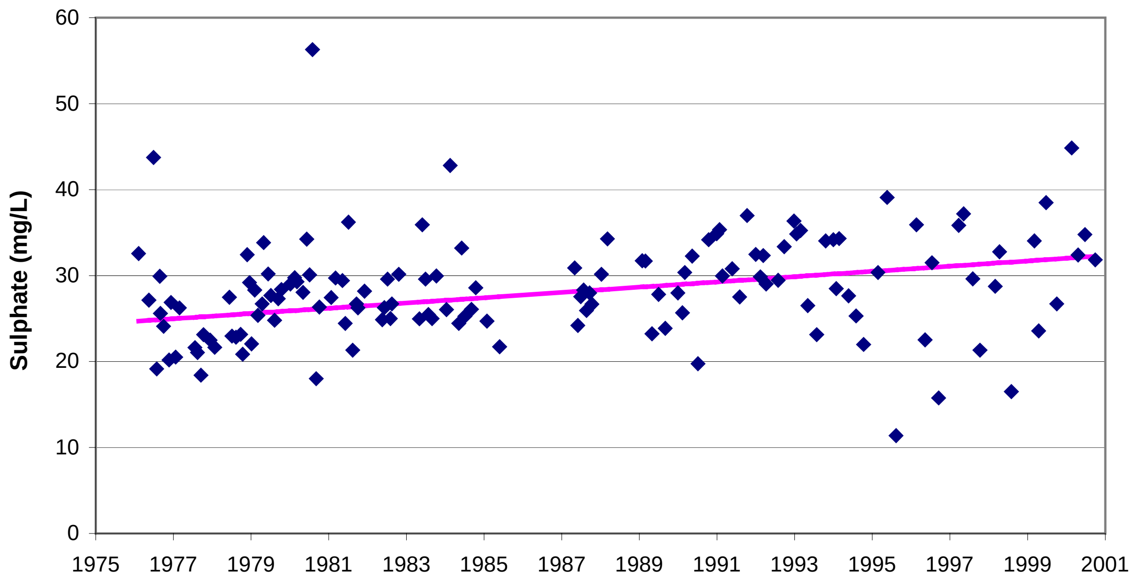
Parameter	Upstream of Fort McMurray			Near Old Fort		
	Sen's slope[a]	n[b]	Z Statistic[c]	Sen's slope[a]	n[b]	Z Statistic[c]
pH	0	139	0.11	-0.008	182	2.13*
dissolved organic carbon	-0.092	132	-2.87*	-0.006	163	0.20
sulphate	0.305	139	4.13*	0.065	184	1.74
total alkalinity	-0.049	143	-0.31	-0.004	184	0.04
total dissolved solids	0.557	151	1.75	0.299	182	1.21
total suspended solids	-2.45	155	-1.45	0.158	184	0.78
total Kjeldahl nitrogen	-0.017	120	-4.36*	-0.014	162	4.47*
total chromium	-0.239	62	-4.95*	-0.100	54	0.71

(a) Units are mg/L per year for DOC, sulphate, total alkalinity, TDS, TSS and TKN;
μg/L per year for total chromium; and
units per year for pH.

(b) n = sample size.

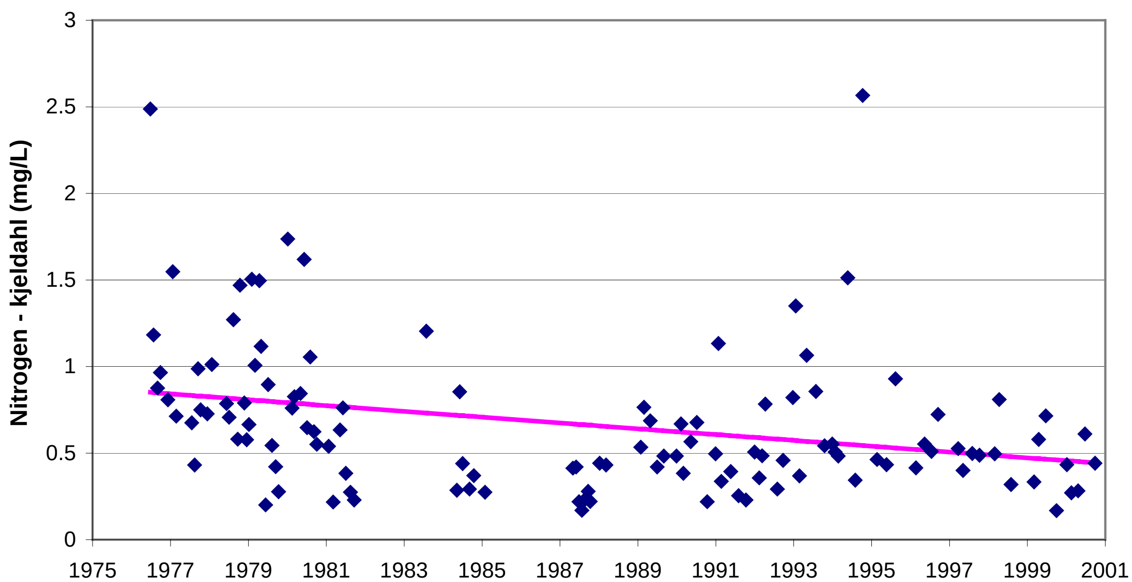
(c) * = $p < 0.05$.

Figure 4.12 Temporal Variations in Sulphate Concentrations Observed in the Athabasca River Upstream of Fort McMurray



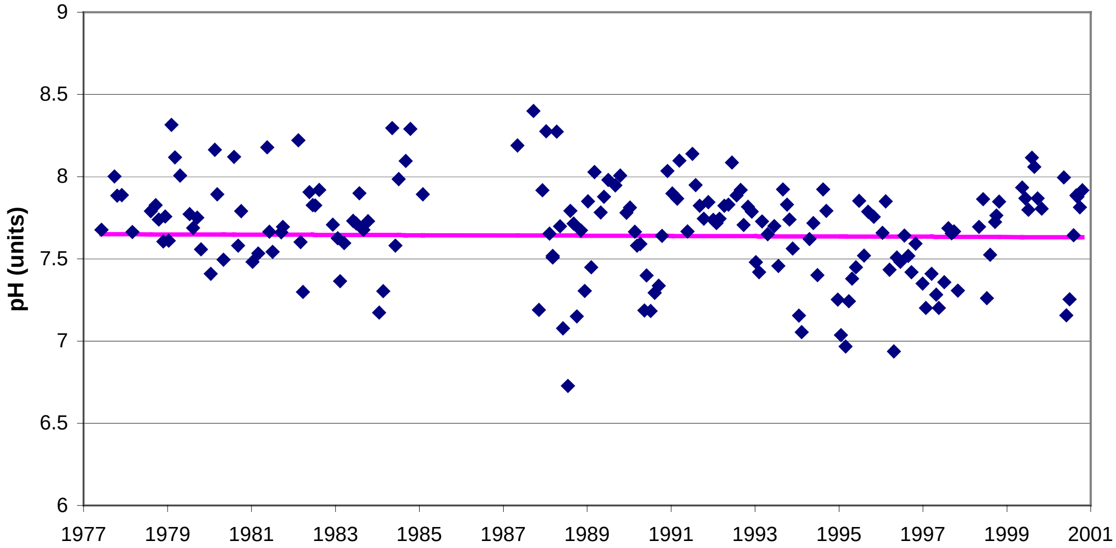
Note: Concentrations have been adjusted to account for variations in flow following the methods outlined in IDT (1998).

Figure 4.13 Temporal Variations in Total Kjeldahl Nitrogen (TKN) Concentrations Observed in the Athabasca River Upstream of Fort McMurray



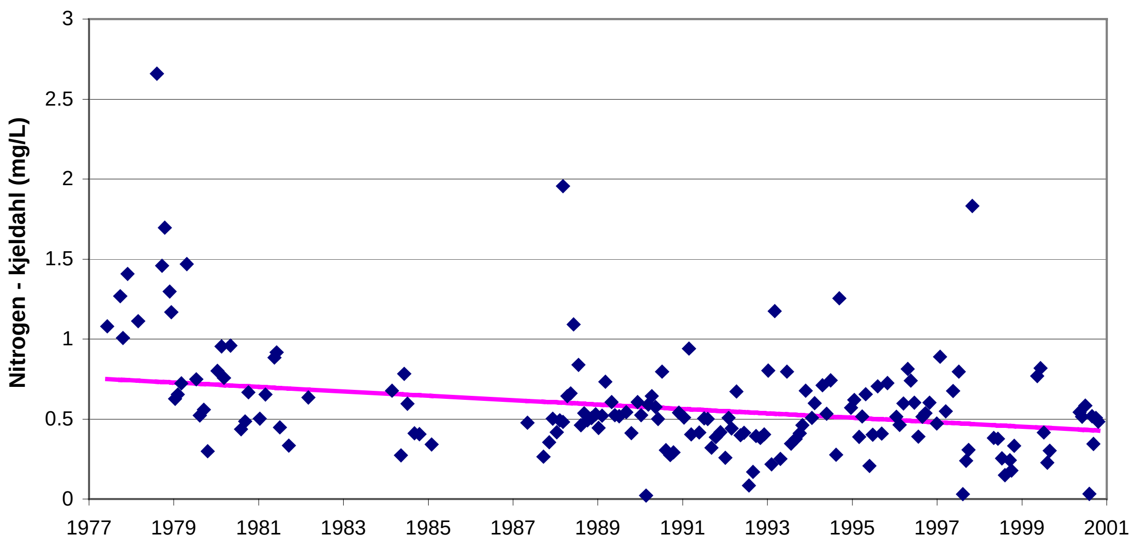
Note: Concentrations have been adjusted to account for variations in flow following the methods outlined in IDT (1998).

Figure 4.14 Temporal Variations in pH Levels Observed in the Athabasca River near Old Fort



Note: Concentrations have been adjusted to account for variations in flow following the methods outlined in IDT (1998).

Figure 4.15 Temporal Variations in Total Kjeldahl Nitrogen (TKN) Concentrations Observed in the Athabasca River near Old Fort



Note: Concentrations have been adjusted to account for variations in flow following the methods outlined in IDT (1998).

Muskeg River

The concentrations of three parameters varied significantly over time in the Muskeg River (Table 4.20). Upstream of Muskeg Creek, TP and total chromium concentrations appear to have significantly increased between 1997 and 2001. In the lower section of the Muskeg River, TP and DOC concentrations were also found to have significantly increased since 1997. However, after variations in water flow were taken into account, the only significant temporal trend observed was increasing total chromium levels upstream of Muskeg Creek (Table 4.21).

AENV (2002a) indicated that pH levels in the lower portion of the Muskeg River have significantly decreased since 1997. This was demonstrated using both discrete data and continuous monitoring information. The discrete data, comparable to those used herein, were analyzed using a linear regression, whereas the continuous monitoring information was analyzed using a Seasonal-Kendall procedure.

Although not statistically significant, a negative trend in pH levels was observed herein, with an estimated rate of decline of -0.068 pH units/year (Table 4.20). As discussed in Gilbert (1987), regression analysis may yield erroneous results when applied to data that exhibit distinct seasonal variations, as is the case with pH levels in the Muskeg River (see Table 4.17). The variation in statistical significance observed between the present study and AENV (2002a) may, therefore, result from the use of different statistical test procedures.

The significant result obtained by AENV (2002a) when using the continuous pH monitoring information likely reflects increased statistical power related to a larger sample size. However, the relevance of this finding requires further study for the following reasons:

- A similar, albeit non-significant, decreasing trend in pH can also be observed in the Muskeg River upstream of Muskeg Creek (Table 4.20).
- The Seasonal-Kendall analysis reported by AENV (2002a) did not include an assessment of the potential influence of flow on the observed pH trend.
- Continuous monitoring data are, by their nature, serially correlated and not truly independent of one another. As outlined in Gilbert (1987), serial correlations within a data set can affect the validity of a Seasonal-Kendall analysis.

Table 4.20 Summary of Temporal Trends Observed in the Muskeg River Upstream and Downsteam of Development Prior to Flow Adjustment (1997 to 2001)

Parameter	Upstream of Muskeg Creek[a]			Between Jackpine Creek and the Mouth of the Muskeg River[a]		
	Sen's slope[b]	n[c]	Z Statistic[d]	Sen's slope[b]	n[c]	Z Statistic[d]
Tributary PC1	-	-	-	0.336	17	1.63
Tributary PC2	-	-	-	-0.047	17	-0.33
pH	-0.037	22	-0.46	-0.068	35	-1.46
dissolved organic carbon	0.403	29	0.66	2.83	41	3.63*
sulphate	-0.217	26	-1.48	-0.631	35	0.34
total alkalinity	6.15	18	0.97	5.59	35	0.73
total dissolved solids	-5.58	26	-0.29	-38.0	32	-1.29
total suspended solids	-0.532	36	-1.89	-0.698	48	-1.76
total Kjeldahl nitrogen	-	-	-	0.105	18	1.78
total phosphorus	21.4	24	3.17*	145	29	2.42*
total aluminum	-3.15	26	-0.42	-17.0	30	-1.13
total boron	-	-	-	0	30	0.36
total chromium	0.102	25	1.96*	0.102	30	1.28

(a) - = less than four samples were available for one or more of the four seasons included in the analysis.

(b) Units are mg/L per year for DOC, sulphate, total alkalinity, TDS, TSS and TKN;
μg/L per year for TP, total aluminum, boron and chromium; and
units per year for pH, Tributary PC1 and Tributary PC2.

(c) n = sample size.

(d) * = $p < 0.05$.

Table 4.21 Summary of Temporal Trends Observed in the Muskeg River Upstream and Downsteam of Development After Adjusting for Variations in Water Flow (1997 to 2001)

Parameter	Upstream of Muskeg Creek			Between Jackpine Creek and the Mouth of the Muskeg River		
	Sen's slope[a]	n[b]	Z Statistic[c]	Sen's slope[a]	n[b]	Z Statistic[c]
dissolved organic carbon	-0.069	27	-0.63	1.21	38	1.57
total phosphorus	18.9	19	1.38	9.86	26	1.93
total chromium	0.336	19	2.46*	0.172	27	1.90

(a) Units are mg/L per year for DOC, and μg/L per year for TP and total chromium.

(b) n = sample size; sample sizes listed herein may be smaller than those listed in Table 4.20, because of a lack of flow information and/or the need to reduce the data set to include only one sample per calendar day per season.

(c) * = $p < 0.05$.

4.3.1.3 Conclusions and Recommendations

Based on the long-term temporal analysis completed using data collected from the Athabasca River upstream of Fort McMurray and near Old Fort, cumulative development located downstream of Fort McMurray has not resulted in the degradation of water quality within this stretch of the river since its initiation in the mid to late 1970s. Similarly, with the possible exception of pH, development within the Muskeg River watershed has not resulted in significant temporal variations in water quality in the lower sections of the Muskeg River since the initiation of RAMP in 1997.

For the reasons outlined in Section 4.3.1.2, it is recommended that the continuous pH monitoring data described in AENV (2002a) be further analyzed to determine if the significant decline in pH levels reported in AENV (2002a) is the result of flow variation, natural variability or human development.

4.3.2 Spatial Trends

As described in Section 4.1.3.2, the investigation into spatial trends in the water quality data set included a discussion of general patterns within the lower Athabasca River watershed as a whole, as well as an examination of potentially significant variations along the length of the Athabasca River and within the Muskeg River watershed. Specific attention was focused on comparing water quality observed upstream and downstream of existing oil sands development along the Muskeg and Athabasca rivers.

4.3.2.1 Methods

General Patterns in the Oil Sands Region

General spatial patterns were examined using ordination plots derived from two of three PCAs described in Section 4.2.1 (i.e., the overall and Athabasca River tributary PCAs). The resolution used in this analysis was limited to four categories that included the Athabasca River mainstem, Athabasca River tributaries, Muskeg River watershed and the four wetlands sampled by RAMP (i.e., Shipyard, Isadore's, Kearl and McClelland lakes).

Trends in the Athabasca River

Ordination plots derived from the Athabasca River PCA were used to examine spatial variations along the length of the river. Specific comparisons of water quality upstream and downstream of oil sands development in the lower Athabasca River were completed using data collected upstream of Fort

McMurray and near Old Fort in a one-way, randomized block design ANOVA. The ANOVA included location as fixed factor, with season and year as blocking variables. The construction of the resulting model was as follows: model = constant + location + year + season. The F-ratio for each term was calculated using the remainder or error MS as the denominator.

As in previous analyses (see Section 4.2.3.1), year was included as a blocking variable in the ANOVA to account for the potential effects of varying year-to-year flow conditions and other environmental variables on water quality. Season was similarly included to account for seasonal variations known to occur in Athabasca River water quality (see Section 4.2.3.2). Seasonal and year-to-year effects were assumed to be consistent across both locations. Hence, the exclusion of interaction terms from the three-way ANOVA. The design of the ANOVA described above is similar to block models discussed in Neter et al. (1990) and Sokal and Rohlf (1995).

Consistent with previous RAMP reports and recent EIAs (Shell 1997; TrueNorth 2001; Shell 2002), fall was defined as running from September 1 to October 31. Winter started November 1 and continued to March 31. Summer encompassed the period from June 1 to August 31, and spring was defined as running from April 1 to May 31. For the purposes of this analysis, the assumed start date for each year was set to April 1. This shift in yearly start date was done so that all of the data collected within a given year had experienced the same annual hydrologic cycle.

Although year and season were included in the ANOVA, discussions of significant and non-significant effects were limited to those associated with location. Significance related to year was not included, since temporal trends were examined separately using different statistical procedures and are discussed in Section 4.3.1. Similarly, the presence of significant seasonal effects has already been discussed in Section 4.2.3. All of the statistical analysis described above was completed using SYSTAT 10 (SPSS 2000), and identified outliers were removed iteratively until either no outliers remained or 10% of the data had been excluded. Parameters considered in the upstream-downstream analysis included the same 13 water quality parameters discussed in Section 4.3.1.

Trends in the Muskeg River

Spatial trends in the Muskeg River were examined by comparing instream water quality observed upstream and downstream of oil sands development in the basin using data collected upstream of Muskeg Creek, and between Jackpine Creek and the river mouth. Since data are available prior to the initiation of development in 1998, an extension of the Athabasca ANOVA was used to complete these comparisons. In this case, the construction of the ANOVA was as follows: model = constant + season + location + timing + timing*location + year (timing), wherein

- location was a fixed with-year factor;
- timing (i.e. before or after spring 1998) was a fixed between-year factor;
- year and season were random factors; and
- the F-ratio for each term was calculated using the remainder or error MS as the denominator.

This design is similar to the split-plot ANOVAs described by Hicks (1973), with year being equivalent to the plots. As before, season and year were included as blocking variables to account for seasonal and year-to-year effects, which were assumed to be consistent across both locations. Hence, the exclusion of any interaction terms involving season and/or year from the ANOVA.

Start and end dates for each season were the same as those used in the Athabasca River analysis, and the assumed start date for each year was again set to April 1. Eleven of the 13 parameters discussed in Section 4.3.1 were considered. The two excluded parameters, PC1 and PC2, were dropped, because insufficient pre-1998 data were available.

Discussions of significant and non-significant effects were limited to those associated with location, timing and the interaction term timing*location. Significance related to year was not included, since temporal trends were examined separately using different statistical procedures and are discussed in Section 4.3.1. Similarly, the presence of significant seasonal effects has already been discussed in Section 4.2.3. When significant interaction between timing and location was observed, post-hoc Tukey tests were used to identify the significantly different pairs.

All of the statistical analysis described above was completed using SYSTAT 10 (SPSS 2000), and identified outliers were removed iteratively until no outliers remained, 10% of the data set had been excluded or further removal would require reduction of the ANOVA (i.e., insufficient data would be available to complete the required calculations).

4.3.2.2 Results and Discussion

General Patterns in the Oil Sands Region

As illustrated in Figures 4.16 and 4.17, water quality in the Athabasca River was generally different from that observed in the Athabasca River tributaries, including the Muskeg River watershed, and the four wetlands (i.e., Shipyard, Kearl, Isadore’s and McClelland lakes). Metal levels and TSS concentrations, as represented by Overall PC1, tended to be higher in the Athabasca River than in the other waterbodies sampled by RAMP (Figure 4.16). Less variability in TDS and major ion levels, as represented by Overall PC2, was observed in the Athabasca River. Samples taken from this river also exhibited a positive, linear correlation between Overall PC1 and Overall PC3 (Figure 4.17). This correlation is indicative of the fact that, as previously discussed, the colour of the river (Overall PC3) is a function of its suspended sediment content (which is represented by Overall PC1). Similar correlations were not apparent in the other sampled waterbodies.

In comparison to the other Athabasca River tributaries sampled by RAMP, total metal concentrations, as represented by Tributary PC1 tended to be lower in the Muskeg River (Figure 4.18). However, concentrations of major ions, TSS, pH, TP and other parameters represented by Tributary PC2 and Tributary PC3 were generally comparable between the Muskeg River and other Athabasca River tributaries (Figures 4.18 and 4.19).

With respect to the four wetlands, the water quality characteristics of McClelland and Kearl lakes, in terms of metals, TSS and major ion levels, tended to be unique in comparison to each other and to the other two lakes (i.e., Isadore’s and Shipyard lakes - Figure 4.20). In contrast, concentrations of total and dissolved metal, TSS, major ions and other parameters represented by Overall PC1 and Overall PC2 were similar in Isadore’s and Shipyard lakes. Greater overlap among the four wetlands occurred with respect to colour levels and the concentration of other parameters associated with Overall PC3 (Figure 4.21).

Figure 4.16 Plot of Overall PC1 Against Overall PC2 Including Water Quality Samples Collected Over the Entire RAMP Study Area

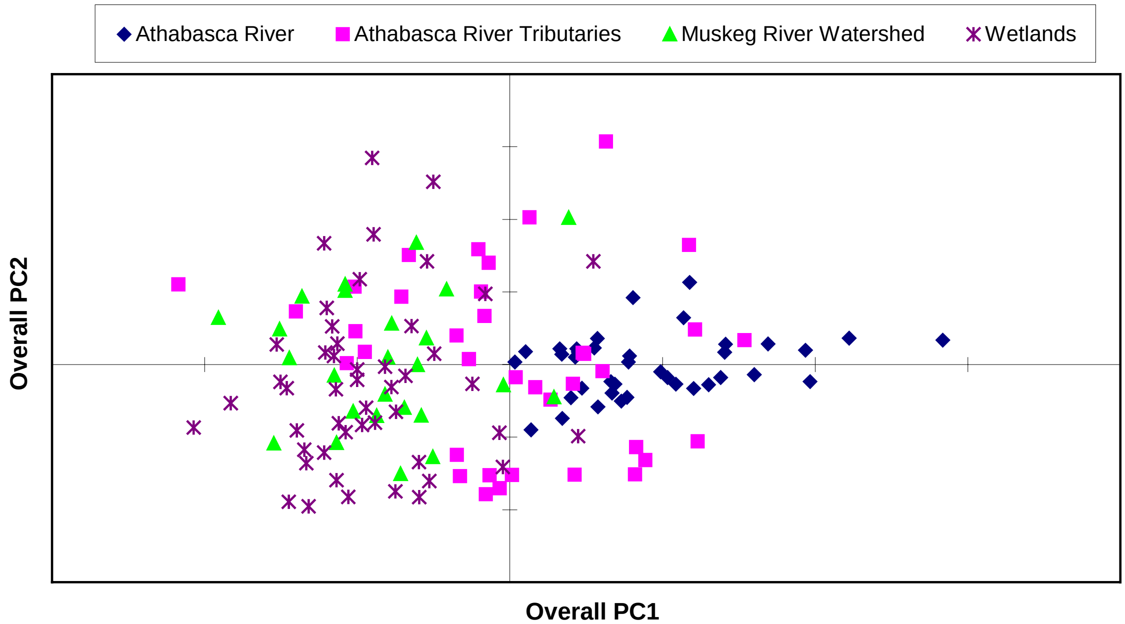


Figure 4.17 Plot of Overall PC1 Against Overall PC3 Including Water Quality Samples Collected Over the Entire RAMP Study Area

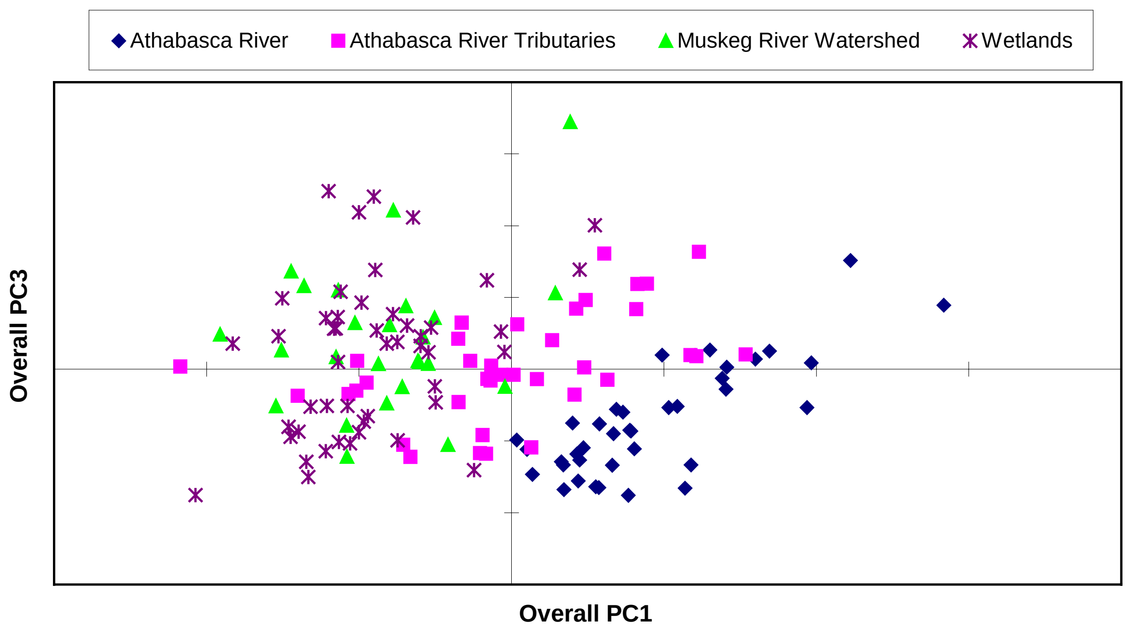


Figure 4.18 Plot of Tributary PC1 Against Tributary PC2 Including Water Quality Samples Collected from Athabasca River Tributaries, including the Muskeg River

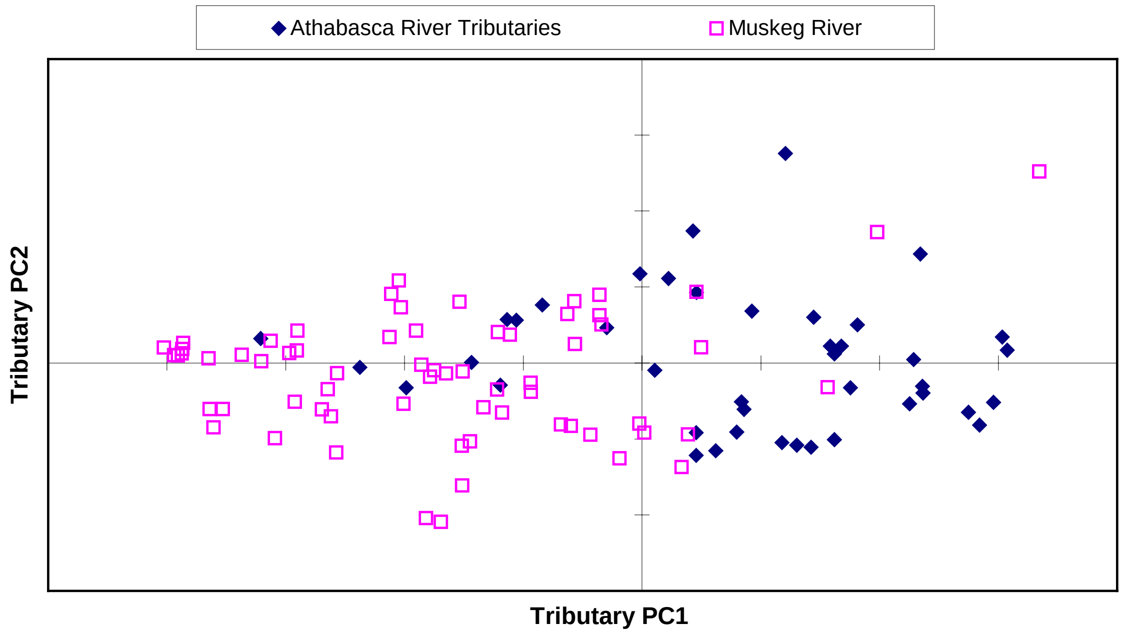


Figure 4.19 Plot of Tributary PC1 Against Tributary PC3 Including Water Quality Samples Collected from Athabasca River Tributaries, including the Muskeg River

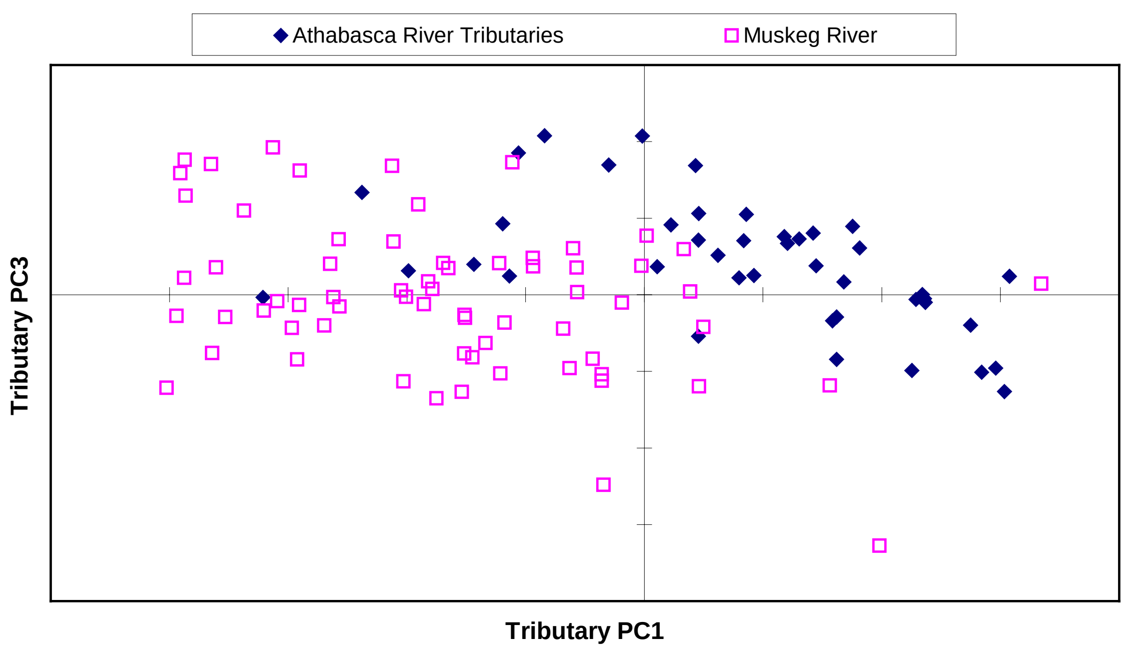


Figure 4.20 Plot of Overall PC1 Against Overall PC2 Including Water Quality Samples Collected from Shipyard, Isadore's, Kearl and McClelland Lakes

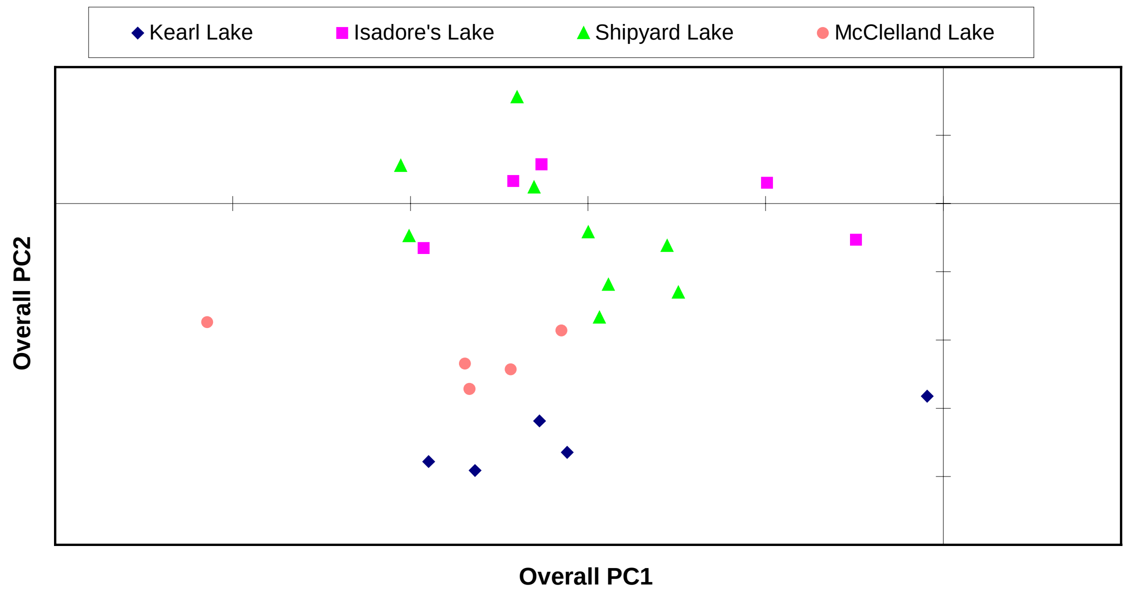
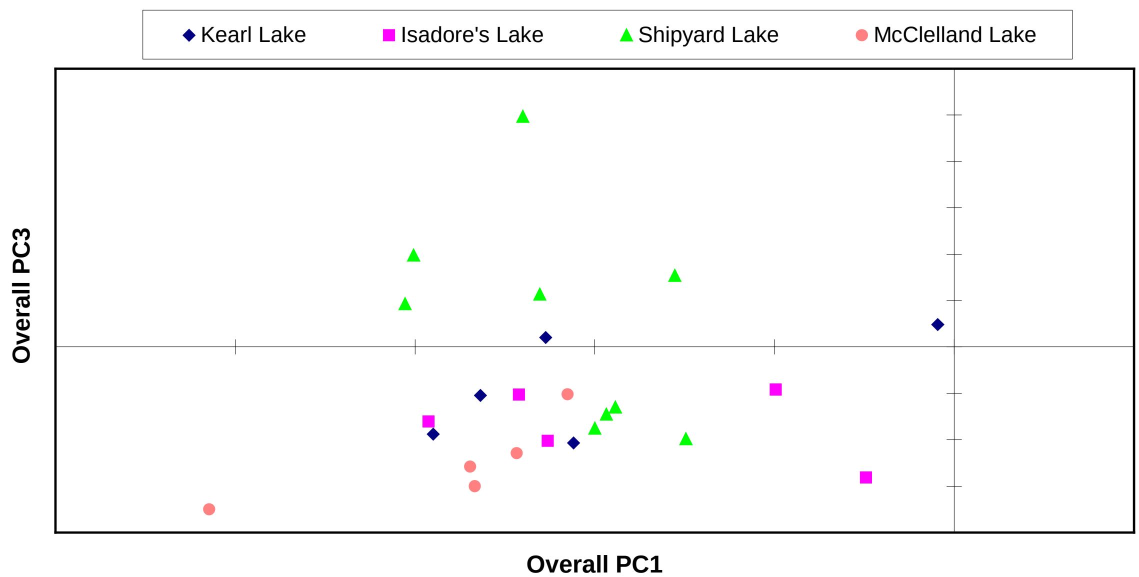


Figure 4.21 Plot of Overall PC1 Against Overall PC3 Including Water Quality Samples Collected from Shipyard, Isadore's, Kearl and McClelland Lakes



Trends in the Athabasca River

Based on the ordination plots produced from the Athabasca River PCA (Figures 4.22 and 4.23), no distinct spatial patterns in water quality were observed along the length of the Athabasca River. Nor were statistically significant differences identified in the upstream-downstream comparisons with reference to Athabasca PC1 and Athabasca PC2 (Table 4.22). However, significant differences were observed when comparing pH, sulphate, total alkalinity, TSS, and TP concentrations measured in samples collected upstream of Fort McMurray with those taken near Old Fort[5].

Total alkalinity, sulphate and pH levels were higher upstream of Fort McMurray than near Old Fort, whereas TSS and TP concentrations were higher near Old Fort (Table 4.22). With respect to pH, the difference between the two locations was, on average, only 0.2 pH units. The differences observed between average concentrations of the other four parameters were also small in magnitude, ranging from 0.003 mg/L for TP to 8 mg/L for total alkalinity. These minor changes in water quality within the Athabasca River downstream of Fort McMurray likely have little or no ecological significance.

Table 4.22 Comparison of Instream Water Quality Observed in the Athabasca River Upstream of Fort McMurray and Near Old Fort (1976 to 2001)

Parameter	Upstream of Fort McMurray			Near Old Fort			F Statistic[(d)]
	Mean[(a)]	CV[(b)]	n[(c)]	Mean[(a)]	CV[(b)]	n[(c)]	
Athabasca PC1	-0.074	1397	31	-0.070	1286	19	0.78
Athabasca PC2	0.254	236	31	0.552	134	18	2.31
pH	7.9	3	140	7.7	4	191	45.3***
dissolved organic carbon	8.3	19	129	8.6	18	171	2.43
sulphate	25.8	13	140	23.2	12	191	62.0***
total alkalinity	120	6	143	112	5	191	70.2***
total dissolved solids	178	6	149	189	6	187	0.75
total suspended solids	19.7	72	154	20.4	60	194	4.68*
total Kjeldahl nitrogen	0.54	103	120	0.52	78	166	2.43
total phosphorus	0.052	36	143	0.055	29	190	8.87*
total aluminum	0.245	145	35	0.240	122	39	0.10
total boron	0.029	12	13	0.022	27	13	0.26
total chromium	0.0023	18	62	0.0024	19	64	0.88

(a) Units are mg/L, except for flow (m^3/s), pH (unitless), Athabasca PC1 (unitless) and Athabasca PC2 (unitless).
(b) CV = coefficient of variation, expressed as a percentage.
(c) n = sample size.
(d) F statistic corresponding to the location term in the ANOVA; * = $p < 0.05$; ** = $p < 0.01$; *** = $p < 0.001$.

[5] Although total alkalinity, TSS, sulphate and TP were correlated with either Athabasca PC1 or Athabasca PC2, sample numbers were larger in the individual parameter comparisons than in the comparisons involving either of the Athabasca PCs (see Table 4.22), allowing for increased statistical power. Hence, the variation in significance between the two sets of tests.

Figure 4.22 Plot of Athabasca PC1 Against Athabasca PC2 with Samples Grouped by Reach

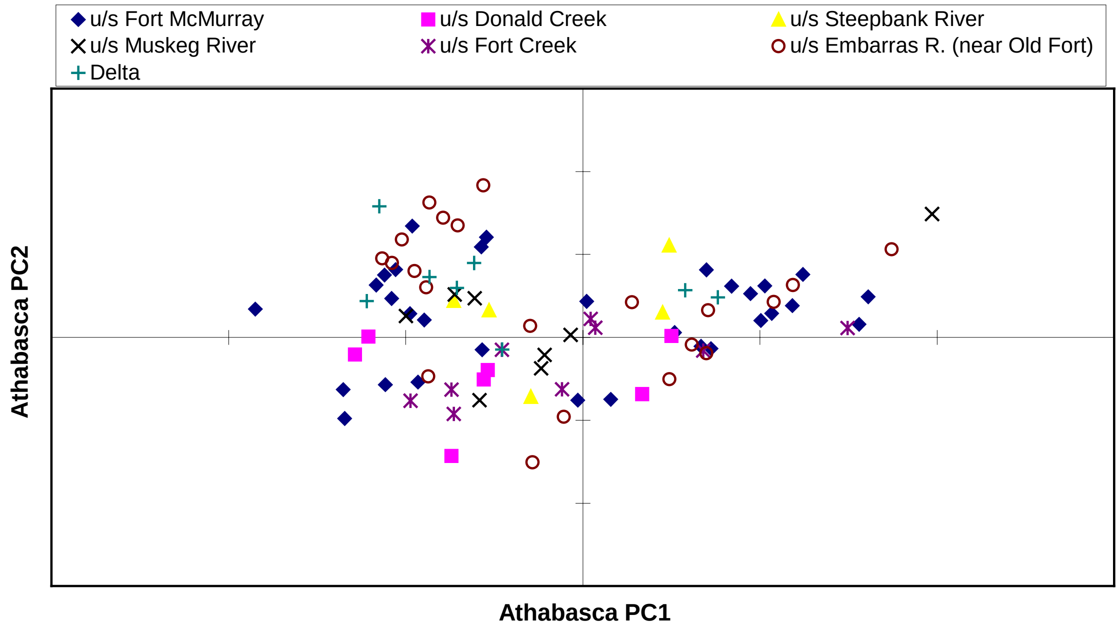
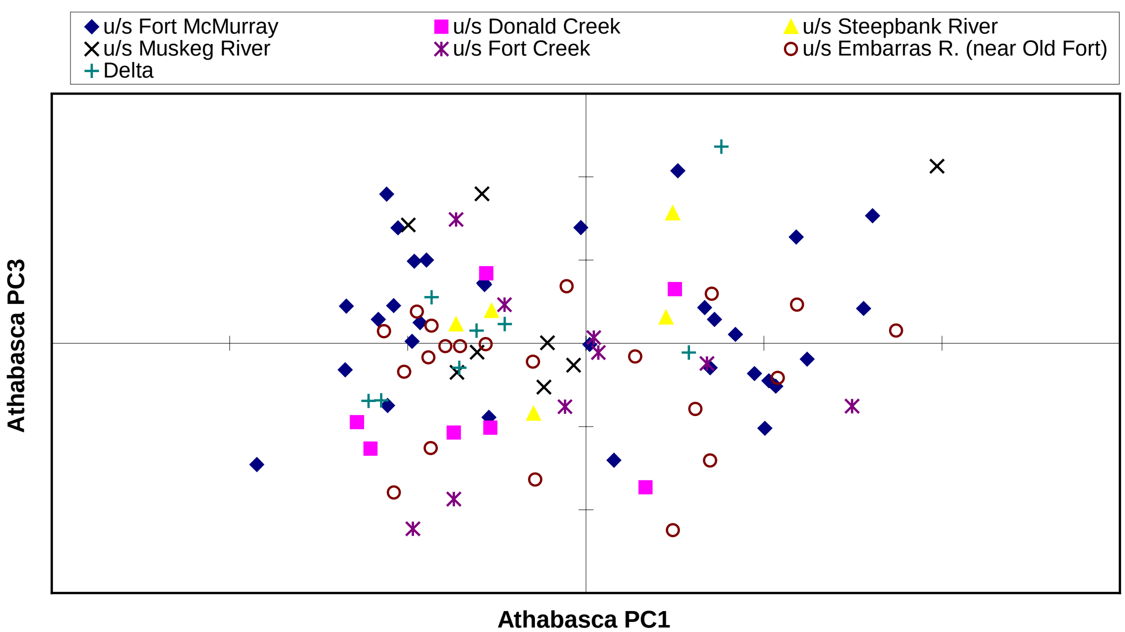


Figure 4.23 Plot of Athabasca PC1 Against Athabasca PC3 with Samples Grouped by Reach



Trends in the Muskeg River

The concentrations of four of the 11 parameters included in the Muskeg River spatial trend analysis were found to vary significantly by location (Table 4.23). Sulphate, total aluminum and total boron levels were consistently higher in the lower section of the river in comparison to upstream of Muskeg Creek, both before and after the initiation of oil sands development in the basin (discharge of dewatering waters from Aurora North began in April 1998). In contrast, total phosphorus concentrations have been consistently higher upstream of Muskeg Creek than in the lower section of the river.

At both locations, TP concentrations recorded since April 1, 1998, were significantly higher than those observed prior to that date (Table 4.23). Total alkalinity, TDS and sulphate levels measured at both locations after April 1, 1998, were also significantly higher than those recorded in previous years. Total chromium concentrations have followed the opposite trend; samples collected prior to April 1, 1998, contained higher total chromium concentrations than those collected since, although this may be a reflection of increased analytical accuracy.

Three significant interactions between location and timing were produced in the analysis, relating to total boron, total chromium and sulphate concentrations (Table 4.23). Post-hoc Tukey testing revealed that sulphate concentrations downstream of development have significantly increased since April 1, 1998 (Table 4.24). The other two significant interaction effects were related to site-specific variations prior to April 1, 1998.

Four tributaries drain to the Muskeg River between the upstream and downstream locations used in the spatial assessment. They include Muskeg Creek, Shelley Creek, Jackpine Creek and the Alsands Drain (Figure 4.1). No development has yet occurred in the Jackpine, Shelley or Muskeg Creek watersheds. The Alsands Drain has, however, been receiving muskeg drainage and overburden dewatering water from Aurora North and the MROSP since mid-1998 and early-1999, respectively. These waters currently flow through Pond 2, which is located within the MROSP, prior to discharge to the Alsands Drain.

Sulphate concentrations in the Alsands Drain were far higher than those in the other three tributaries (Figure 4.24). They also appear to have increased since the initiation of development within the basin (Figure 4.25), whereas average sulphate concentrations in Jackpine, Shelley and Muskeg creeks were lower than the average sulphate concentration observed in the lower section of the Muskeg River after April 1, 1998 (see Figure 4.24 and Table 4.23). Therefore, it is unlikely that discharges from Jackpine, Shelley or Muskeg creeks were responsible for the significant increase in sulphate concentrations detected in the lower reach of the Muskeg River after the initiation of development in the basin.

Table 4.23 Comparison of Water Quality Observed in the Muskeg River Upstream of Muskeg Creek and Between Jackpine Creek and the River Mouth

Parameter	Upstream of Muskeg Creek						Between Jackpine Creek and the River Mouth						F Statistics[d]		
	Before April 1, 1998			After April 1, 1998			Before April 1, 1998			After April 1, 1998					
	Mean[a]	CV[b]	n[c]	Mean[a]	CV[b]	n[c]	Mean[a]	CV[b]	n[c]	Mean[a]	CV[b]	n[c]	Location	Timing	Interaction
pH	7.5	6	9	7.7	3	18	7.7	4	75	7.9	4	32	1.96	3.09	0.59
dissolved organic carbon	19.1	9	9	16.9	6	25	21.8	9	60	18.2	9	39	0.10	0.13	1.04
sulphate	1.16	611	20	1.76	188	22	4.25	50	77	13.1	55	32	35.7***	6.63*	6.51*
total alkalinity	173	7	20	229	5	14	169	8	74	197	7	31	1.30	6.55*	0.23
total dissolved solids	183	7	20	254	5	22	206	8	77	278	7	30	0.15	10.7**	1.29
total suspended solids	3.66	95	20	3.85	67	32	3.66	78	79	2.48	106	44	1.19	1.04	0.10
total Kjeldahl nitrogen	0.99	3670	16	0.85	144	12	1.09	448	66	0.75	97	16	0.51	1.51	1.66
total phosphorus	0.044	18	20	0.072	35	20	0.033	14	70	0.044	32	26	6.26*	26.6***	3.19
total aluminum	0.022	24	20	0.026	27	22	0.034	52	5	0.054	34	28	4.11*	0.82	0.51
total boron	0.029	16	17	0.036	7	14	0.050	7	4	0.044	9	27	18.3***	0.21	6.11*
total chromium	0.0011	21	19	0.0008	15	22	0.0021	29	5	0.0007	16	28	2.37	12.4***	4.27*

(a) Units are mg/L, except for pH (unitless).

(b) CV = coefficient of variation, expressed as a percentage.

(c) n = sample size.

(d) * = p < 0.05; ** = P < 0.01; *** = p < 0.001.

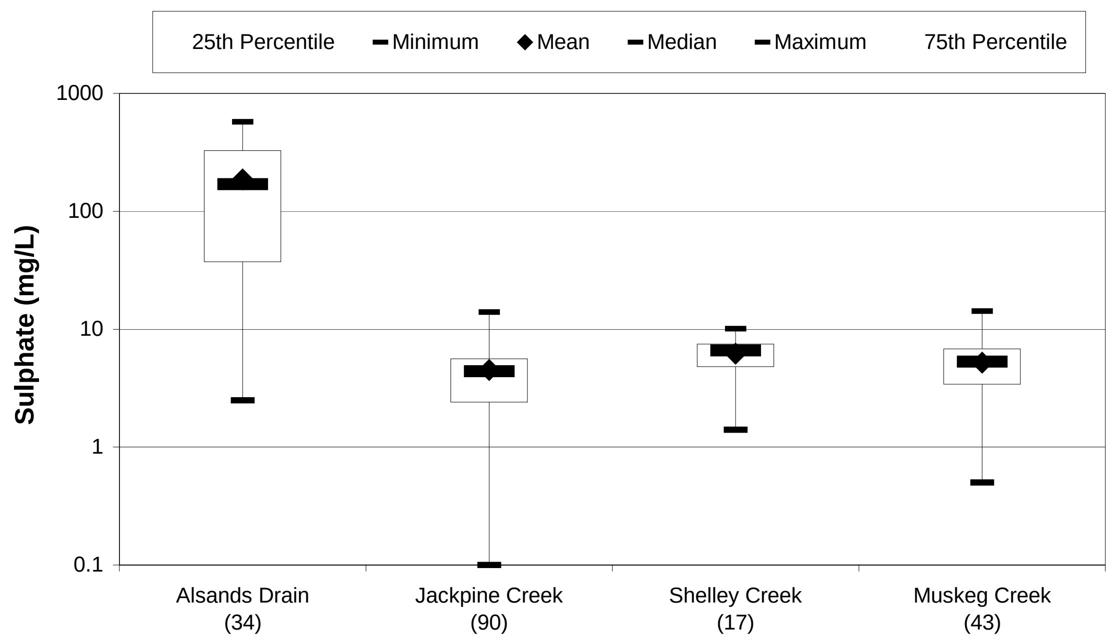
Table 4.24 Results of the Post-hoc Tukey Tests Used to Identify Significantly Different Water Quality Results in the Muskeg River

Parameter	Variable	Upstream of Muskeg Creek		Between Jackpine Creek and the River Mouth	
		Before April 1, 1998	After April 1, 1998	Before April 1, 1998	After April 1, 1998
Sulphate	Mean concentration[a]	1.16 (611)	1.76 (188)	4.25 (50)	13.1 (55)
	Tukey test results[b]	12	1	2	3
Total boron	Mean concentration[a]	0.029 (16)	0.036 (7)	0.05 (7)	0.044 (9)
	Tukey test results[b]	1	12	2	2
Total chromium	Mean concentration[a]	0.0011 (21)	0.0008 (15)	0.0021 (29)	0.0007 (16)
	Tukey test results[b]	1	1	2	1

[a] Units are mg/L.

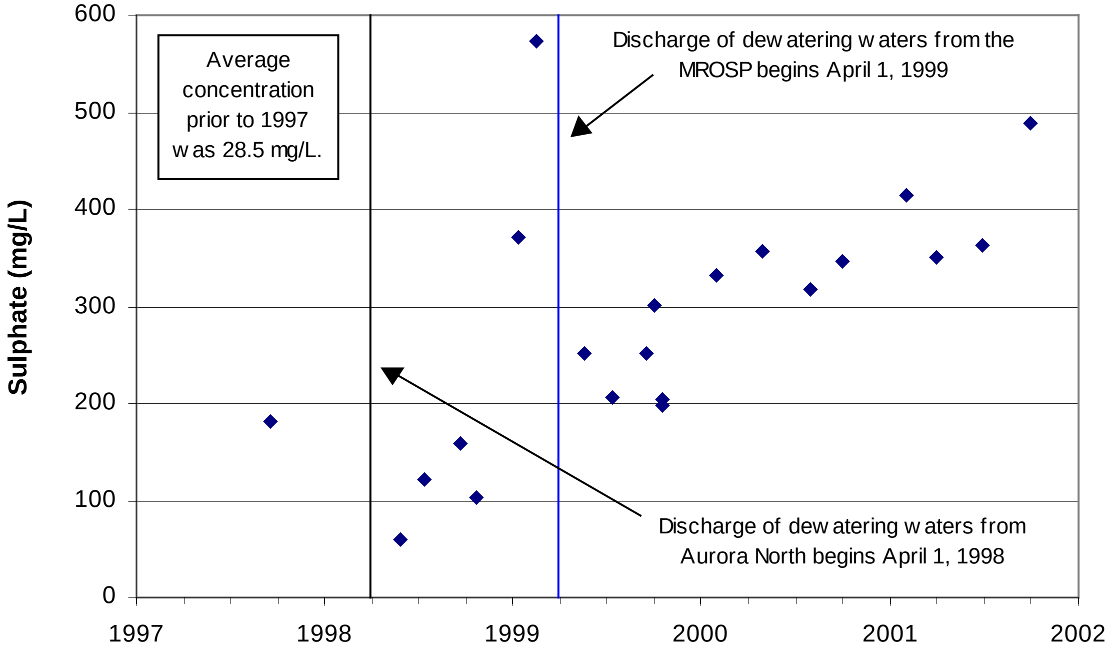
[b] Numbers are used to identify significantly different concentrations, whereby locations with different numbers were found to be significantly different from one another ($p < 0.05$).

Figure 4.24 Comparison of Sulphate Concentrations in the Alsands Drain and Jackpine, Muskeg and Shelley Creeks, 1974 - 2001



Note: Sample size shown in Parenthesis.

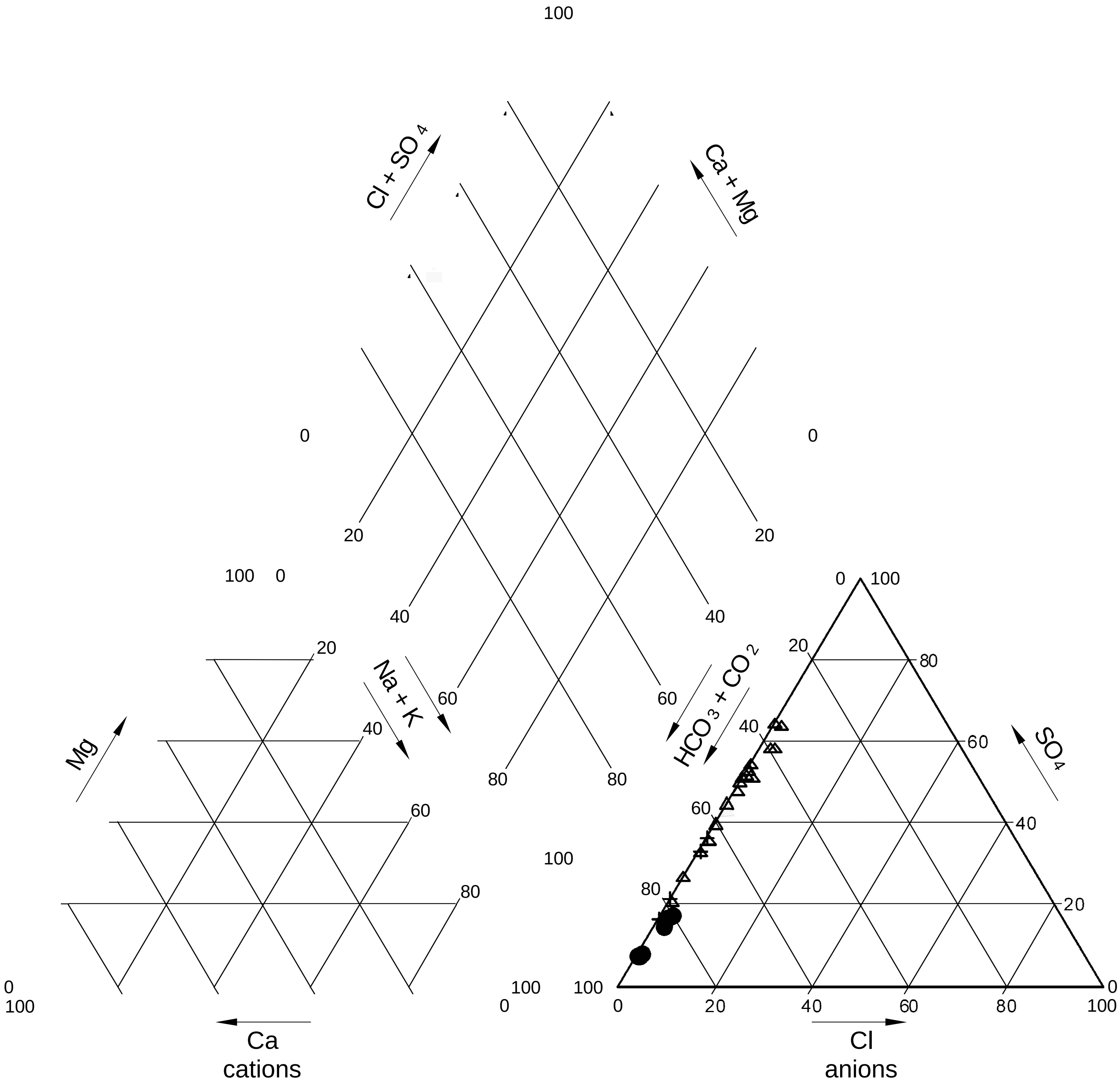
Figure 4.25 Sulphate Concentrations Observed in the Alsands Drain Between 1997 and 2001



Note: MROSP = Muskeg River Oil Sands Plant

Outflows from two polishing ponds are also situated between the upstream and downstream assessment points. These two ponds, Pond 3 and Pond 5, have been receiving muskeg drainage and overburden dewatering waters from the MROSP since the beginning of 2000. However, the ionic content of the waters discharging through Ponds 3 and 5 was different than that of the waters passing through the Alsands Drain since April 1, 1998 (Figure 4.26). Specifically, sulphate concentrations were much higher in the Alsands Drain than in either Pond 3 or Pond 5 (i.e., average of 289 mg/L in the Alsands Drain versus 64.2 mg/L across Ponds 3 and 5). Flow rates through Ponds 3 and 5 were also lower than those through Pond 2 and, subsequently, the Alsands Drain (C. Theriault, Albian Sands Energy Inc., pers. com. 2003).

Together, these findings suggest that the increased sulphate levels observed downstream of development in the Muskeg River after April 1, 1998, resulted from the discharge of high sulphate waters through the Alsands Drain. Based on the variations observed between the sulphate content of waters passing through the Alsands Drain and those flowing through Ponds 3 and 5, it would appear that one or both of the following hypotheses may explain the observed variation:



Legend:

- Alsands Drain
- Pond 3
- Pond 5

PROJECT

RAMP FIVE YEAR REPORT

TITLE

IONIC COMPOSITION OF WATER SAMPLES COLLECTED FROM POND 3, POND 5 AND THE ALSANDS DRAIN BETWEEN 1998 AND 2001

Golder Associates
Calgary, Alberta

PROJECT	No. 022-2301.6150		FILE No.	Pond Piper Plot
DESIGN	TH	10/12/02	SCALE AS SHOWN	REV. 1
CADD	AS	06/03/03		
CHECK			**FIGURE: 4.26**	
REVIEW				

R:\CAD\2300\022-2301\6150\ Drawing file: Pond Piper Plot.dwg Mar 06, 2003 - 2:49pm

- The areas being dewatered and drained to the Alsands Drain are unique in relation to their water quality characteristics; hence, the observed differences in water quality between Pond 2 and Ponds 3 and 5.
- Other types of waters have been released to the Alsands Drain.

RAMP is an aquatic effects monitoring program; the core program is not specifically designed to determine the cause of changes in water quality. Thus, the above are hypotheses requiring further study, possibly as part of the non-core program.

4.3.2.3 Conclusions and Recommendations

Based on the ordination plots derived from the three PCAs discussed in Section 4.2.1, it appears that:

- metals and TSS concentrations in the Athabasca River are typically higher than those observed in its tributaries;
- major ion levels tend to vary to a smaller extent in the Athabasca River mainstem, in comparison to sampled tributaries located downstream of Fort McMurray;
- total metal concentrations in the Muskeg River are generally lower than those in the other tributaries sampled by RAMP; and
- McClelland and Kearl lakes are unique with reference to each other and to Shipyard and Isadore’s lakes in terms of their metals, TSS and major ion content, whereas the latter two lakes tend to contain similar metal, TSS and major ion levels.

More detailed examination of the Athabasca River revealed that water quality within the river does not appear to have been affected by cumulative development situated downstream of Fort McMurray since 1976. With the exception of sulphate, development also does not appear to have affected water quality in the Muskeg River. Sulphate levels have significantly increased downstream of current oil sands facilities since the initiation of development.

For the reasons outlined in Section 4.3.2.2, the increased sulphate levels observed downstream of development in the Muskeg River after April 1, 1998, result from the discharge of high sulphate waters through the Alsands Drain. Based on the variations observed between the sulphate content of waters passing through the Alsands Drain and those flowing through Ponds 3 and 5, it would appear that one or both of the following hypotheses may explain the observed variation:

- The areas being dewatered and drained to the Alsands Drain are unique in relation to their water quality characteristics; hence, the observed differences in water quality between Pond 2 and Ponds 3 and 5.
- Other types of waters have been released to the Alsands Drain.

It is recommended that the source of the sulphate entering the Alsands Drain be identified to determine (1) if it is associated with the area being dewatered or if other types of water were discharged to the Alsands Drain, and (2) if the release of high sulphate waters is expected to continue. It is also recommended that a review of available toxicological information for sulphate be undertaken to determine if an ecological threshold can be established for the Muskeg River beyond which detrimental ecological effects may be expected to occur.

4.3.3 Ability to Detect Change

The ability of the current RAMP sampling program to detect significant temporal variations in water quality at a given location was evaluated based on the minimum data requirements of the chosen statistical test procedure. The ability of the current sampling program to detect significant spatial variations was examined using power analysis. The focus of the power analysis was to resolve the power associated with the statistical tests used to examine potentially significant differences in water quality in the Athabasca River upstream and downstream of development.

The Muskeg River was not included the power analysis, because, as outlined in Section 4.3.2.2, significant variations that may be caused by oil sands development in the basin were identified by the interaction term included in the ANOVA. Based on Zar (1984), power analysis on an interaction term is limited to looking at the power of a performed test. One cannot calculate minimum detectable differences or other useful statistics from this type of retrospective analysis, as outlined by Steidl et al. (1997).

4.3.3.1 Temporal Trends

The Seasonal Kendall test for trend is a nonparametric test that relies on relative magnitudes of the data rather than absolute values. Significance of a trend is determined by looking at how often and how consistently data collected through time are higher or lower than previously collected data, while accounting for seasonal effects (Gilbert 1987). A minimum of four data points per season are required for this test. Test resolution also improves with increased sampling.

As the program is currently designed, RAMP collects three years of seasonal water quality data (one sample per season) to define baseline conditions prior to development (Golder 2002f). It is recommended that the RAMP Water and Sediment Subgroup of the Technical Subcommittee consider expanding this period of baseline characterization from three to more than five years. This expansion would allow the subcommittee to determine statistically if temporal trends detected after the initiation of development were already occurring under baseline conditions. More than five years of baseline data would also allow for "before and after" comparisons to test for potentially significant step changes, with more reasonable estimates of baseline variance than can be provided with only three baseline samples.

This recommendation should not affect the amount of baseline data required to complete the water quality component of an EIA. As has been demonstrated in Suncor (1998), TrueNorth (2001) and Golder and Cantox (2002), available baseline data can be effectively supplemented by using information from comparable waterbodies and/or probabilistic distributions developed from existing data to predict impacts in an EIA.

4.3.3.2 Spatial Trends

Methods

Power analyses were used to examine the resolution of the current RAMP water quality sampling program. Specific attention was focused on the one-way ANOVA used to assess spatial variations in the Athabasca River in terms of the effect size, or relative difference, required for samples to be deemed significantly different. The effect size associated with each ANOVA was estimated using the following equation from Zar (1984):

$$\delta = (2*k*s^2*\phi^2/n)^{0.5}$$

where: δ = effect size

s^2 = variance associated with the error term in the relevant ANOVA

k = number of levels for the factor in question

ϕ = non-centrality parameter

n = samples per location

The value of the non-centrality parameter is dependant on three other parameters: the degrees of freedom (DF) associated with the factor in question, the DF associated with the error term and the assumed power of the test. In this case, the factor in question was location, and there were two locations or “levels” of interest (i.e., upstream of Fort McMurray and near Old Fort). Therefore, “k” was assigned a value of 2, and the DF associated with location was 1 (i.e., k-1). Other assumptions or values used in the analysis are summarized below:

- effect sizes were estimated using a power of 80%;
- the DF associated with error term were estimated by subtracting the DF associated with the location, season and year terms from the total DF available for each ANOVA;
- the non-centrality parameter for each of the three levels of power was derived by using Figure B.1 from Zar (1984); and
- the variable *n* (samples per location) varied by parameter and was based on the number of samples available upstream of Fort McMurray, with the exception of Athabasca PC1 and Athabasca PC2; for these two parameters, *n* was based on the number of samples available near Old Fort, because fewer data were available at this location.

Power analysis is based on the underlying assumption of equal replication (i.e., same number of samples for each location) (Zar 1984). In this case, sample numbers varied by location, with more data typically available to describe instream conditions near Old Fort than in the Athabasca River upstream of Fort McMurray. As such, the effect sizes discussed herein are approximate and may not describe the exact resolution of each ANOVA used to detect significant spatial variations along the length of the Athabasca River.

Parameters considered in this analysis included those discussed in Section 4.3.2.2 where no significant differences in instream concentrations were observed between the two locations. These parameters included Athabasca PC1, Athabasca PC2, DOC, TDS, TKN, total aluminum, total boron and total chromium. The remaining five parameters (i.e., sulphate, pH, total alkalinity, TSS and TP) were not examined, because significant differences were detected in the original analysis. By definition, the variation in concentrations observed between the two locations was, therefore, greater than the minimal detectable difference afforded by the relevant ANOVA.

Results and Discussion

The resolution of the ANOVAs used to test for possible significant variations in the Athabasca River was estimated to range from ± 815% for Athabasca PC1 to approximately ± 6% for TDS (Table 4.25). These values suggest that TDS concentrations, for example, near Old Fort would have to be, on average, at least 6% higher or lower than those upstream of Fort McMurray for the difference to be statistically significant. The variation in resolution among the different parameters resulted from differences in data availability and levels of within-site variability. Resolution was lowest for those parameters (e.g., Athabasca PC1, Athabasca PC2 and total boron) with the fewest samples and/or greatest level of within-site variability.

The average observed difference in TDS concentrations between the two locations was 6%, which is equivalent to the estimated effect size, or minimum detectable difference, required for a significant test result (Table 4.25). However, as indicated in Table 4.22, this observed 6% difference was not found to be statistically significant. This paradoxical finding results from the fact that there was unequal replication between the two sites, whereas power analysis is based on the underlying assumption of equal replication. As such, the minimum detectable differences put forth in Table 4.25 likely under-estimate the actual differences required to conclude that concentrations near Old Fort are statistically different from those observed upstream of Fort McMurray.

Table 4.25 Resolution of the ANOVAs Used to Detect Significant Spatial Variations in Water Quality in the Athabasca River

Parameter	Observed Average Concentration [(a)]		Difference (%)[(b)]	Estimated Effect Size (%) at a Power of 80%[(c)]	
	Upstream of Fort McMurray	Near Old Fort		Increase	Decrease
Athabasca PC1	-0.074	-0.07	-5	814	-814
Athabasca PC2	0.254	0.552	117	215	-215
Dissolved organic carbon	8.3	8.6	4	12	-11
Total dissolved solids[(d)]	178	189	6	6	-5
Total Kjeldahl nitrogen	0.54	0.52	-4	17	-15
Total aluminum	0.245	0.240	-2	139	-58
Total boron	0.029	0.022	-24	228	-70
Total chromium	0.0023	0.0024	4	59	-37

(a) Units are mg/L, except for Athabasca PC1 (unitless) and Athabasca PC2 (unitless).

(b) Calculated as (concentration near Old Fort - concentration upstream of Fort McMurray)/ concentration upstream of Fort McMurray * 100.

(c) Effect size is expressed as a percentage of the average concentration observed upstream of Fort McMurray (i.e., minimum detectable difference/average concentration observed upstream of Fort McMurray * 100). Since statistical analysis was done using log-transformed abundance data, effect sizes differ depending on direction when back-transformed. Athabasca PC1 and Athabasca PC2 were not back-transformed for analysis, which is why % increases and % decreases are equal for these two parameters.

4.3.3.3 Conclusions and Recommendations

The Seasonal-Kendall test for trend requires at least four samples per season to detect a significant upward or downward trend. As previously stated, RAMP currently collects three years of seasonal water quality data (one sample per season) to define baseline conditions prior to development (Golder 2002f). It is recommended that the RAMP Water and Sediment Subgroup of the Technical Subcommittee consider expanding this period of baseline characterization from three to five years. This expansion would allow the subcommittee to determine if temporal trends detected after the initiation of development were already occurring under baseline conditions. Five years of baseline data would also allow for "before and after" comparisons to test for potentially significant step changes, with more reasonable estimates of baseline variance than can be provided with only three baseline samples.

With respect to identifying spatial trends, the relative difference required for water quality near Old Fort to be deemed significantly different from that observed upstream of Fort McMurray was estimated to range from ± 815% for Athabasca PC1 to approximately ± 6% for TDS. However, because, of unequal replication, the minimum detectable differences discussed herein likely under-estimate the actual differences required to conclude that concentrations near Old Fort are statistically different from those observed upstream of Fort McMurray.

4.4 MONITORING TO VERIFY EIA PREDICTIONS

Whether the information collected by RAMP can be used to verify EIA predictions was addressed through an examination of the following questions:

- Are RAMP water quality sites situated in appropriate locations (e.g., at or near EIA water quality assessment nodes or other relevant areas)?
- Are water samples collected by RAMP being analyzed for all of the water quality assessment parameters discussed in recent EIAs?
- Is RAMP collecting or otherwise obtaining the type of water quality information required to differentiate natural variability from changes associated with human activities?

4.4.1 Sampling Locations

As outlined in, for example, Shell (1997), TrueNorth (2001) and Golder and Cantox (2002), EIA water quality assessment nodes are situated downstream of existing, approved and planned developments within the relevant watershed(s). In tributaries to the Athabasca River, this results in assessment nodes typically being placed at river or creek mouths. Within the Athabasca River, assessment nodes are placed downstream of the incoming tributary(ies) scheduled for development. Water quality samples collected by RAMP have generally been taken at the mouth of potentially affect tributaries, consistent with assessment node locations. However, within the Athabasca River, RAMP water quality sampling sites are currently positioned upstream, not downstream, of selected tributaries.

The decision to situate water quality sampling sites upstream of selected tributaries within the Athabasca River was based on a desire to be consistent with the sampling design outlined by AENV in the MROSP's EPEA approval (i.e., Approval # 20809-00-01). This design specifies that samples from the receiving stream are to be collected upstream of relevant discharge outfalls. Locating water quality sampling sites upstream, rather than downstream, of the pertinent tributaries does not, however, preclude verification of EIA predictions. Each site can be used to monitor potential effects from upstream operations. Further, the inclusion of the upstream of the Embarras River site near Old Fort permits the potential verification of cumulative development within the basin. Therefore, the answer to the first question is yes, RAMP water quality sample sites are situated in appropriate locations.

4.4.2 Analytical Parameter List

The standard RAMP water quality parameter list contains all of the substances included in relevant sections of recent EIAs (e.g., Golder and Cantox 2002), with the exception of acrylamide and polyacrylamide. Fish health and tainting indices and measures of acute and chronic aquatic toxicity have also been included in the water quality assessments completed as part of recent EIAs (TrueNorth 2001; Golder and Cantox 2002). These last four assessment parameters are being monitored by RAMP through the inclusion of occasional chronic and acute toxicity testing in the RAMP water quality program (as outlined in Section 4.1.1) and as part of the work being undertaken by the fisheries component of RAMP (see Section 7.1.1).

The potential inclusion of acrylamide and polyacrylamide in oil sands release waters is related to the use of thickened tailings technology. At present, this process is still in the experimental stage. It has not yet been applied at a commercial scale at any of the existing oil sands operations located within the lower Athabasca River watershed.

Therefore, in response to the second question, RAMP is currently testing for all of the water quality assessment parameters discussed in recent EIAs that can reasonably be expected to be in potential oil sands release waters at this time. It is recommended that the RAMP Water and Sediment Subgroup of the Technical Subcommittee consider expanding the parameter list to include acrylamide once thickened tailings technology moves beyond the experimental stage. The committee may also consider adding polyacrylamide to the parameter list, although acrylamide is generally considered to be the more toxic of the two compounds (WBK 2001).

4.4.3 Identifying Changes Related to Human Activity

To attribute instream changes in water quality to human activity, one must ascertain that the observed significant variation is not a reflection of natural conditions. This process is generally completed through comparison to adequate baseline data from the area and/or data from an upstream reference area. In addition, one must also determine that the significant variation does not result from one or more confounding factors (e.g., changes in flow regime).

In response to the question “Is RAMP collecting or otherwise obtaining the type of information required to differentiate natural variability from changes associated with human activity?”, the answer is mixed. In the case of sulphate levels in the Muskeg River, adequate baseline data had been collected before and after the initiation of development at both upstream and downstream locations to clearly identify a significant change attributable to human activity in the basin. However, as discussed in Section 4.3.3, sufficient baseline information may not be available in less well-studied systems to determine if, for example, significant temporal variations can be detected prior to development.

Establishing that a change in instream water quality is likely the result of human activity does not automatically indicate that oil sands development is responsible for the observed variation. A causal link between on-site activity and the observed variation must first be developed to substantiate this assumption, as illustrated in Section 4.3.2.2. This endeavour generally requires on-site monitoring data to identify a probable source and an exit pathway by which material can travel from the source to the receiving environment where it was detected.

On-site monitoring data are not typically collected as part of environmental effects monitoring programs, such as RAMP. As such, additional studies would likely be required to establish if a significant change identified by RAMP resulted from oil sands development. This work may entail either simply requesting on-site information from member companies or completing an on-site study if insufficient information is available.

Conclusions and Recommendations

As discussed in Section 4.4.3, RAMP sample sites are located in appropriate locations. RAMP is also currently testing for all of the water quality assessment parameters discussed in recent EIAs (e.g., TrueNorth 2001; Golder and Cantox 2002) that can reasonably be expected to be present in potential oil sands release waters at this time. However, it is recommended that the RAMP Water and Sediment Subgroup of the Technical Subcommittee consider expanding the parameter list to include acrylamide once thickened tailings technology moves beyond the experimental stage.

In waterbodies where historical information is not available, RAMP is not currently collecting sufficient baseline data to determine if, for example, significant temporal variations can be detected prior to development. Hence, it is recommended that the RAMP Water and Sediment Subgroup of the Technical Subcommittee consider expanding the period of baseline sampling from three to more than five years, as discussed in Section 4.3. It is also beyond the scope of RAMP, as it is currently designed, to establish causal links between significant instream water quality variations and on-site oil sands activities. Additional studies would be required to complete this endeavour, should a significant variation be identified.

4.5 SUMMARY

4.5.1 Characterizing Existing Variability

4.5.1.1 Parameter Correlations

Existing variability in the RAMP study area was examined, in part, by looking at general correlations among parameters included in the standard RAMP parameter list. This analysis was completed to determine the following:

- which substances are typically found together and/or follow consistent patterns with respect to other similar substances (e.g., do water quality samples with high colour levels typically contain high concentrations of dissolved iron);
- how TSS concentrations influence total metal and total phosphorus levels; and
- if a small number of key parameters could be identified to reduce statistical testing requirements and to simplify subsequent analyses.

Water quality data collected by RAMP between 1997 and 2001 were combined with comparable information collected by AENV (2001), Albian (2000, 2002), Syncrude (2002), Komex (1997a), RL&L (1982, 1989), Shell (1975), TrueNorth (2001) and Golder (1996a, 1997b, 2002g) to form one large water quality data set for the lower Athabasca River watershed. Principal component analysis (PCA) was used to evaluate potential correlation among the water quality parameters across the entire data set, as well as across two subsets focusing on the Athabasca River and tributaries to the Athabasca River. A separate wetlands PCA was not included in this study, as there is not yet enough data available from Shipyard, Isadore's, Kearl and McClelland lakes to satisfy the input requirements of this statistical procedure.

With respect to the investigation into the influence of TSS on total metal and total phosphorus levels, data from the Athabasca River, tributaries to the Athabasca River and the four wetlands sampled by RAMP were examined separately using pairwise Pearson correlations with Bonferroni adjustments and linear regression analysis.

Analysis of available data from the lower Athabasca River watershed revealed that water quality characteristics in the area follow expected patterns. These patterns included the following:

- Total metals, TSS and dissolved metals were all generally positively correlated with the same Overall PC, reflective of the fact that total metal concentrations include both the dissolved metal fraction and that associated with suspended materials.
- Total metal concentrations tended to follow consistent, positively correlated trends, whereby samples containing high levels of one metal (e.g., total aluminum) also generally contained high levels of other total metals (e.g., cobalt, nickel and vanadium).
- Manganese and iron were positively correlated, along with colour and DOC, to Overall PC3, reflective of the fact that iron, manganese and DOC tend to impart colour to water.
- High TDS and total alkalinity measurements were recorded for samples containing high levels of calcium, magnesium, chloride and other major ions.
- Barium, strontium, lithium and boron were typically present in the dissolved form, with minor suspended fractions.

Within the Athabasca River, similar correlations among parameters were observed. Conclusions specific to Athabasca River water quality that extend beyond those discussed above include the following:

- The brown, opaque colour of the Athabasca River results from suspended particles, as reflected by the common correlation of total metals, including iron and manganese, TSS and colour to the same principal component.
- Although 12 of the 19 total metals included in this study exhibited statistically significant correlations with TSS, only total aluminum, arsenic, iron and manganese concentrations appear to be strongly influenced by TSS levels (i.e., $R^2 > 0.50$).
- TP concentrations also tend to be strongly influenced by TSS levels in the Athabasca River.

Other conclusions that can be drawn from the results discussed in Section 4.2.1.2 include the following:

- The deep, translucent, tea stained colour common to Athabasca River tributaries, the Muskeg River and other waterbodies within the RAMP study area results from DOC, dissolved iron and other dissolved ions (Golder 2002g; AENV 2002a). Hence, the common correlation of these parameters to the same principal component.
- Total metal and TP concentrations in the Athabasca River tributaries are generally less influenced by TSS levels than those in the Athabasca River, with only nine of the 20 parameters examined in this study demonstrating significant TSS correlations and corresponding regression equations explaining less than 50% of the observed variation.
- Total metal and TP concentrations in Shipyard, Isadore's, McClelland and Kearl lakes are largely independent of TSS levels.

4.5.1.2 Influence of Instream Flow

The potential influence of instream flow on water quality was examined first by using flow and corresponding water quality data from the Athabasca River in a linear regression analysis. This analysis was then repeated using similar information from tributaries of the Athabasca River sampled by RAMP to determine if common relationships were present in the two data sets. Wetlands were excluded from this analysis, since these waterbodies are lentic (i.e., non-flowing) systems.

Parameters considered in this investigation included the first two PCs from the Athabasca River and Athabasca River tributary PCAs, as well as the following individual substances:

- DOC
- pH
- total alkalinity
- TDS
- TSS
- sulphate
- TKN
- total phosphorus
- total aluminum
- total boron
- total chromium

DOC, total phosphorus and TKN were selected to provide a general indication of nutrient status. Total alkalinity and pH were selected as key variables for monitoring potential acidification. TDS, sulphate, total aluminum, total boron and total chromium were chosen, because recent EIAs (e.g., Shell 1997; Golder and Cantox 2002) indicate that concentrations of these substances may increase as a result of development. Finally, TSS was included, due to its likely influence on total metal levels. Average daily and 14-day average flows were incorporated into the analysis to determine which is a better predictor of instream concentrations.

Conclusions that can be drawn from the results of this investigation include the following:

- DOC, TSS, TKN and total metal concentrations in the Athabasca River tend to increase as flow increases.
- In contrast, major ion concentrations in the Athabasca River tend to increase during periods of low flow, as the contribution of groundwater inflow increases relative to surface water inputs.
- Water quality in the Athabasca River tributaries follows similar trends; dissolved ion concentrations tend to peak during periods of low flow, and TP, TSS and total metal concentrations generally increase as flow increases.
- In both the Athabasca River and the Athabasca River tributaries, average daily flow tends to be a slightly better predictor of instream concentrations than 14-day averaged flow.

Based on the amount of scatter observed within the tributary data set, it is recommended that future work concerning flow relationships in Athabasca River tributaries focus on rivers and creeks of similar size that experience similar flow regimes.

4.5.1.3 Fall Versus Winter Water Quality

A statistical comparison of fall and winter water flow and water quality was completed using data collected from the long-term monitoring stations positioned in the Athabasca River upstream of Fort McMurray and near Old Fort, as well as monitoring stations situated in the lower Muskeg River between Jackpine Creek and the river mouth. Parameters considered in this analysis were the same as those discussed with reference to the investigation into the influence of instream flow.

Significant seasonal variations were observed between fall and winter water flows and water quality, with the magnitude of change ranging, on average, from < 3 to > 900 %. In the past, routine water quality monitoring completed by RAMP has been conducted in the fall for the following reasons:

- RAMP benthic and sediment sampling both occur in the fall. Coordination of the three sampling programs is both cost-efficient and allows for a complete water, sediment and benthic data set from the same season.
- Mine water releases, including muskeg and overburden dewatering and end pit lake outflows, are projected to be highest during the open water season, which includes the fall.
- Winter water quality sampling can be more problematic than fall sampling, because of increased health and safety issues related to exposure, travel (e.g., ice roads) and working over ice, as well as increased risk of sample spoilage as a result of freezing during both sample collection and transport.
- AENV currently maintains two long-term, seasonal monitoring stations in the Athabasca River upstream and downstream of oil sands development.
- EPEA approvals, such as those issued to Aurora North and the MROSP (i.e., Approval #s 18942-00-00 and 20809-00-01, respectively), often include seasonal instream monitoring requirements when developers are actively discharging to smaller receiving streams, such as the Muskeg River.

As detailed in recent EIAs (e.g., Shell 1997; TrueNorth 2001; Golder and Cantox 2002), future mine water releases will include seepage from external facilities and in-pit deposits. These waters are expected to flow year-round, and they will day-light, at least in part, in smaller tributaries which may or may not be receiving overland discharge, suggesting that additional winter monitoring by RAMP may be prudent.

As a result, it is recommended that the RAMP Water and Sediment Subgroup of the Technical Subcommittee consider additional winter sampling in areas experiencing a high level of development. Adding winter sampling to the existing fall sampling will preserve the advantages of the fall sampling. Additional winter sampling should be considered under the following conditions:

- relevant EIAs have shown that they are or will be receiving seepage input; and
- existing operators are not already collecting sufficient winter data as part of their approval requirements.

An instream loading analysis is also recommended. This modelling would be waterbody specific. It would include an examination of parameter loading rates under winter and fall conditions, with the goal of establishing the season in which the largest changes in instream loading rates and, consequently, instream concentrations are expected to occur.

4.5.2 Detecting and Assessing Regional Trends

4.5.2.1 Temporal Trends

The investigation into temporal trends in the water quality data set included an examination of long-term (i.e., 1976 to 2001) and short-term (i.e., 1997 to 2001) temporal variability observed at several locations within the Athabasca and Muskeg rivers, respectively. The two long-term, Athabasca River sites are situated upstream of Fort McMurray and near Old Fort. The two short-term, Muskeg River sites are located upstream of Muskeg Creek and in the lower section of the Muskeg River between of Jackpine Creek and the river mouth. These locations were selected, because they are positioned upstream and downstream of current oil sands development within their respective watersheds.

The non-parametric Seasonal-Kendall test for trend was used in combination with Sen's slope estimation procedure (Gilbert 1987) to determine both the magnitude and potential significance of apparent temporal trends observed in the data collected from the four locations listed above. When significant temporal trends were observed, concentrations were adjusted to account for variations in flow over time following the methods outlined by IDT (1998). The analysis was then repeated to determine if changes in water flow were primarily responsible for the observed temporal trend.

Based on the long-term temporal analysis completed using data collected from the Athabasca River upstream of Fort McMurray and near Old Fort, cumulative oil sands development located downstream of Fort McMurray has not resulted in the degradation of water quality within this stretch of the river since its initiation in the mid to late 1970s. Similarly, with the possible exception of pH, oil sands development within the Muskeg River watershed has not resulted in significant temporal variations in water quality in the lower sections of the Muskeg River since the initiation of RAMP in 1997.

For the reasons outlined in Section 4.3.1.2, it is recommended that the continuous pH monitoring data described in AENV (2002a) be further analyzed to determine if the significant decline in pH levels reported in AENV (2002a) is the result of flow variation and/or oil sands development.

4.5.2.2 Spatial Trends

The examination of spatial trends in the water quality data set included a discussion of general patterns within the lower Athabasca River watershed as a whole, as well as an examination of potentially significant variations along the length of the Athabasca River and within the Muskeg River watershed. Specific attention was focused on comparing water quality observed upstream and downstream of existing oil sands development along the Muskeg and Athabasca rivers.

General spatial patterns were examined using ordination plots derived from the three PCAs described in Section 4.2.1. Specific comparisons of water quality upstream and downstream of oil sands development in the lower Athabasca River were completed using data collected upstream of Fort McMurray and near Old Fort in a one-way, randomized block design ANOVA. The ANOVA included location as fixed factor, with season and year as blocking variables. The construction of the resulting model was as follows: model = constant + location + year + season.

An extension of the Athabasca ANOVA was used to compare water quality in the Muskeg River upstream and downstream of oil sands development in this basin. To account for the availability of data at both upstream and downstream locations prior to the initiation of development in 1998, the Muskeg River ANOVA was constructed as follows: model = constant + season + location + timing + timing*location + year(timing), wherein:

- location was a fixed with-year factor;

- timing (i.e. before or after spring 1998) was a fixed between-year factor; and
- year and season were random factors included as blocking variables to account for seasonal and year-to-year effects.

Based on the ordination plots derived from the three PCAs, it appears that

- metal and TSS concentrations in the Athabasca River are typically higher than those observed in its tributaries;
- major ion levels tend to vary to a smaller extent in the Athabasca River mainstem, in comparison to sampled tributaries located downstream of Fort McMurray;
- total metal concentrations in the Muskeg River are generally lower than those in the other tributaries sampled by RAMP; and
- McClelland and Kearl lakes are unique with reference to each other and to Shipyard and Isadore’s lakes in terms of their metal, TSS and major ion content, whereas the latter two lakes tend to contain similar metal, TSS and major ion levels.

More detailed examination of the Athabasca River revealed that water quality within the river does not appear to have been affected by cumulative oil sands development situated downstream of Fort McMurray since 1976. With the exception of sulphate, oil sands development also does not appear to have affected water quality in the Muskeg River. Sulphate levels have significantly increased downstream of current oil sands facilities since the initiation of development.

The increased sulphate levels observed downstream of development in the Muskeg River after April 1, 1998, likely resulted from the discharge of high sulphate waters through the Alsands Drain. Based on the variations observed between the sulphate content of waters passing through the Alsands Drain and those flowing through Ponds 3 and 5, it would appear that one or both of the following hypotheses may explain the variation:

- The areas being dewatered and drained to the Alsands Drain are unique in relation to their water quality characteristics; hence, the observed differences in water quality between Pond 2 and Ponds 3 and 5.
- Other types of waters have been released to the Alsands Drain.

It is recommended that the source of the sulphate entering the Alsands Drain be identified to determine (1) if it is associated with the area being dewatered or if other types of water were discharged to the Alsands Drain, and (2) if the release of high sulphate waters is expected to continue. It is also recommended that a review of available toxicological information for sulphate be undertaken to determine if an ecological threshold can be established for the Muskeg River beyond which detrimental ecological effects may be expected to occur.

4.5.2.3 Ability to Detect Change

Temporal Variations

The Seasonal Kendall test for trend is a nonparametric test that relies on relative magnitudes of the data rather than absolute values. Significance of a trend is determined by looking at how often and how consistently data collected through time are higher or lower than previously collected data, while accounting for seasonal effects (Gilbert 1987). A minimum of four data points per season are required for this test. Test resolution also improves with increased sampling.

As the program is currently designed, RAMP collects three years of seasonal water quality data (one sample per season) to define baseline conditions prior to development (Golder 2002f). It is recommended that the RAMP Water and Sediment Subgroup of the Technical Subcommittee consider expanding this period of baseline characterization from three to more than five years. This expansion would allow the subcommittee to determine if temporal trends detected after the initiation of development were already occurring under baseline conditions. More than five years of baseline data would also allow for “before and after” comparisons to test for potentially significant step changes, with more reasonable estimates of baseline variance than can be provided with only three baseline samples.

This recommendation should not affect the amount of baseline data required to complete the water quality component of an EIA. As has been demonstrated in Suncor (1998), TrueNorth (2001) and Golder and Cantox (2002), available baseline data can be effectively supplemented by using information from comparable waterbodies and/or probabilistic distributions developed from existing data to predict impacts in an EIA.

Spatial Variations

The current program’s ability to detect significant spatial variations in water quality was examined using power analysis. Specific attention was focused on the one-way ANOVA used to assess spatial variations in the Athabasca River in terms of the effect size, or relative difference, required for samples to be deemed significantly different. Using the procedures outlined in Zar (1984), relative difference required for water quality near Old Fort to be deemed significantly different from that observed upstream of Fort McMurray was estimated to range from ± 815% for Athabasca PC1 to approximately ± 6% for TDS. However, because, of unequal replication in the RAMP water quality sampling program, the minimum detectable differences discussed herein are likely under-estimates of the actual differences required to conclude that concentrations near Old Fort are statistically different from those observed upstream of Fort McMurray.

4.5.3 Monitoring to Verify EIA Predictions

Whether the information collected by RAMP can be used to verify EIA predictions was addressed through an examination of the following questions:

- Are RAMP water quality sites situated in appropriate locations (e.g., at or near EIA water quality assessment nodes or other relevant areas)?
- Are water samples collected by RAMP being analyzed for all of the water quality assessment parameters discussed in recent EIAs?
- Is RAMP collecting or otherwise obtaining the type of information required to differentiate natural variability from changes associated with human activities?

RAMP sample sites are located in appropriate locations. RAMP is also currently testing for all of the water quality assessment parameters discussed in recent EIAs (e.g., TrueNorth 2001; Golder and Cantox 2002) that can reasonably be expected to be in potential oil sands release waters at this time. However, it is recommended that the RAMP Water and Sediment Subgroup of the Technical Subcommittee consider expanding the parameter list to include acrylamide once thickened tailings technology moves beyond the experiment stage.

In waterbodies where historical information is not available, RAMP is not currently collecting sufficient baseline data to determine if, for example, significant temporal variations can be detected prior to development. Hence, it is recommended that the RAMP Water and Sediment Subgroup of the Technical Subcommittee consider expanding the period of baseline sampling from three to more than five years, as discussed above. It is also beyond the scope of RAMP, as it is currently designed, to establish causal links between significant instream water quality variations and on-site oil sands activities. Additional studies would be required to complete this endeavour, should a significant variation be identified.

5 SEDIMENT QUALITY

5.1 INTRODUCTION

5.1.1 Program Overview

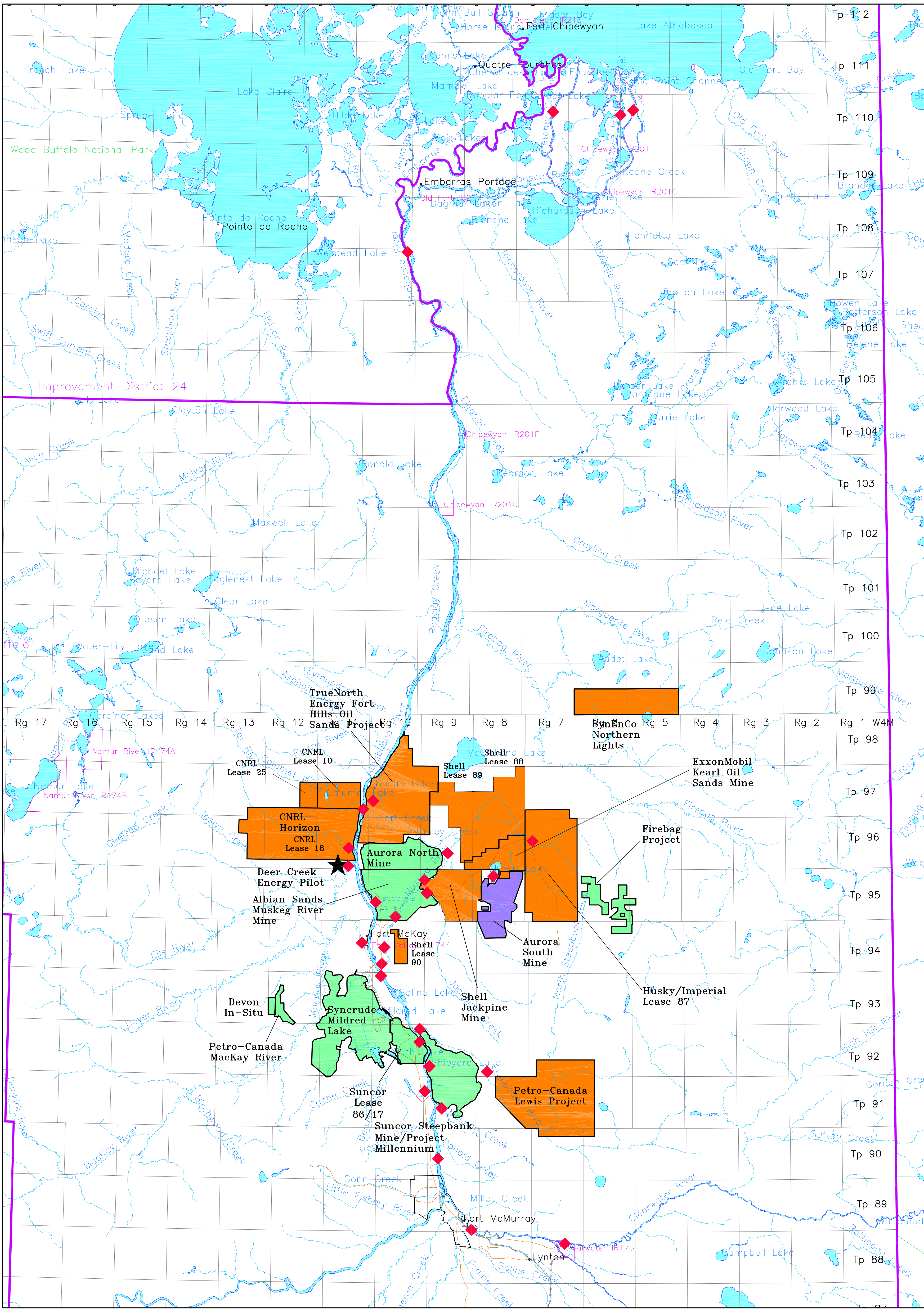
The sediment quality monitoring program has increased in scope since its inception in 1997, with the addition of new parties to the Regional Aquatics Monitoring Program (RAMP) and the expansion of oil sands development in the lower Athabasca River watershed. The history of RAMP is described in more detail in Chapter 1. Sediment sampling was restricted to 11 sites in 1997, whereas over 22 samples were collected in 2001 (Table 5.1). The sediment program will likely continue to expand in response to further development proposed within the Oil Sands Region, including the Shell Canada Limited Jackpine Mine – Phase 1 and the Canadian Natural Resources Limited Horizon Project. Locations of existing sediment sampling sites included in the RAMP sediment monitoring program are shown in Figure 5.1.

The rationale upon which the program is based has also evolved over time in response to expanded development and annual findings[1]. As a result of both the expansion in the program and the alteration of the program's underlying rationale, few locations have been sampled continuously over the five year history of RAMP, as illustrated in Table 5.1. However, consistent sampling techniques have been used throughout the program, and sediment samples collected by RAMP have typically been analyzed for all of the parameters listed in Table 5.2. Occasional toxicity testing, involving screening-level testing with *Chironomus tentans*, *Hyalella azteca* and *Lumbriculus variegatus*, has also been included in the sediment monitoring program, as outlined in Table 5.1.

The design of the annual monitoring is determined by committee using a consensus process; thus, committee changes result in design changes as a new consensus is achieved. The structure of subcommittees, committee membership, program funding and RAMP objectives have varied since the program's inception. Therefore, the Five Year Report provides an opportunity to assess whether the results of the first five years of RAMP monitoring meet the current RAMP objectives.

[1] A summary of the current program rationale is presented in Golder (2002f).

R:\CAD\2300\022-2301\6150\5 Year Report\ Drawing file: RAMP-Sediment-Sampling-1997-2001.dwg Mar 06, 2003 - 2:58pm



15 0 15
SCALE KILOMETRES

LEGEND

- SEDIMENT SAMPLING LOCATION
- EXISTING and APPROVED DEVELOPMENTS
- PLANNED DEVELOPMENTS
- EUB APPROVED DEVELOPMENT

NOTE

INCLUDES ONLY THOSE SITES MONITORED AS PART OF THE CORE PROGRAM.

REFERENCE

ALBERTA NTDB DIGITAL DATA OBTAINED FROM GEOMATICS CANADA, AUGUST 2001. SASKATCHEWAN NTDB DATA OBTAINED FROM ISC, AUGUST 2001. DATUM: NAD 83 PROJECTION: UTM ZONE 13

PROJECT
RAMP FIVE YEAR REPORT

TITLE
RAMP SEDIMENT SAMPLING SITES, 1997 TO 2001

Golder Associates
Calgary, Alberta

PROJECT No. 022-2301.6150			FILE No. Sediment Sampling	
DESIGN	JPB	06/01/03	SCALE AS SHOWN	REV. 2
CADD	AS	06/03/03		
CHECK			**FIGURE: 5.1**	
REVIEW				

Table 5.1 RAMP Sediment Quality Monitoring Program, 1997 to 2001

Location		Year[a]				
		1997	1998	1999	2000	2001
Athabasca River						
upstream of Donald Creek	- west bank		♎		❍	♎
	- east bank		♎		❍	♎
	- cross-channel	♎				
upstream of Steepbank River	- west bank				❍	♎
	- east bank				❍	♎
upstream of the Muskeg River	- west bank[b]		♎		❍	♎
	- east bank[b]		♎		❍	♎
upstream of Fort Creek	- west bank[b]		♎		❍	♎
	- east bank[b]		♎		❍	♎
	- cross-channel	♎				
upstream of the Embarras River					♎	♎
Athabasca Delta						
Delta composite[c]				♎	♎	
Big Point Channel						♎
Goose Island Channel						♎
Fletcher Channel						♎
Athabasca River Tributaries (South of Fort McMurray)						
Clearwater River	- upstream of Fort McMurray					❍
	- upstream of Christina River					❍
Athabasca River Tributaries (North of Fort McMurray)						
McLean Creek	- mouth			♎	♎	❍
Poplar Creek	- mouth	❍				
Steepbank River	- mouth	❍	❍			
MacKay River	- mouth	❍	❍			❍
	(upstream of P.C. Mackay)					❍
Ells River	- mouth		❍			
Tar River	- mouth		❍			
Fort Creek	- mouth				❍	
Muskeg River						
mouth		❍	❍	♎	❍	❍
1 km upstream of mouth					❍	
upstream of Canterra Road Crossing					❍	
upstream of Jackpine Creek		❍			❍	
upstream of Muskeg Creek					❍	
upstream of Wapasu Creek					❍	
Muskeg River Tributaries						
Jackpine Creek	- mouth	❍				
Wetlands						
Kearl Lake	- composite					❍
Isadore's Lake	- composite					❍
Shipyard Lake	- composite					❍
Additional Sampling (Non-Core Programs)						
Flour Bay (Lake Athabasca)					♎	
testing intra-site variability in the Athabasca River					❍	

[a] ❍ = standard sediment quality parameters, as outlined in Table 5.2; ♎ = analysis includes standard parameters and toxicity testing with *Chironomus tentans, Lumbriculus variegatus, Hyalella azteca*.

[b] Samples were collected downstream of named tributary in 1998.

[c] In 1999, one composite sample was collected from the Delta, which contained sediment collected from Big Point, Goose Island, Embarras and an unnamed side channel.

Table 5.2 Standard RAMP Sediment Quality Parameter List

Group Name[(a)]	Individual Parameters
particle size	percent sand
	percent silt
	percent clay
	moisture content
carbon content	total inorganic carbon
	total organic carbon
	total carbon
organics	total recoverable hydrocarbons
	total volatile hydrocarbons (C_5-C_{10})
	total extractable hydrocarbons (C_{11}-C_{30})
total metals	aluminum (Al)
	arsenic (As)
	barium (Ba)
	beryllium (Be)
	boron (B)
	cadmium (Cd)
	calcium (Ca)
	chromium (Cr)
	cobalt (Co)
	copper (Cu)
	iron (Fe)
	lead (Pb)
	magnesium (Mg)
	manganese (Mn)
	mercury (Hg)
	molybdenum (Mo)
	nickel (Ni)
	potassium (K)
	selenium (Se)
	silver (Ag)
	sodium (Na)
	strontium (Sr)
	thallium (Tl)
	uranium (U)
	vanadium (V)
	zinc (Zn)
target PAHs	acenaphthene
	acenaphthylene
	anthracene
	benzo(a)anthracene/chrysene
	benzo(a)pyrene
	benzofluoranthenes
alkylated PAHs	benzo(g,h,i)perylene
	biphenyl
	dibenzo(a,h)anthracene
	dibenzothiophene
	fluoranthene
	fluorene
	indeno(c,d-123)pyrene
	naphthalene
	phenanthrene
	pyrene

Table 5.2 Standard RAMP Sediment Quality Parameter List (continued)

Group Name[a]	Individual Parameters
alkylated PAHs (continued)	C1 substituted acenaphthene
	C1 substituted benzo(a)anthracene/chrysene
	C2 substituted benzo(a)anthracene/chrysene
	C1 substituted biphenyl
	C2 substituted biphenyl
	C1 substituted benzofluoranthene/benzo(a)pyrene
	C2 substituted benzofluoranthene/benzo(a)pyrene
	C1 substituted dibenzothiophene
	C2 substituted dibenzothiophene
	C3 substituted dibenzothiophene
	C4 substituted dibenzothiophene
	C1 substituted fluoranthene/pyrene
	C2 substituted fluoranthene/pyrene
	C3 substituted fluoranthene/pyrene
	C1 substituted fluorene
	C2 substituted fluorene
	C3 substituted fluorene
	C1 substituted naphthalenes
	C2 substituted naphthalenes
	C3 substituted naphthalenes
	C4 substituted naphthalenes
	C1 substituted phenanthrene/anthracene
	C2 substituted phenanthrene/anthracene
	C3 substituted phenanthrene/anthracene
	C4 substituted phenanthrene/anthracene
	1-methyl-7-isopropyl-phenanthrene (retene)

[a] PAHs = polycyclic aromatic hydrocarbons.

The current sediment quality monitoring program consists of two major components:

- core RAMP sediment quality monitoring that is consistently implemented year after year; and
- non-core RAMP sediment quality monitoring, which tends to include either short-term investigations or samples collected to supplement data collected as part of the core-program.

5.1.2 Objectives

The scope of the sediment quality component of the Five Year Report was defined by three of the eight broad objectives that guide the overall RAMP program (see also Chapter 2). For convenience, the headings of this section are based on the following three objectives:

- collecting scientifically defensible baseline and historical data to characterize variability in the oil sands area;
- monitoring aquatic environments in the oil sands area to detect and assess cumulative effects and regional trends; and
- collecting data against which predictions contained in environmental impact assessments (EIAs) can be verified.

The RAMP Water and Sediment Subgroup of the Technical Subcommittee also identified the following issues for consideration in the sediment quality component of the five-year report:

- presence of spatial trends within the lower Athabasca River watershed;
- correlation between monitored parameters, including, for example:
  - total recoverable hydrocarbon and polycyclic aromatic hydrocarbon (PAH) levels in sediment;
  - sediment composition and PAH content; and
- use of three years of data to describe baseline variability in a previously unsampled waterbody.

To address both the broad objectives of RAMP and the specific issues raised by the Water and Sediment Subgroup, the specific objectives of the sediment quality component were established to determine the following:

1. Which sediment quality parameters may be correlated to each other.
2. Whether there are temporal or spatial trends in the existing sediment quality data set.
3. Given existing levels of variability and sampling frequency, how effective is the current sediment quality monitoring program at detecting change, and are three years of data sufficient to assess baseline variability.
4. Whether the information being collected by RAMP can be used to verify EIA predictions and establish causal links between on-site activities and instream observations.
5. Whether and how the sediment component of RAMP may be improved.

The first four specific sediment quality objectives relate back to the three broad program objectives as outlined in Table 5.3. The fifth objective (i.e., developing recommendations for program improvement) applies to all three broad program objectives.

Each data point (e.g., concentration of each parameter) represents the cumulative effect of all changes (e.g., natural variability, development impacts) at each site on each date. The entire data set analyzed in this report is, in this sense, cumulative effects data. Therefore, the assessment identified by the second broad objective will focus on the determination of regional trends.

Table 5.3 Relationship of the Specific Sediment Quality Study Objectives to RAMP's Overall Objectives

Overall Program Objectives	Relevant Component-Specific Objectives
characterizing existing variability	examine potential parameter correlations
detecting cumulative effects and regional trends	identify temporal and/or spatial trends in the existing water and sediment quality data set
	examine the power of the existing sampling program to detect change
monitoring to verify EIA predictions	determine if the information collected by RAMP can be used to verify EIA predictions and establish causal links between on-site activities and instream observations

5.1.3 Scope

The following section outlines the work undertaken to address each of the specific objectives listed in Section 5.1.2. It also provides a brief description of the data used and the parameters considered in this report. For each objective, the scope represents a balance between economical limitations, time constraints and scientific potential.

5.1.3.1 Characterizing Existing Variability

The existing variability of sediment quality within the RAMP study area was characterized by an exploration of potential parameter correlations within the sediment data set, as recommended by the Water and Sediment Subgroup of the Technical Subcommittee. This exploration looked at the following across all of the waterbodies sampled by RAMP:

- general correlations among the metals and among the PAHs included in the standard RAMP parameter list (Table 5.2), with noted exceptions[2];

[2] Parameters, including silver, acenaphthylene, C1 and C2 substituted biphenyl, anthracene and dibenzo(a,h)anthracene, were excluded from the sediment analysis, because more than 70% of the available data were non-detectable results.

- significant correlations between metal levels and sediment composition (i.e., percent sand, silt and clay); and
- significant correlations between PAH concentrations, sediment composition, total organic carbon (TOC) content, total extractable hydrocarbon (TEH) levels and total recoverable hydrocarbon (TRH) content.

These analyses were completed using Principal Component Analysis (PCA), explicit Pearson correlations (where required) on data collected by Albian (2000) and Golder (1996a), in addition to that collected by RAMP between 1997 and 2001. This examination of parameter correlations was also limited to the entire data set. Although other sediment quality studies have been completed in the lower Athabasca River watershed (Lutz and Hendzel 1977; Allan and Jackson 1978; C&GL 1979; Beak 1988; Dobson et al. 1996; Crosley 1996; Brownlee et al. 1997), restrictive analytical parameter lists prevented their inclusion in the current report. Conclusions are based on the entire data set, which was not subdivided by waterbody.

5.1.3.2 Detecting and Assessing Regional Trends

Temporal Trends

The investigation into temporal trends in the sediment quality data set was limited to an examination of the temporal variability observed at the following five locations where more than four years of sediment data are available:

- the mouth of the Muskeg River;
- along the east and west banks of the Athabasca River upstream of Donald Creek; and
- along the east and west banks of the Athabasca River upstream of Fort Creek.

Parameters considered in this investigation included both metals and PAHs, represented by the relevant Principal Components (PCs) identified from the work described in Section 5.1.3.1. The temporal analysis was restricted to key metal and PAH PCs to limit the probability of committing a Type I error (i.e., wrongly concluding that a significant difference exists) which can result from repeated statistical testing of the same underlying hypothesis (i.e., has sediment quality significantly changed over time at the selected location?). Further information about the probability of committing a Type I error with repeated testing is provided in Zar (1984).

Spatial Trends

The examination of spatial trends in sediment quality within the lower Athabasca River included the following:

- a general overview of spatial variations in the RAMP study area based on sediment composition, metal concentrations and PAH levels; and
- a focused analysis of potentially significant variations in metal and PAH concentrations along the length and width of the Athabasca River, upstream and downstream of cumulative oil sands development in the basin.

Consistent with the temporal trend analysis, spatial variations in PAH and metal concentrations were evaluated indirectly using the key metal and PAH PCs identified from the work described in Section 5.1.3.1.

Ability to Detect Change

The ability of the current RAMP sediment sampling program to detect significant temporal variations in sediment quality at a given location was evaluated based on the requirements of the chosen statistical test procedure, in terms of minimum data inputs and test resolution. The ability of the current sampling program to detect significant spatial variations in sediment quality was examined using power analysis. The focus of the power analysis was to determine the effect size, or relative difference, that could be detected (i.e., deemed statistically significant) in the Athabasca River based on:

- the data collected to date;
- a doubling of the current sampling effort; and
- a tripling of the current sampling effort.

Parameters included in this analysis were the same as those discussed in reference to observed temporal and spatial trends.

5.1.3.3 Monitoring to Verify EIA Predictions

Whether the information collected by RAMP can be used to verify EIA predictions was addressed through an examination of the following questions:

- Are RAMP sediment sample sites situated in appropriate locations (e.g., at or near EIA water quality assessment nodes and other relevant depositional areas)?

- Does the RAMP sediment analytical test list include all of the parameters discussed in relevant sections of the EIA?
- Is RAMP collecting or otherwise obtaining the type of information required to differentiate natural variability from changes associated with human activities?

5.2 CHARACTERIZING EXISTING VARIABILITY

Correlations among sediment quality parameters were examined to determine the following:

- if substances of a common nature are typically found together and/or follow consistent patterns (e.g., do sediments with high aluminum content also contain high barium concentration?);
- how sediment chemistry may be affected by sediment composition (e.g., are PAH levels generally higher in sediments with high silt content?); and
- if indicator parameters can be identified to allow for the possible reduction of the standard RAMP sediment test list (e.g., possibly using TRH as an indicator of PAH concentrations).

This analysis was also used to identify key parameters that could be used in subsequent examinations of potential temporal and spatial trends.

5.2.1 Methods

Sediment data collected by RAMP between 1997 and 2001 were combined with comparable information collected by Albian (2000) and Golder (1996a) to create a sediment quality data set for the lower Athabasca River watershed. Split and duplicate samples were reduced to single samples to guarantee data independence. This process was completed through either random selection or, in cases of unequal analysis, by choosing the sample that had been submitted for the more complete analysis.

Across the entire data set, values recorded as zeros were eliminated. Non-detectable results were replaced with half of the corresponding method detection limit. All data, with the exception of pH, sediment composition (i.e., percent sand, silt and clay) and TOC content, were $\log_{10}$-transformed. Parameters that are measured as percent dry weight, such as TOC and percent sand, silt and clay, were transformed using the following arcsine transformation (Zar 1984):

$$p' = \arcsin\sqrt{p}$$

where p' = transformation value, expressed in radians; and
p = proportion dry weight (i.e., percentage/100).

Potential correlations among TOC and the physical parameters, such as percent sand, silt and clay, were examined using explicit pairwise Pearson correlations with Bonferroni adjustments. PCA was used to evaluate potential correlations among the metals and among the PAHs included in the standard RAMP parameter list (Table 5.2). Although silver is listed in Table 5.2, it was not included in any of the sediment analyses, because more than 70% of the available data were non-detectable results. For the same reason, acenaphthylene, C1 and C2 substituted biphenyl, anthracene and dibenzo(a,h)anthracene were excluded from this study.

As described in Section 4.2.1.1, PCA requires a complete two-dimensional input table, wherein every sample included in the analysis has data for all of the corresponding parameters included in the PCA. This prerequisite resulted in a compromise between maximizing the number of parameters and maximizing the number of samples included in each PCA. To achieve this requirement, and to maintain an approximate sample to parameter ratio of 3:1, the metal PCA was completed using 78 samples and the following 22 parameters:

- aluminum
- arsenic
- barium
- beryllium
- cadmium
- calcium
- chromium
- cobalt
- copper
- iron
- lead
- magnesium
- manganese
- mercury
- molybdenum
- nickel
- potassium
- selenium
- sodium
- strontium
- vanadium
- zinc

Boron, thallium and uranium were excluded from the metal PCA, because insufficient data were availabile. However, potential correlation of these three metals to the 22 metals included in the PCA was examined using pairwise Pearson correlations with Bonferroni adjustments to compare concentrations of each of these metals to the key PCs identified from the metals PCA.

A similar approach was adopted for the PAH analysis. The PAH PCA was completed based on a smaller sample to parameter ratio using 68 samples and the following 29 parameters:

- acenaphthene
- benzo(a)anthracene/chrysene
- benzo(a)pyrene
- benzo(g,h,i)perylene
- benzofluoranthenes
- dibenzothiophene
- fluorene
- fluoranthene
- naphthalene
- phenanthrene
- C1 and C2 substituted benzo(a)anthracene/chrysene
- C1 to C3 substituted dibenzothiophene
- C1 substituted fluoranthene/pyrene
- C1 and C3 substituted fluorene
- C1 to C4 substituted naphthalenes
- C1 to C4 substituted phenanthrene/anthracene
- pyrene
- indeno(c,d-123)pyrene
- TRH

Because of data gaps, 10 parameters were excluded from the PAH PCA, including C1 substituted acenaphthene, biphenyl, C1 and C2 substituted benzofluoranthene/benzo(a)pyrene, C4 substituted dibenzothiophene, 1-methyl-7-isopropyl-phenanthrene (retene), C2 and C3 substituted fluoranthene/pyrene, C2 substituted fluorene and TEH. As was done with the omitted metals, these individual PAHs were compared to the key PCs to evaluate possible parameter correlations and to establish if the PAH PCs could be used to represent the excluded parameters in further analyses. These comparisons were completed using pairwise Pearson correlations with Bonferroni adjustments.

Both the metal PCA and the PAH PCA were performed without rotation in SYSTAT 10 (SPSS 2000), using pairwise correlations. The areas represented by the 78 and 68 samples included in the metal and PAH PCAs, respectively, are detailed in Table 5.4. In each case, a loading of 0.4 was used to identify a significant correlation between an individual parameter and a PC. This threshold was selected based on the results of the explicit Pearson correlations completed as part of this study (i.e., 0.4 was generally the level at which the corresponding Bonferroni adjusted probabilities were less than 0.05). In cases where parameter loadings were greater than 0.4 on several PCs, the PC containing the highest loading was considered the most representative of that parameter.

Table 5.4 Origin of Sediment Samples Included in the Metal and PAH Principal Component Analyses

Waterbody	Location[a]	Sample Size	
		Metal PCA	PAH PCA
Athabasca River	u/s of Donald Creek	7	7
	u/s of the Steepbank River	9	4
	u/s of the Muskeg River	6	6
	u/s of Fort Creek	9	7
	u/s of Embarras	5	5
	Delta	6	6
Athabasca River tributaries	Steepbank River	8	6
	Poplar Creek	1	1
	McLean Creek	4	4
	MacKay River	4	4
	Fort Creek	1	1
	Ells River	1	1
	Tar River	1	1
Muskeg River watershed	Muskeg River	11	11
	Jackpine Creek	1	1
wetlands	Shipyard Lake	1	1
	Isadore's Lake	2	1
	Kearl Lake	1	1
Total		**78**	**68**

[a] u/s = upstream.

Finally, the potential influence of sediment composition on sediment chemistry was examined using explicit pairwise Pearson correlations with Bonferroni adjustments to compare percent sand, silt and clay ratios with the key PCs identified from the metal and PAH PCAs. Correlations of TOC content to PAH levels were investigated by the same method using the key PAH PCs produced from the PAH PCA. All statistical tests, including both the PCAs and the pairwise Pearson correlations, were completed using SYSTAT 10 (SPSS 2000).

5.2.2 Results and Discussion

5.2.2.1 Correlations Among Physical Parameters and TOC

The physical components of sediment (i.e., sand, silt and clay content) were significantly correlated to one another (Table 5.5). Silt and clay content were positively correlated, indicating that sediments with high silt content also contained high clay content and vice versa. Both of these parameters were negatively correlated to sand content, meaning that sediments with high sand content contained little silt or clay. Sand content also demonstrated a significant negative correlation to TOC content, whereas TOC content was significantly positively correlated to clay content. No significant correlations were observed between TOC content and corresponding silt concentrations.

Table 5.5 Correlation of Physical Parameters to One Another and to Total Organic Carbon Content

Parameter	TOC[a]	Percent Clay [a]	Percent Sand[a]
percent clay	**0.562***** (68)	-	-
percent sand	**-0.446**** (68)	**-0.919***** (77)	-
percent silt	0.277 (67)	**0.758***** (76)	**-0.929***** (76)

[a] Correlation coefficients are presented with sample numbers in parentheses. Significant correlations are bolded, with * = $p<0.05$, ** = $p<0.01$ and *** = $p<0.001$.

5.2.2.2 Correlations Among Individual Metals

PCA was used to transform the large metal and PAH data sets into multi-dimensional data sets with independent variables called PCs. Since the first few PCs will generally account for a large proportion of the total variance in the original data set, they can be used to simplify subsequent analyses with minimal loss of information. As such, PCA is a tool to simplify, and better understand, the variance in complex data sets, but further analysis is required to determine the sources of the variance. PCA is explained in more detail in Section 4.2.1.1.

The first three PCs produced from the metals PCA accounted for approximately 75% of the total variance contained within the two dimensional input table, with metal PC1, 2 and 3 accounting for 55, 12 and 8% of the total variance, respectively (Table 5.6). Successive metal PCs explained little of the total variance, and they did not provide further information about potential correlations among the individual metals included in the PCA. Therefore, only the first three PCs are reported herein and used in subsequent analyses.

Results of the PCA indicate that metal concentrations in sediment tend to be strongly correlated to one another, and that sediments containing high levels of one metal often contained high concentrations of other metals. These conclusions are based on the positive correlation of all but two metals with PC1, with correlation coefficients of greater than 0.4 (Table 5.6). Illustrations of these strong positive correlations of individual metals to one another and to PC1 are presented in Figures 5.2 and 5.3, respectively. Mercury and molybdenum were the two metals included in the metal PCA that were not strongly correlated to PC1 (i.e., correlation coefficients < 0.4 - Table 5.6).

Table 5.6 Correlation of Individual Metals to Each of the Three Key Principal Components Derived from the Metal Principal Components Analysis

Parameter	Metal PC1[(a)]	Metal PC2[(a)]	Metal PC3[(a)]
cobalt (Co)	**0.93**	-0.11	-0.08
magnesium (Mg)	**0.91**	0.03	0.07
potassium (K)	**0.90**	-0.18	0.18
iron (Fe)	**0.90**	0.12	0.18
strontium (Sr)	**0.86**	**-0.40**	0.09
barium (Ba)	**0.87**	**-0.45**	-0.02
aluminum (Al)	**0.85**	**-0.44**	-0.04
chromium (Cr)	**0.83**	-0.09	-0.22
calcium (Ca)	**0.76**	0.10	0.19
nickel (Ni)	**0.77**	**0.45**	-0.14
zinc (Zn)	**0.74**	**0.44**	0.14
sodium (Na)	**0.73**	**-0.66**	0.01
vanadium (V)	**0.73**	-0.17	0.09
selenium (Se)	**0.72**	0.13	0.08
arsenic (As)	**0.72**	0.21	0.06
copper (Cu)	**0.70**	**0.59**	0.11
manganese (Mn)	**0.68**	0.26	0.33
lead (Pb)	**0.54**	**0.63**	0.11
mercury (Hg)	-0.18	**0.43**	-0.25
molybdenum (Mo)	0.36	0.21	**-0.68**
beryllium (Be)	**0.59**	-0.14	**-0.64**
cadmium (Cd)	**0.45**	0.16	**-0.58**
Eigenvalue	12.0	2.6	1.7
percent of variance explained	54.6	12.0	7.5

(a) Correlation coefficients > | 0.4 | are bolded, and shading is used to identify the PC that best represents the parameter in question. Samples included in this analysis are summarized in Table 5.4.

Mercury, although not generally correlated to most metals, did appear to be positively correlated to lead, as illustrated by high loadings for both metals on PC2 (i.e., 0.43 and 0.63 for mercury and lead, respectively - Table 5.6). Sediments with high lead concentrations, therefore, tended to also contain high mercury concentrations and vice versa. The correlation between mercury and PC2 improved substantially when six high non-detectable values in the mercury data set (see Figure 5.4) were removed (i.e., correlation coefficient increased from 0.43 to 0.67), emphasizing the general positive coincidental occurrence of mercury and lead in sediment.

Figure 5.2 Illustration of the Strong Positive Correlation Observed Between Zinc and Cobalt Concentrations in Sediment

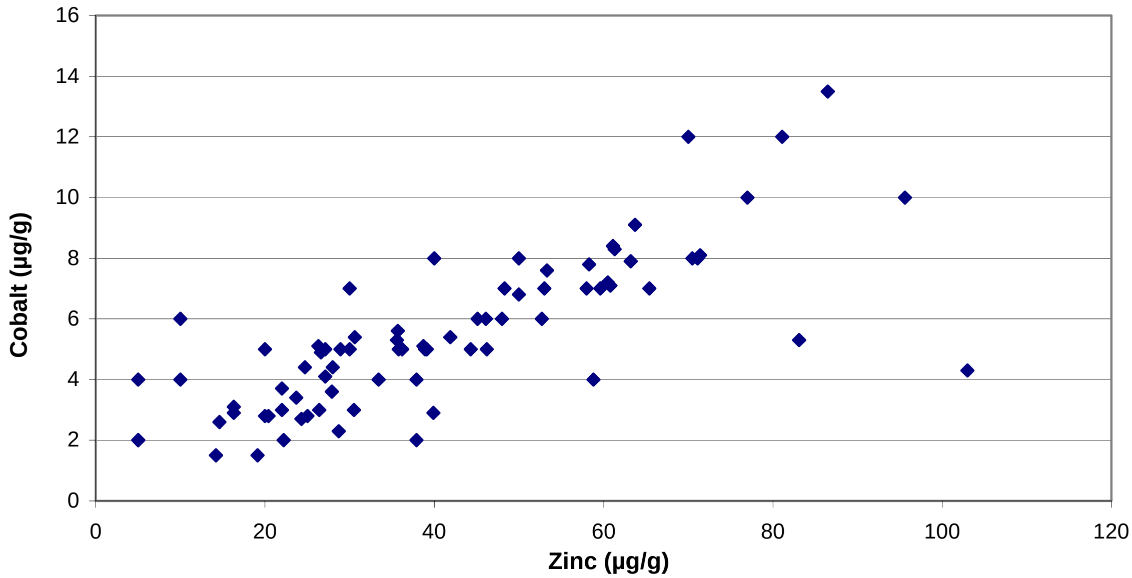


Figure 5.3 Illustration of the Strong Positive Correlation Observed Between Aluminum Concentrations in Sediment and Metal PC1

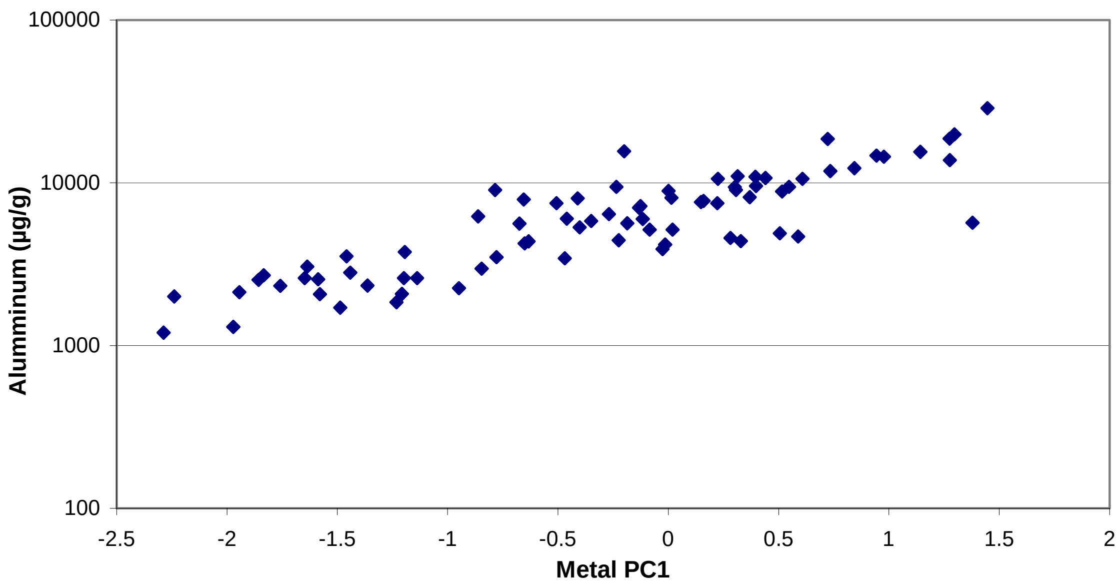
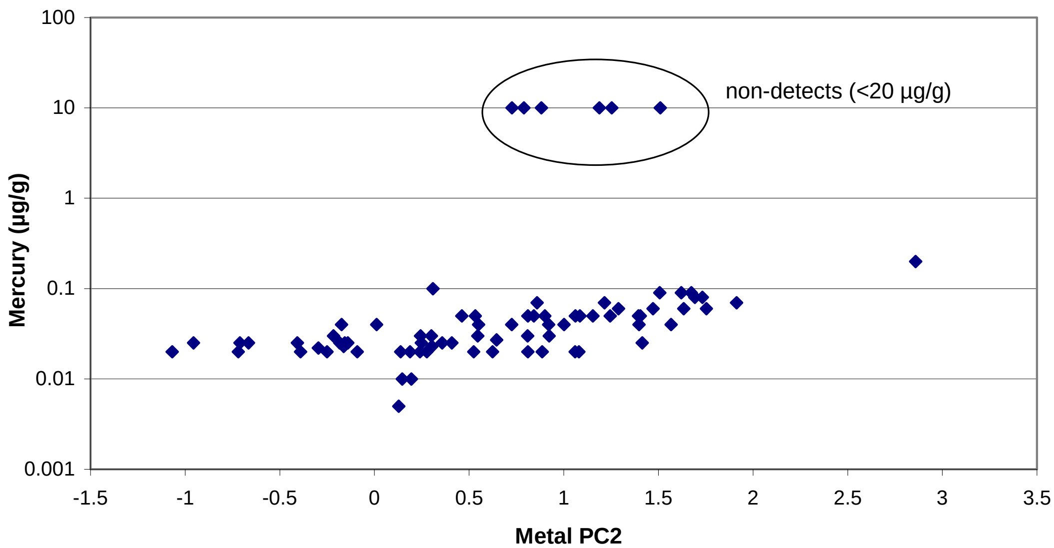


Figure 5.4 Relationship Between Observed Mercury Concentrations in Sediment and Metal PC2



Molybdenum, beryllium and cadmium were most strongly correlated to PC3 (Table 5.6). Uranium and thallium, two of the three metals not included in the metal PCA, were also significantly correlated to PC3 (Table 5.7). A common characteristic of all five of these parameters was the relatively high proportion of non-detectable results present in their respective data sets (i.e., 39, 40, 41, 54 and 65% of the available data for thallium, beryllium, uranium, molybdenum and cadmium, respectively, were non-detectable results). In contrast, the proportion of non-detectable to detectable results for the remaining metals was generally less than 10%.

Boron, the last of the three metals not included in the metal PCA, was significantly, positively correlated to PC1 (Table 5.7), indicating that sediments containing, for example, high cobalt, aluminum or vanadium concentrations also tended to contain high boron levels. The significant correlation of boron to PC1 also indicates that PC1 can be used to indirectly examine trends in boron concentrations in subsequent analyses.

Table 5.7 Correlation of Uranium, Boron and Thallium to Each of the Three Key Principal Components Derived from the Metal Principal Components Analysis

Parameter	Metal PC1[(a)]	Metal PC2[(a)]	Metal PC3[(a)]
uranium	-0.137 (58)	-0.067 (58)	**-0.513***** (58)
thallium	0.415 (44)	0.200 (44)	**-0.661***** (44)
boron	**0.718***** (48)	0.258 (48)	-0.142 (48)

[(a)] PC = principal component; correlation coefficients are presented with sample numbers in parentheses. Significant correlations are bolded, with * = p<0.05, ** = p<0.01 and *** = p<0.001.

5.2.2.3 Correlations Among Organic Parameters

The first two PCs produced from the PAH PCA accounted for approximately 79% of the total variance contained within the two-dimensional input table, with PAH PC1 and PAH PC2 accounting for 69 and 10% of the total variance, respectively (Table 5.8). Successive PAH PCs explained little of the total variance. Furthermore, all of the parameters included in the PAH PCA were correlated with either PAH PC1 or PC2. Therefore, only these first two PAH PCs are discussed herein.

The majority of the PAHs included in the PAH PCA were highly correlated to one another and to TRH levels, as reflected by the high positive correlation (i.e., correlation coefficients ≥ 0.55 - Table 5.8) of all but two parameters to PAH PC1. These results indicate that sediments containing high levels of one PAH often contained high levels of other PAHs, a relationship illustrated in Figure 5.5 using pyrene and fluorene. These results also indicate that sediment containing elevated PAH concentrations also tended to contain high levels of TRH, as illustrated in Figure 5.6.

Table 5.8 Correlation of Individual PAHs and Total Recoverable Hydrocarbons to the Two Key Principal Components Derived from the PAH Principal Components Analysis

Parameter	PAH PC1[(a)]	PAH PC2[(a)]
C2 substituted phenanthrene/anthracene	**0.96**	-0.05
C3 substituted phenanthrene/anthracene	**0.94**	-0.07
C1 substituted fluoranthene/pyrene	**0.94**	-0.07
Pyrene	**0.93**	0.05
Benzo(a)anthracene/chrysene	**0.93**	-0.06
Benzo(a)pyrene	**0.93**	0.01
C1 substituted dibenzothiophene	**0.93**	0.06
Benzo(g,h,i)perylene	**0.92**	0.10
Dibenzothiophene	**0.92**	0.03
Fluoranthene	**0.91**	0.13
C4 substituted phenanthrene/anthracene	**0.91**	0.10
Benzofluoranthenes	**0.90**	-0.04
Phenanthrene	**0.89**	0.28
Indeno(1,2,3,cd)pyrene	**0.89**	0.12
C2 substituted dibenzothiophene	**0.89**	-0.19
C1 substituted phenanthrene/anthracene	**0.85**	0.08
Fluorene	**0.84**	0.27
Total recoverable hydrocarbons	**0.83**	-0.20

Table 5.8 Correlation of Individual PAHs and Total Recoverable Hydrocarbons to the Two Key Principal Components Derived from the PAH Principal Components Analysis (continued)

Parameter	PAH PC1[(a)]	PAH PC2[(a)]
C3 substituted naphthalenes	**0.82**	0.19
C1 substituted fluorene	**0.79**	-0.22
C4 substituted naphthalenes	**0.79**	-0.34
Acenaphthene	**0.77**	0.22
C3 substituted dibenzothiophene	**0.75**	**-0.47**
C3 substituted fluorene	**0.68**	**-0.43**
C2 substituted benzo(a)anthracene/chrysene	**0.67**	**-0.53**
C1 substituted benzo(a)anthracene/chrysene	**0.58**	**-0.50**
C2 substituted naphthalenes	**0.55**	**0.44**
Naphthalene	**0.45**	**0.78**
C1 substituted naphthalenes	**0.44**	**0.70**
Eigenvalue	19.9	2.8
percent of variance explained	68.5	9.6

(a) Correlation coefficients > | 0.4 | are bolded, and shading is used to identify the PC that best represents the parameter in question. Samples included in this analysis are summarized in Table 5.4.

Figure 5.5 Illustration of the Strong Positive Correlation Observed Between Pyrene and Fluorene Concentrations in Sediment

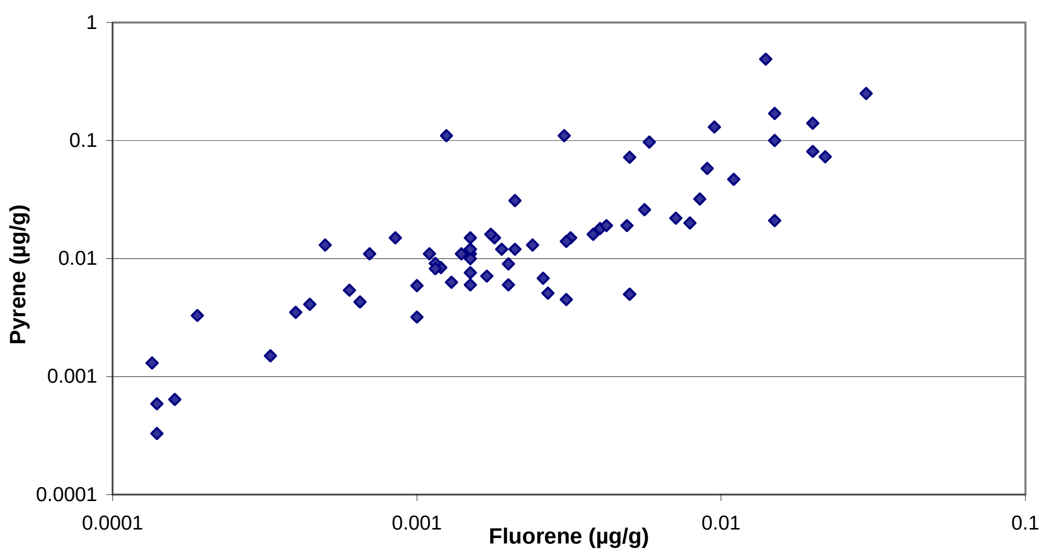
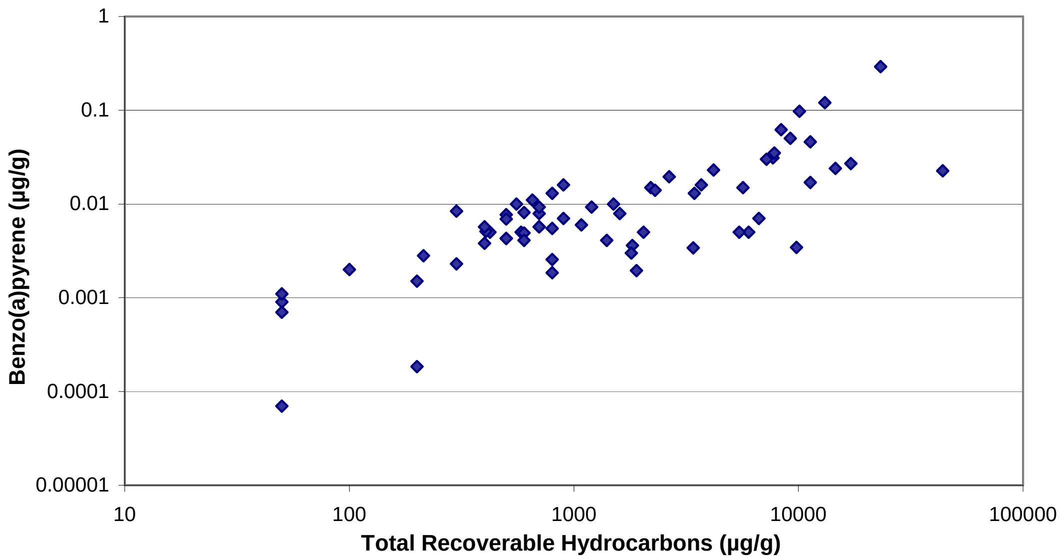
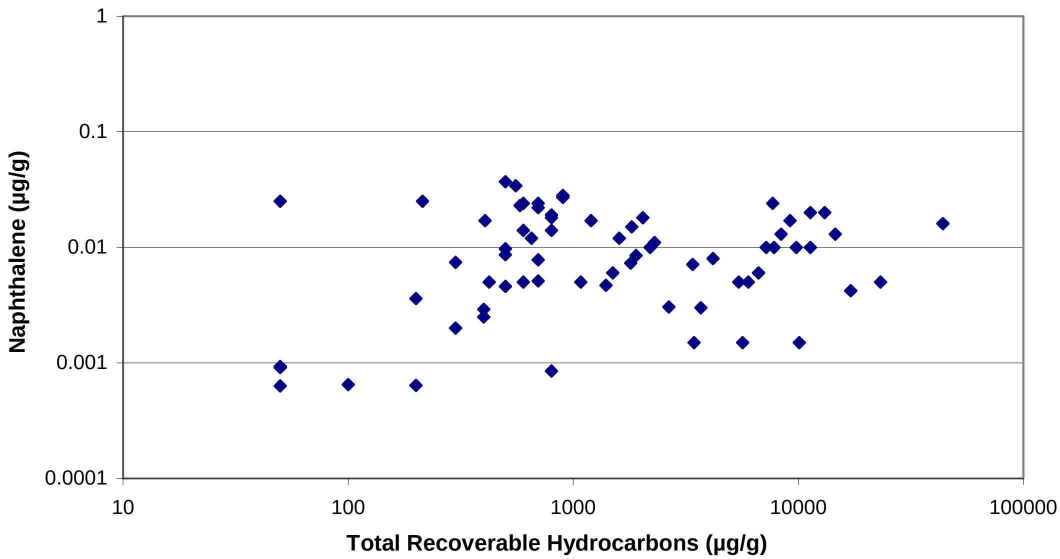


Figure 5.6 Illustration of the Strong Positive Correlation Observed Between Benzo(a)pyrene Concentrations and Total Recoverable Hydrocarbon Content



Although the correlation coefficients derived for naphthalene and C1 substituted naphthalene in relation to PAH PC1 were greater than 0.4, these two parameters were more strongly correlated to PAH PC2 (Table 5.8). This finding suggests that different physical and/or chemical mechanisms influence the distribution of naphthalene and C1 substituted naphthalene in the environment, relative to those controlling the distribution of other PAHs in the environment. Hence, the poor relationship observed between naphthalene concentrations and TRH levels (Figure 5.7). Two such mechanisms may include the fact that naphthalene, for example, is more easily biodegraded and volatilizes faster than other PAHs (CCME 1999).

Figure 5.7 Illustration of the Weak Correlation Observed Between Naphthalene Concentrations and Total Recoverable Hydrocarbon Content



As was observed in the metal analysis, parameters not included in the PCA due to data limitations were found to be significantly correlated to one of the key PCs produced from the PCA. In this case, all 10 parameters not included in the PAH PCA (i.e., C1 substituted acenaphthene, biphenyl, C1 and C2 substituted benzofluoranthene/benzo(a)pyrene, C4 substituted dibenzothiophene, 1-methyl-7-isopropyl-phenanthrene (retene), C2 and C3 substituted fluoranthene/pyrene, C2 substituted fluorene and TEH) demonstrated significant, positive correlations to PAH PC1 (Table 5.9).

These results suggest that concentrations of the nine PAHs and alkylated PAHs listed above followed similar patterns to those observed for parameters included in the PCA. In other words, sediments containing high levels of pyrene or another PAH included in the PAH PCA also generally contained high levels of biphenyl and high levels of the other parameters listed in Table 5.9. The results also indicate that sediments with high TEH levels also contain high PAH and TRH concentrations, and vice versa.

Table 5.9 Correlation of Parameters Excluded from the PAH Principal Components Analysis to the Two Key Principal Components Derived from that Analysis

Parameter	PAH PC1[(a)]	PAH PC2[(a)]
C1 substituted acenaphthene	**0.721***** (68)	-0.186 (68)
Biphenyl	**0.702***** (68)	-0.157 (68)
C2 substituted benzofluoranthene/benzo(a)pyrene	**0.749***** (68)	**-0.467**** (68)
C1 substituted benzofluoranthene/benzo(a)pyrene	**0.707***** (68)	**-0.428*** (68)
C4 substituted dibenzothiophene	**0.610***** (53)	**-0.495*** (53)
1-methyl-7-isopropyl-phenanthrene (retene)	**0.658***** (45)	0.353 (45)
Total extractable hydrocarbons	**0.771***** (41)	-0.146 (41)
C2 substituted fluoranthene/pyrene	**0.931***** (41)	0.044 (41)
C3 substituted fluoranthene/pyrene	**0.881***** (41)	0.004 (41)
C2 substituted fluorene	**0.737***** (41)	-0.174 (41)

[(a)] Correlation coefficients are presented with sample numbers in parentheses. Significant correlations are bolded, with * = $p<0.05$, ** = $p<0.01$, *** = $p<0.001$.

5.2.2.4 Influence of Sediment Composition on Sediment Chemistry

Comparisons of sediment sand, silt and clay content to the three key metal PCs discussed in Section 5.2.2.2 indicate that metal concentrations were significantly correlated to sediment composition, with the possible exception of those parameters represented by metal PC3 (i.e., beryllium, cadmium, uranium, thallium and molybdenum) (Table 5.10). However, as previously noted, the parameters correlated to metal PC3 contained relatively large numbers of non-detectable results. As such, the lack of a significant relationship between metal levels and sediment composition is not unexpected for these five metals.

With respect to the organics, PAH PC1 was significantly correlated to TOC content, whereas PAH PC2 was not (Table 5.10). In a similar contrast, PAH PC2 was positively correlated to silt content, whereas PAH PC1 was not. The relationship between PAH PC2 and silt content was not, however, as strong as that observed with the metal PCs (see Figures 5.8 and 5.9).

As previously discussed, significant positive and negative correlations were observed between TOC content and clay and sand content, respectively (Table 5.5). Neither PAH PC1 nor PAH PC2 was significantly correlated to either of these parameters (Table 5.10). This paradoxical result suggests that PAHs represent a small component of the TOC present in sediments taken from the lower Athabasca River watershed. As such, TOC content can not be used effectively to indirectly monitor PAH levels in sediment.

Table 5.10 Correlation Between Parameters Describing Sediment Composition to Those Describing Sediment Chemistry

Parameter	TOC[a,b]	Percent clay [a]	Percent sand[a]	Percent silt[a]
Metal PC1	-	**0.663***** (65)	**-0.787***** (65)	**0.819***** (64)
Metal PC2	-	**0.680***** (65)	**-0.782***** (65)	**0.762***** (64)
Metal PC3	-	-0.145 (65)	0.147 (65)	-0.042 (64)
PAH PC1	**0.375*** (67)	0.376 (62)	-0.370 (62)	0.324 (61)
PAH PC2	0.062 (67)	0.255 (62)	-0.348 (62)	**0.455**** (61)

[a] Correlation coefficients are presented with sample numbers in parentheses. Significant correlations are bolded, with * = p<0.05, ** = p<0.01, *** = p<0.001.

[b] - = not tested.

Figure 5.8 Illustration of the Positive Correlation Observed Between Sediment Silt Content and Corresponding Metal Levels Expressed in terms of Metal PC1

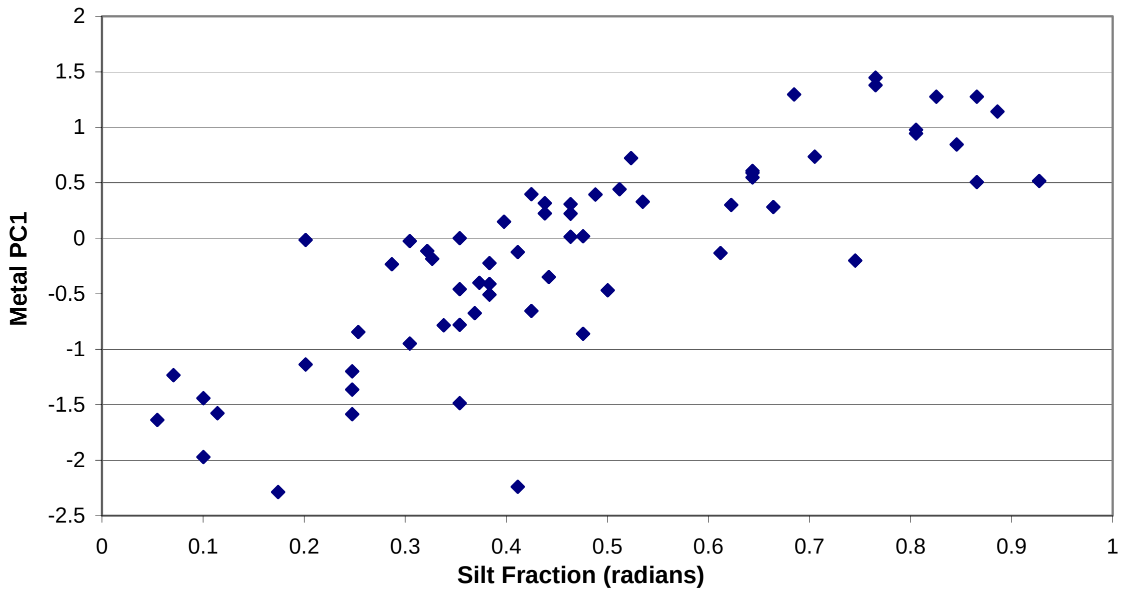
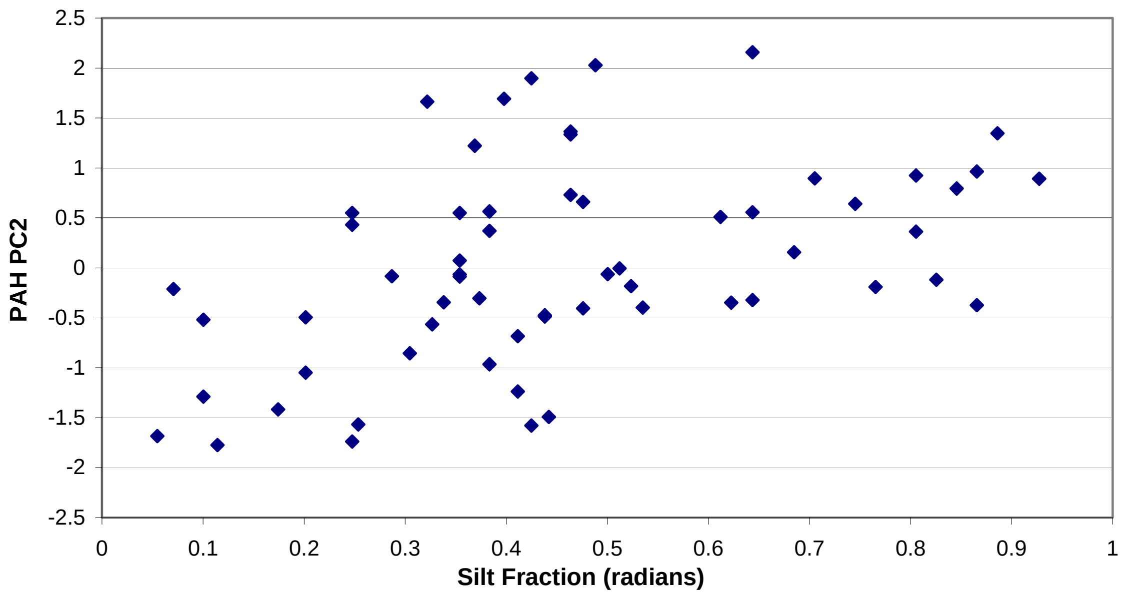


Figure 5.9 Illustration of the Positive Correlation Observed Between Sediment Silt Content and Corresponding Naphthalene and C1 substituted Naphthalene Levels Expressed in terms of PAH PC2



Based on the metal and PAH results described above, the following patterns were observed within the RAMP study area:

- Sediments with high silt content generally contained elevated naphthalene and C1 substituted naphthalene concentrations in comparison to sediments with lower silt content.
- Sediments with high silt and/or clay content tended to contain higher metal concentrations than those with lower silt and clay content.
- High sand content was generally accompanied by low metal concentrations.

5.2.3 Conclusions and Recommendations

Based on the results presented in Section 5.2.2, sediments collected from the RAMP study area exhibited the following patterns:

- High silt content was generally accompanied by high clay and low sand content.

- Metal concentrations tended to follow consistent, positively correlated trends, whereby sediments containing high levels of, for example, aluminium, also generally contained high levels of cobalt, nickel, vanadium and other metals. Exceptions to this general pattern included mercury and molybdenum, although mercury concentrations tended to be high in sediments with high lead levels.
- PAH concentrations tended to follow similar consistent, positively correlated trends, whereby sediments containing high levels of, for example, pyrene, also generally contained high levels of fluorene, acenaphthene and other parent and alkylated PAHs. Exceptions to this general pattern included naphthalene and C1 naphthalene, two parameters strongly correlated to each other with weaker correlation to other parameters included in the organics analysis.
- With the possible exception of metals with a high proportion of non-detectable results (beryllium, cadmium, uranium, thallium and molybdenum), sediments with high silt and/or clay content generally contained higher metal levels than those with larger amounts of sand and less silt and/or clay.
- PAH levels were not significantly correlated to sediment composition, with the exception of naphthalene and C1 naphthalene. Concentrations of these two compounds were significantly, positively correlated to silt content.

Other conclusions that can be drawn from the results presented in Section 5.2.2 include the following:

- TOC content could not be used effectively to indirectly monitor PAH levels in sediment.
- It may be unnecessary for RAMP to monitor both TRH and TEH, since they are highly correlated to one another.
- The number of PAHs included in the RAMP parameter list could be reduced, in reflection of the high correlation observed between almost all of the parent and alkylated PAHs included in the organics analysis.
- Comparable reductions in the metals test list could be pursued for similar reasons. However, limited financial gain would result, because metals are generally analyzed using broad spectrum scans. Thus, the incremental cost associated with adding or subtracting elements to the scan is small.
- The strong correlations observed between TRH and almost all of the PAHs (parent and alkylated) included in the organics analysis suggests that TRH could be used as an indicator of PAH content in areas where naphthalene and C1 naphthalene concentrations are not expected to change as a result of development.

Building upon these conclusions, it is recommended that the RAMP Water and Sediment Subgroup of the Technical Subcommittee consider revising the "Organics" and "PAH" portions of the standard sediment parameter list (see Table 5.2), as well as the 2003 to 2009 study plan described in Golder (2002f). Suggested changes include the following:

- dropping TEH from the parameter list;
- reducing standard PAH testing to naphthalene and C1 naphthalene; and
- using TRH as a surrogate for the remaining PAHs, with more extensive PAH analysis occurring only once every two to three years.

In combination, these changes could results in cost savings of approximately $300 per sample. Based on the 39 samples included in the 2002 sediment sampling program (Golder 2002f), these modifications would reduce the sediment program's analytical costs by approximately $11,700 per year.

5.3 DETECTING AND ASSESSING REGIONAL TRENDS

5.3.1 Temporal Trends

The investigation into temporal trends in the sediment quality data set included an examination of the temporal variability at the following locations:

- the mouth of the Muskeg River;
- along the east and west banks of the Athabasca River upstream of Donald Creek; and
- along the east and west banks of the Athabasca River upstream of Fort Creek.

5.3.1.1 Methods

The nonparametric Mann-Kendall test for trend was used in combination with Sen's slope estimation procedure (Gilbert 1987) to determine both the magnitude and potential significance of apparent temporal trends observed in the data collected from the five locations listed above. Data from the east and west banks in the Athabasca River were combined and analyzed together to meet the minimum data requirements for a two-tailed test with a level of significance of 0.05. The analysis was performed using WQStat Plus (IDT 1998), with required modifications to accommodate samples collected during the same time period. Parameters considered in this investigation included the five PCs discussed in Section 5.2.

5.3.1.2 Results and Discussion

No significant temporal trends were observed at the mouth of the Muskeg River or in the Athabasca River upstream of Fort Creek (Table 5.11). In the Athabasca River upstream of Donald Creek, two of the five parameters (i.e., metal PC1 and metal PC2) were shown to be experiencing significant decreasing trends between 1997 and the end of 2001, as illustrated in Figures 5.10 and 5.11. Based on the relationships of individual metals to each of these PCs (see Table 5.6), these results indicate that metal levels at this sample location have been, with the possible exception of metals with a high proportion of non-detestable results (beryllium, cadmium, uranium, thallium and molybdenum), significantly declining since the initiation of RAMP in 1997.

Although no other significant trends were observed, the estimated slopes calculated for each parameter at each location were negative, with the exception of metal PC3 at the mouth of the Muskeg River. These findings suggest that, since 1997, oil sands development within the lower Athabasca River watershed has not resulted in increased sediment metal or PAH concentrations at the mouth of the Muskeg River or in the Athabasca River upstream of Fort Creek.

Table 5.11 Summary of Temporal Trends Observed in Sediments Collected from the Mouth of the Muskeg River and from the Athabasca River, Upstream of Donald and Fort Creeks

Location	Parameter	Sen's slope (units/yr)[(a)]	Sample size
mouth of the Muskeg River	metal PC1	-0.161	5
	metal PC2	-0.066	5
	metal PC3	0.384	5
	PAH PC1	-0.248	5
	PAH PC2	-0.736	5
Athabasca River upstream of Donald Creek	metal PC1	**-0.543***	7
	metal PC2	**-0.361***	7
	metal PC3	-0.261	7
	PAH PC1	-0.514	7
	PAH PC2	-0.284	7
Athabasca River upstream of Fort Creek	metal PC1	-0.114	7
	metal PC2	-0.254	7
	metal PC3	-0.045	7
	PAH PC1	-0.125	7
	PAH PC2	-0.532	7

(a) Significant slopes, which are indicative of significant temporal trends, are bolded with * = $p<0.05$.

Figure 5.10 Temporal Trend Observed in Metal PC1 Scores in the Athabasca River Upstream of Donald Creek

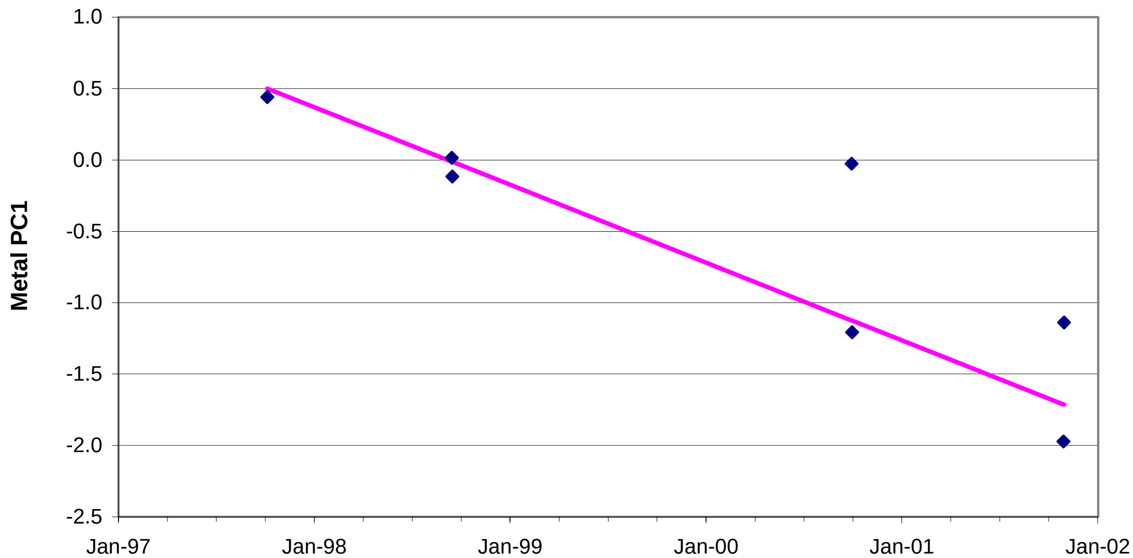
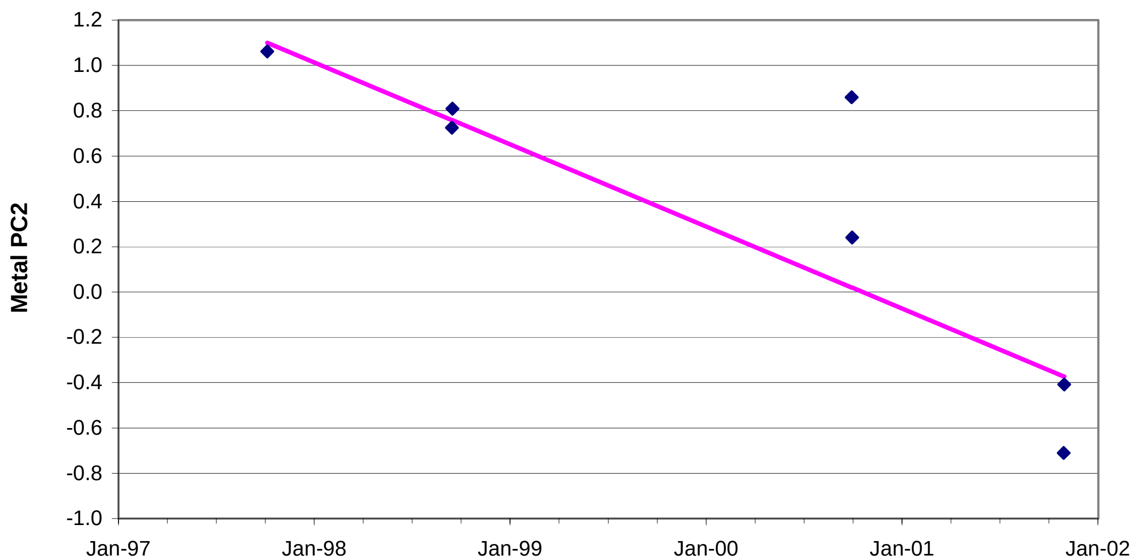


Figure 5.11 Temporal Trend Observed in Mercury and Lead Concentrations (represented by Metal PC2) in Sediments Collected from the Athabasca River Upstream of Donald Creek



5.3.1.3 Conclusions and Recommendations

With the possible exception of beryllium, cadmium, uranium, thallium and molybdenum, metal and PAH concentrations in sediments collected from the mouth of the Muskeg River and in the Athabasca River upstream of Fort Creek have been declining over time, as have metal and PAH concentrations in sediments collected from the Athabasca River upstream of Donald Creek. Although these trends were not all statistically significant, they suggest that oil sands development within the lower Athabasca River watershed has not resulted in increased sediment metal or PAH concentrations at either downstream location (i.e., mouth of the Muskeg River and in the Athabasca River upstream of Fort Creek) since the initiation of RAMP in 1997.

5.3.2 Spatial Trends

The examination of spatial trends in sediment quality within the lower Athabasca River included the following:

- a general overview of spatial variations in the RAMP study area based on sediment composition, metal concentrations and PAH levels; and
- a focused analysis of potentially significant variations in metal and PAH concentrations along the length and width of the Athabasca River.

Consistent with the temporal trend analysis, spatial variations in PAH and metal concentrations were evaluated indirectly using the key metal and PAH PCs identified in Section 5.2.

5.3.2.1 Methods

General spatial patterns were examined using sediment distribution figures (i.e., adapted piper plots) and ordination plots derived from the metal and PAH PCAs described in Section 5.2. The resolution used in this analysis was limited to four categories that included the Athabasca River mainstem, Athabasca River tributaries, Muskeg River watershed and the three wetlands sampled by RAMP (i.e., Shipyard, Isadore's and Kearl lakes).

Potentially significant variations in metal and PAH concentrations along the length and width of the Athabasca River were analyzed using a two-step process. For each of the five parameters considered in this investigation (i.e., metal PC1, metal PC2, metal PC3, PAH PC1 and PAH PC2), a two-way analysis of variance (ANOVA) model was first used to test for the significance of potential bank and location effects, with year included as a blocking variable. The construction of the resulting model was as follows: model = constant + year + location + bank + bank*location. The F-ratio for each term was calculated using the remainder or error mean sum of squares (MS) as the denominator.

If both the bank and bank*location terms were not significant (i.e., $p \geq 0.05$), then the two-way ANOVA was reduced to a single factor ANOVA, with year continuing to act as a blocking variable (i.e., model = constant + location + year). F-ratios were again calculated using the remainder or error MS as the denominator. Year was included as a blocking variable in both ANOVAs to account for the potential effects of varying flow conditions and other environmental variables on sediment quality. The effects of these environmental variables, including flow, were assumed to be consistent across all locations and both banks. Hence, the exclusion of the interaction terms involving year from the three-way and two-way ANOVAs.

The design of the ANOVAs described above follows from randomized block design discussed in Zar (1984) and similar block models discussed in Neter et al. (1990). When significant results were detected in either ANOVA, other than those associated with year, post-hoc Tukey tests were used to identify the significantly different pairs. If the significant results were related to metal PC1, metal PC2 or PAH PC2, the relevant analysis was repeated with individual metal PC1, metal PC2 or PAH PC2 scores normalized for silt content.

This normalization was completed using linear regression models with the form PC score = slope*(silt content) + intercept. For each individual measurement, the PC score predicted by the relevant regression equation was subtracted from the original observation to produce a series of residuals. The mean of the original data series was then added to each residual. Where required, a final correction factor was added to each sum to produce a series of silt-adjusted PC scores that had the same mean as the original data series produced by the relevant metal or PAH PCA. This normalization procedure was based on the flow-adjustment procedure described in IDT (1998), and all of the statistical analysis described above was completed using SYSTAT 10 (SPSS 2000).

Discussions of significant and non-significant effects were limited to those associated location, bank and bank*location terms. Significance related to year was not included, since temporal trends were examined separately using Mann-Kendall test procedures and are discussed in Section 5.3.1.

5.3.2.2 Results and Discussion

General Patterns in the Oil Sands Region

As illustrated in Figure 5.12, wetlands sediments generally contained the least amount of sand, in comparison to sediments collected from the Athabasca River, the Muskeg River watershed and from tributaries of the Athabasca River. Sediments collected from tributaries of the Athabasca River, including those from the Muskeg River watershed, typically contained more than 60% sand, with the remaining 40% consisting of approximately equal portions of silt and clay. Athabasca River sediments generally contained less than 30% silt, with widely ranging sand and clay components.

Metal concentrations, as described by metal PC1 and PC2, were highest in the silt and clay dominated wetlands sediments (Figure 5.13), illustrating the inverse relationship between sand content and metal concentrations discussed in Section 5.2. The positive correlation of metal PC1 and metal PC2 observed in samples collected from the Athabasca River and the Muskeg River watershed (see Figure 5.13) indicates that, within these areas, sediments containing high or low levels of aluminum, cobalt and other metals represented by metal PC1 also contained corresponding high or low concentrations of mercury and lead (the two parameters represented by metal PC2). This correlation between metal PC1 and metal PC2 was not observed in the other Athabasca River tributaries.

The metal PC1 versus metal PC2 ordination plot (Figure 5.13) also indicates that:

- metal levels measured in sediments from the Muskeg River watershed tend to be lower than those in the Athabasca River; and
- mercury and lead concentrations were generally higher in Athabasca River tributary sediments than in samples taken from the Muskeg River watershed.

No spatial trends were observed with respect to metal PC3 in any of the four sample groups (Figure 5.14). This was likely due to the prevalence of non-detectable values in the molybdenum, beryllium and cadmium data sets.

Similarly, no spatial trends were observed in the distribution of either naphthalene or C1 naphthalene among the different waterbodies (represented by PAH PC2 in Figure 5.15). However, concentrations of pyrene, fluorene and other PAH represented by PAH PC1 were generally lower in Athabasca River sediments, in comparison to those collected from Athabasca River tributaries other than the Muskeg River watershed. PAH content in sediments from the

Muskeg River watershed was comparable to that of the Athabasca River and lower than that observed in the other Athabasca River tributaries.

Figure 5.12 Variations in Sediment Composition as a Function of Sample Location

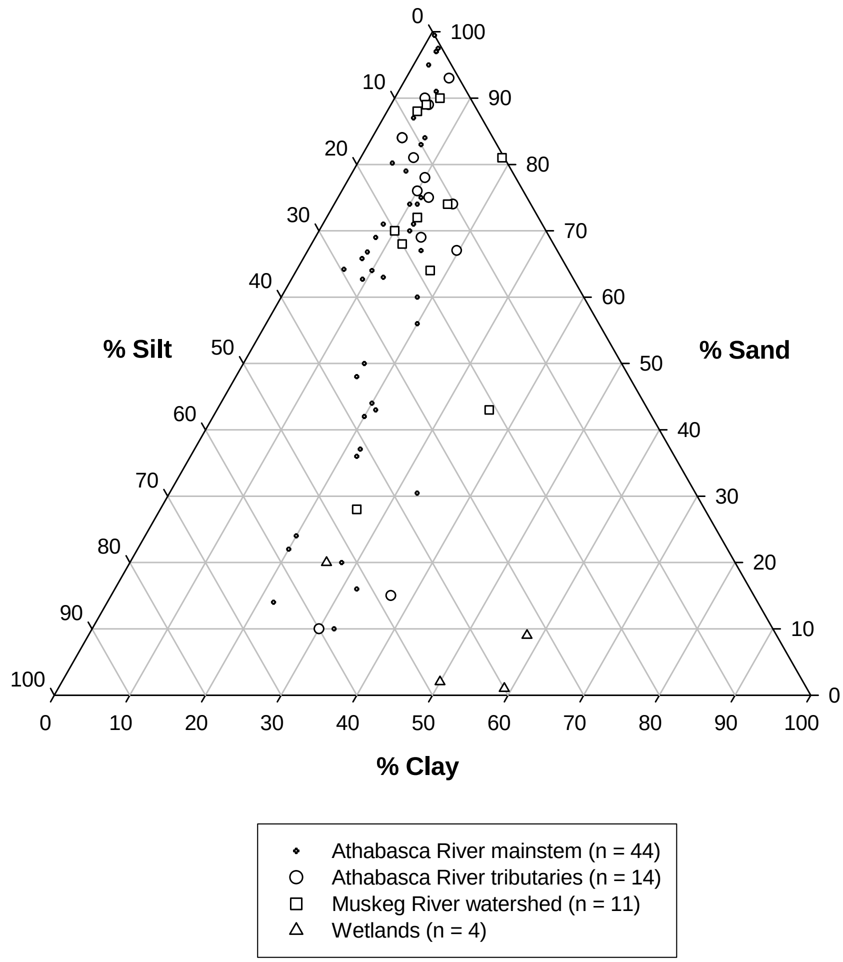


Figure 5.13 Plot of Metal PC1 Against Metal PC2 Including Sediment Samples Collected Over the Entire RAMP Study Area

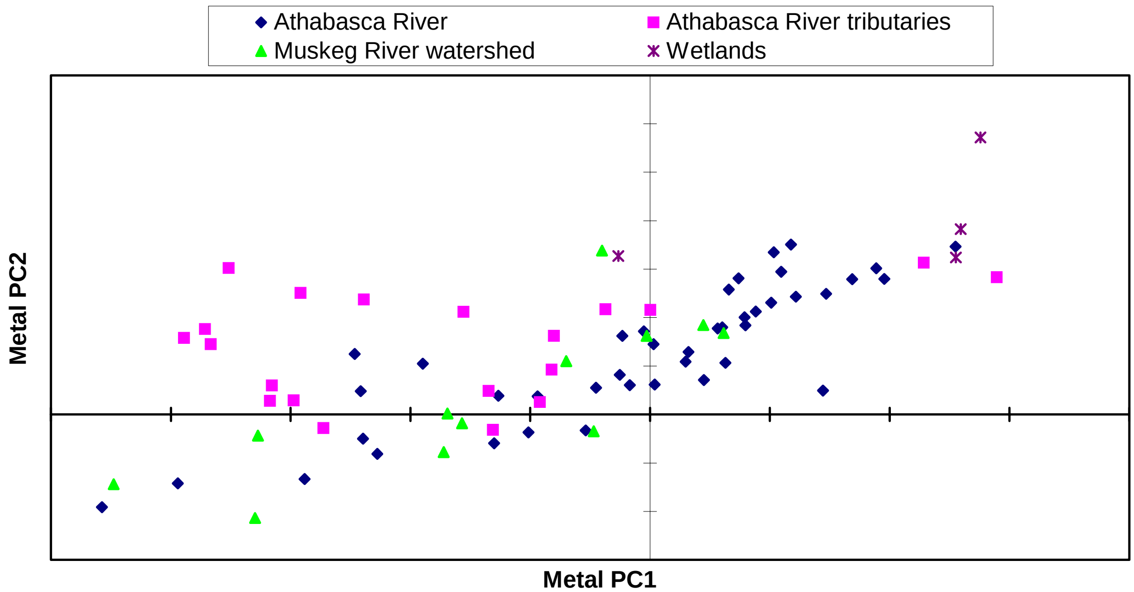


Figure 5.14 Plot of Metal PC1 Against Metal PC3 Including Sediment Samples Collected Over the Entire RAMP Study Area

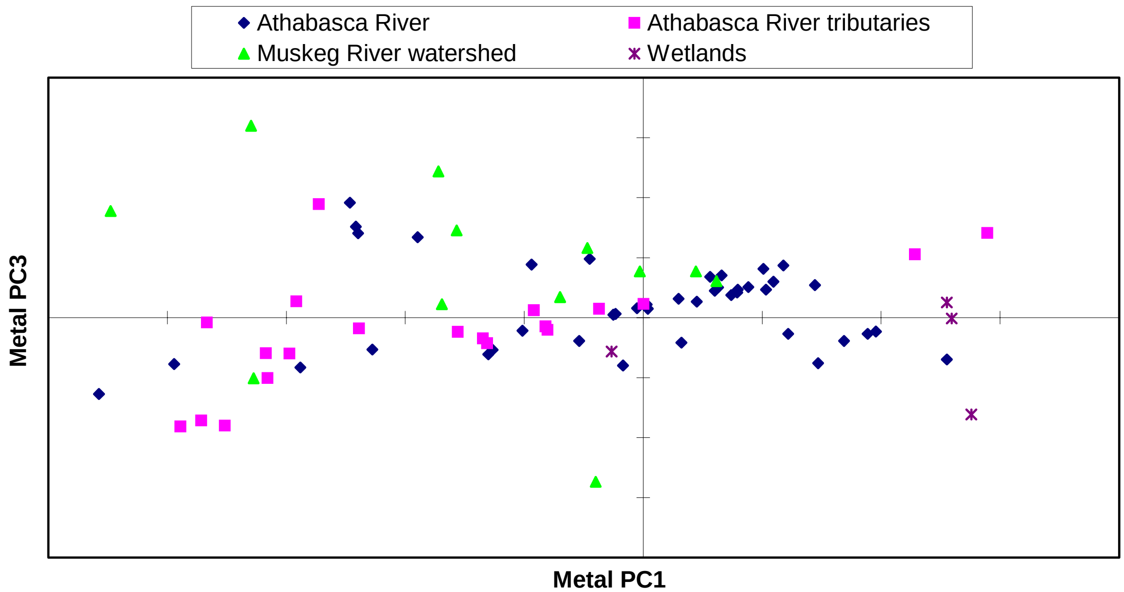
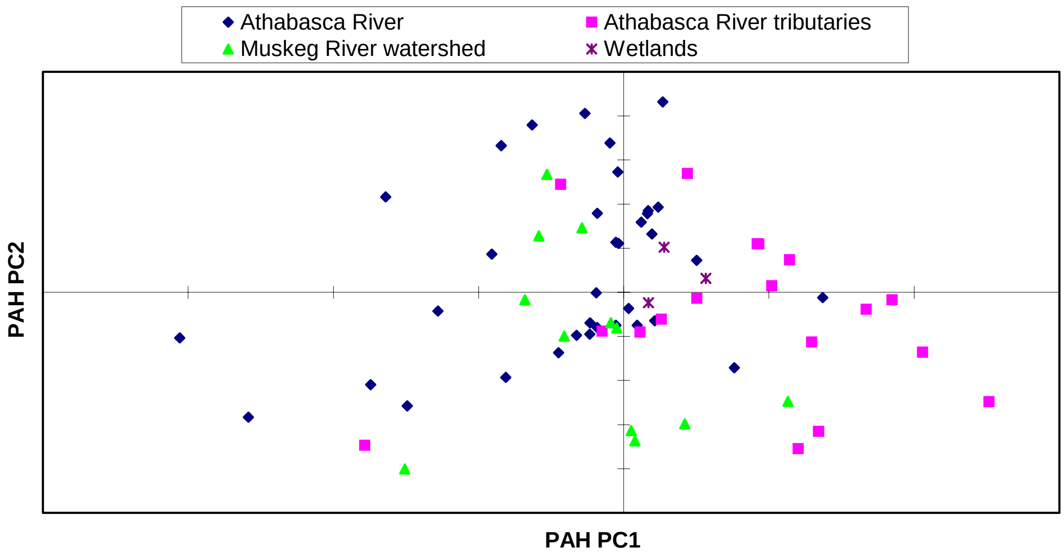


Figure 5.15 Plot of PAH PC1 Against PAH PC2 Including Sediment Samples Collected Over the Entire RAMP Study Area



Trends along the Width and Length of the Athabasca River

No significant bank or bank*location effects were observed for metals or PAHs in any of the two-way ANOVAs. As illustrated in Figures 5.16 and 5.17, metal concentrations, with the possible exception of those associated with PC3 (i.e., molybdenum, cadmium, beryllium, uranium and thallium), were generally higher in sediments collected upstream of the Embarras River and in the Delta than in samples collected between Fort McMurray and Fort Creek. Statistically significant differences were observed with both metal PC1 and metal PC2, but not with metal PC3 ($p < 0.05$, $p < 0.001$ and $p > 0.6$, respectively). Pairwise Tukey tests revealed that sediments collected upstream of Donald Creek contained significantly lower metal concentrations (as represented by metal PC1) than those taken from the Delta (Table 5.12).

Mercury and lead concentrations (represented by metal PC2) were also found to be significantly higher in sediments collected from the Delta and upstream of the Embarras River than in those collected between Fort McMurray and the Muskeg River. However, when tests were repeated using silt-adjusted values, no significant variations among the six locations were detected ($p > 0.45$ for both metal PC1 and metal PC2). These results are reflective of the following facts:

- sediments collected from the Delta and upstream of the Embarras River contained higher silt and clay content than those collected from upstream sample sites (Figure 5.18); and

- as discussed in Section 5.2, metal concentrations in the RAMP study area were found to be positively correlated to silt and clay content, a relationship established using sediments from a wide range of locations.

Consequently, the elevated metal concentrations observed in the Delta and upstream of the Embarrass River result from variations in sediment composition.

Figure 5.16 Plot of Metal PC1 Against Metal PC2 Using Sediment Samples Collected From the Athabasca River

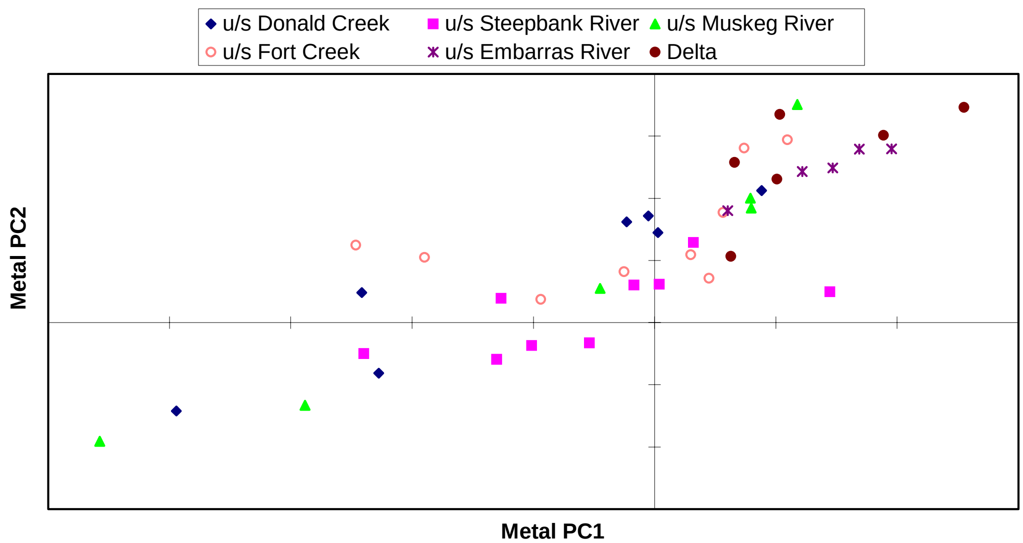


Figure 5.17 Plot of Metal PC1 Against Metal PC3 Using Sediment Samples Collected From the Athabasca River

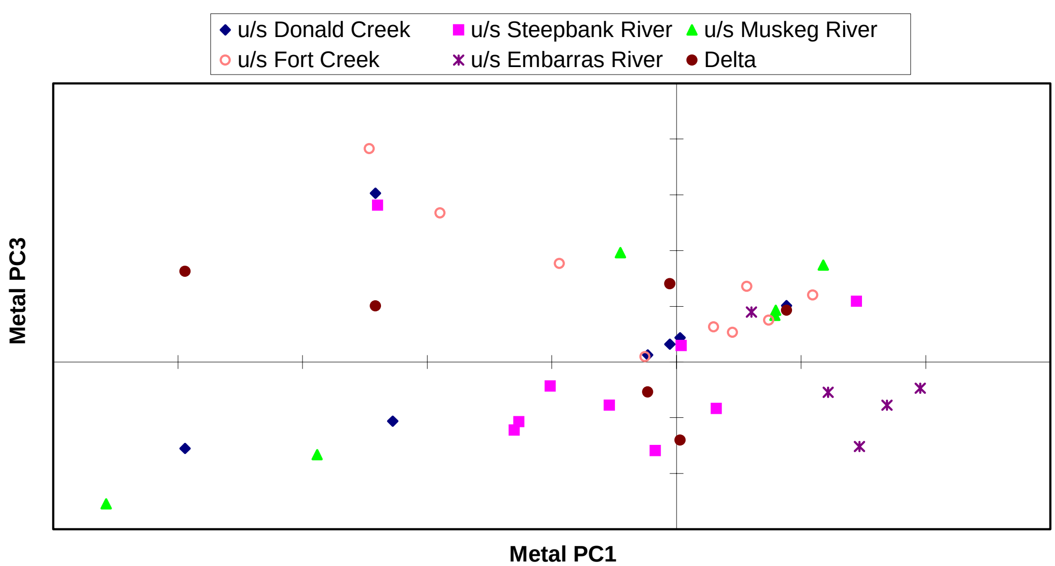


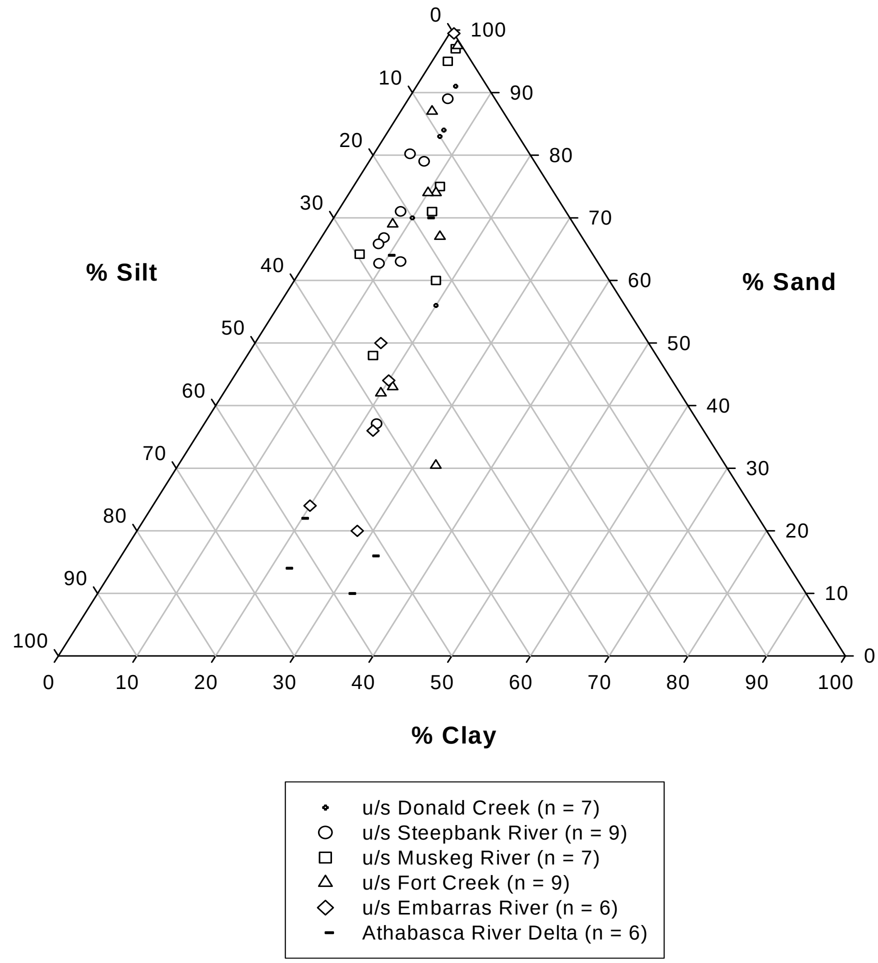
Table 5.12 Results of the Post-hoc Tukey Test Identifying Locations in the Athabasca River with Significantly Different Metal Concentrations

Location	Metal PC1			Metal PC2		
	Mean	Stdev.[(a)]	Tukey test results[(b)]	Mean	Stdev.[(a)]	Tukey test results[(b)]
upstream of Donald Creek	-0.572	0.872 (7)	1	0.368	0.686 (7)	1
upstream of the Steepbank River	-0.241	0.813 (4)	12	0.030	0.288 (4)	1
upstream of the Muskeg River	-0.429	1.176 (6)	12	0.389	1.044 (6)	1
upstream of Fort Creek	-0.077	0.609 (7)	12	0.714	0.514 (7)	12
upstream of the Embarras River	0.518	0.306 (2)	12	1.072	0.244 (2)	23
Athabasca River Delta	0.588	0.396 (5)	2	1.276	0.483 (5)	3

(a) Stdev. = standard deviation, with sample number in parentheses.

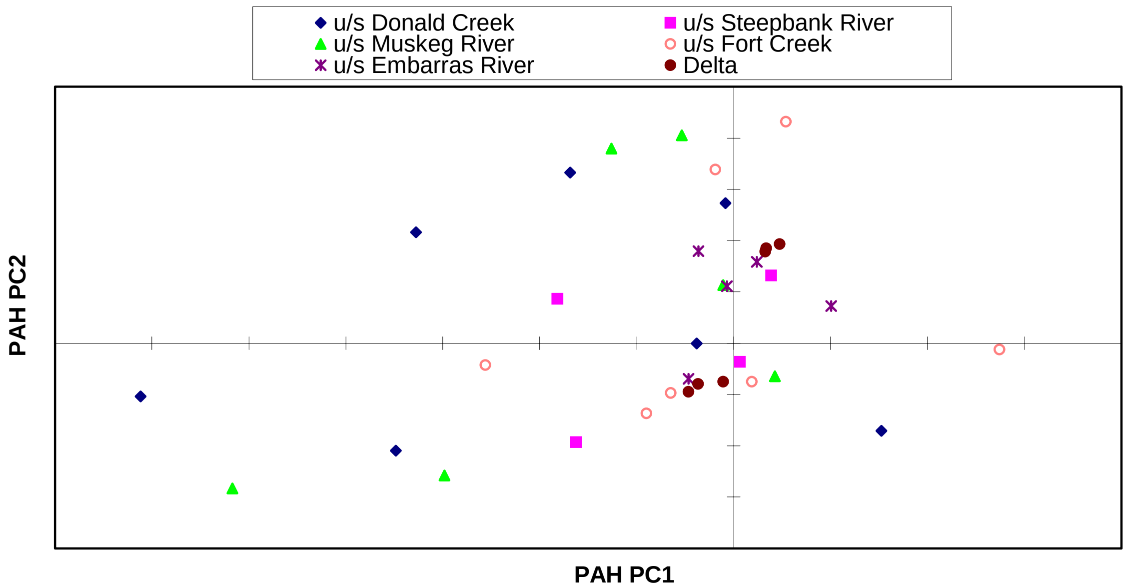
(b) Numbers are used to identify significantly different concentrations, whereby locations with different numbers were found to be significantly different from one another ($p < 0.05$).

Figure 5.18 Variations in Sediment Composition Within the Athabasca River as a Function of Sample Location



No distinct spatial patterns in PAH concentrations in Athabasca River sediment were observed (Figure 5.19), and no significant effects were detected. Derived F-statistics from the relevant ANOVAs were 1.36 and 1.96 for PAH PC1 and PAH PC2, respectively. The corresponding p values were both > 0.1. These results mirror those of Brownlee (1990), Brownlee et al. (1997) and Crosley (1996), all of whom found varying PAH levels along the length of the Athabasca River without clear spatial trends.

Figure 5.19 Plot of PAH PC1 Against PAH PC2 Using Sediment Samples Collected From the Athabasca River



5.3.2.3 Conclusions and Recommendations

The following conclusions can be drawn from the spatial analysis described above:

- Metal concentrations in sediments from the Muskeg River watershed tend to be lower than those in sediments from in the Athabasca River, whereas sediment PAH concentrations tend to be comparable between the two systems.
- Mercury, lead and PAH concentrations, excluding naphthalene and C1 naphthalene, are generally lower in Muskeg River watershed sediments than in sediments from the other Athabasca River tributaries sampled by RAMP.

- With the possible exception of metals with a high proportion of non-detectable results (molybdenum, cadmium, beryllium, uranium and thallium), metal concentrations in the Athabasca River are generally higher in sediments collected upstream of the Embarras River and in the Delta than in samples collected between Fort McMurray and Fort Creek.
- The variation in metal levels in the Athabasca River is a reflection of differing sediment composition (i.e., higher proportion of silt and/or clay upstream of the Embarras River and in the Delta).
- PAH concentrations vary over the length of the Athabasca River, with no clear spatial pattern.
- Shipyard, Kearl and Isadore's lakes sediments generally contain higher metal levels and a greater proportion of silt and clay compared to those in the other waterbodies sampled by RAMP.

5.3.3 Ability to Detect Change

The ability of the current RAMP sediment sampling program to detect significant temporal variations in sediment quality at a given location was evaluated based on a comparison of the rate at which RAMP is collecting sediment data and the resolution of the Mann-Kendall test procedure with differing sample sizes. The current program's ability to detect significant spatial variations in sediment quality was examined using power analysis. The focus of the power analysis was to determine the effect size, or relative difference, that could be detected (i.e., deemed significant) in the Athabasca River based on the following:

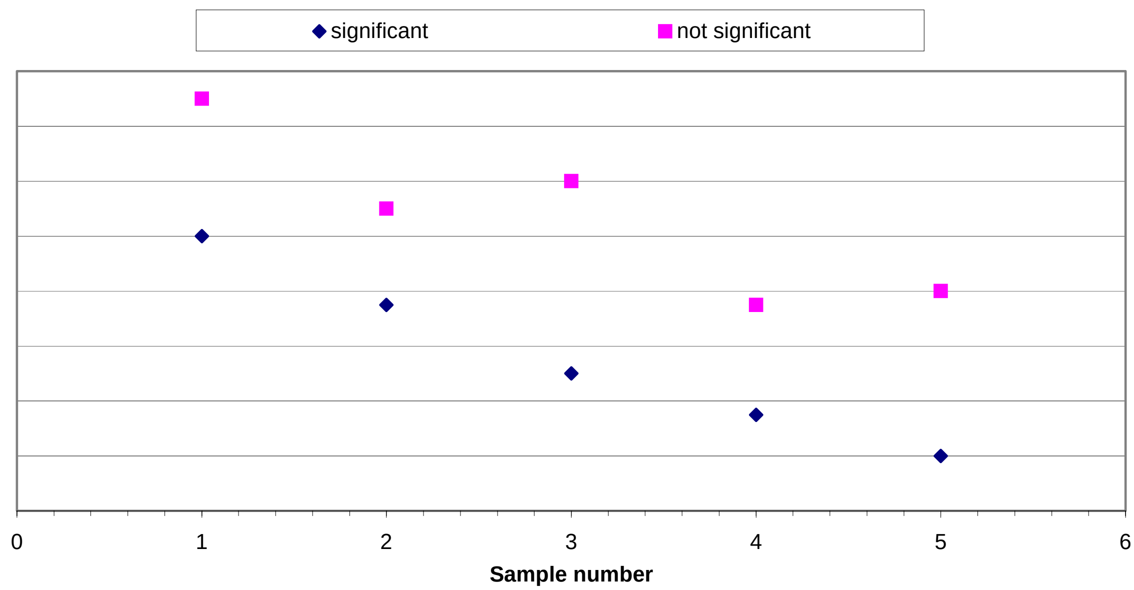
- the data collected to date;
- a doubling of the current sampling effort; and
- a tripling of the current sampling effort.

5.3.3.1 Temporal Trends

The Mann-Kendall test for trend is a nonparametric test that relies on relative magnitudes of the data rather than absolute values. Significance of a trend is determined by looking at how often and how consistently data collected through time are higher or lower than previously collected data (Gilbert 1987). A minimum of four data points are required for this test. However, if one is interested in looking for either a significant upward or downward trend with a 95% test threshold (i.e., theta = 0.05), then at least five data points are required.

With five samples, the resolution of the Mann-Kendall procedure is limited to detecting consistent, monotonic trends. In other words, each consecutive data point has to be lower or higher than the previous one to detect a significant declining or inclining trend, respectively. This limitation is illustrated in Figure 5.20 with two data sets showing similar declining trends, only one of which is statistically significant. Test resolution improves substantially with six or more data points. Significance is no longer dependant on consistent, monotonic characteristics, as is the case with four or five samples.

Figure 5.20 Example of Two Declining Temporal Trends, One of Which is Statistically Significant



As the program is currently designed, RAMP collects three years of sediment data (one sample per year) to define baseline conditions prior to development (Golder 2002f). Based on the data requirements and resolution of the Mann-Kendall procedure, it is recommended that the RAMP Water and Sediment Subgroup of the Technical Subcommittee consider expanding this period of baseline characterization from three to more than five years. This expansion would allow the subcommittee to determine if temporal trends detected after the initiation of development were already occurring under baseline conditions. More than five years of baseline data would also allow for "before and after" comparisons to test for potentially significant step changes, with more reasonable estimates of baseline variance than can be provided with only three baseline samples.

If timelines are such that more than five years are not available for baseline sampling prior to the initiation of development, sediment samples could be collected from multiple seasons in a given year. This type of accelerated sampling schedule would allow for adequate baseline characterization in a shortened period of time. However, caution must be exercised when moving to an accelerated sampling plan since it is important to quantify inter-year variability. The extreme case of collecting all samples in one year would not, for example, be recommended.

This recommendation should not affect the amount of baseline data required to complete the sediment quality component of an EIA. As previously discussed in Section 4.3.3.1, available baseline data can be effectively supplemented by using information from comparable waterbodies and/or probabilistic distributions developed from existing data to predict impacts in an EIA.

5.3.3.2 Spatial Trends

Methods

Power analyses were used to examine the resolution of the current RAMP sediment sampling program. Specific attention was focused on resolving the power of the one-factor ANOVAs used to assess spatial variations within the Athabasca River in terms of the effect size, or relative difference, required for samples to be deemed significantly different. Effect size refers to the difference between the mean concentrations being compared. It is frequently expressed as the percentage of the reference area (e.g., average concentration observed upstream of Donald Creek) to put the magnitude of the effect size into context. Parameters considered in this exercise included those discussed in the spatial trend analysis (i.e., the five PCs from the metal and PAH PCAs).

The effect size associated with each ANOVA was estimated using the same equation from Zar (1984) (i.e., $\delta = (2*k*s^2*\phi^2/n)^{0.5}$) that was described in Section 4.3.3.2. In this case, there were six locations or “levels” of interest (i.e., upstream of Donald Creek, the Steepbank River, the Muskeg River, Fort Creek, the Embarras River and the Athabasca Delta). Therefore, “k” was assigned a value of six, and the DF associated with location was 5 (i.e., k-1). Other assumptions or values used in the analysis are summarized below:

- number of samples per location was set to 6, which is based on having approximately two samples per location (i.e., east and west bank composites) per year over three years;
- effect sizes were estimated using a power of 80%;

- the DF associated with the error term were estimated by subtracting the DF associated with the location and year terms from the total DF available for each ANOVA; and
- the non-centrality parameter for each of the three levels of power was derived by using Figure B.1 from Zar (1984).

To examine how effect size would change with increased sampling effort, the calculations described above were repeated, and samples per level first doubled and then tripled.

It is important to note that power analysis is based on the underlying assumption of equal replication (i.e., same number of samples for each location). Because of the evolving nature of the RAMP sediment sampling program, there is unequal replication among locations. As such, the effect sizes discussed herein are approximate and may not describe the exact resolution of each ANOVA used to detect significant spatial variations along the length of the Athabasca River.

Results and Discussion

As outlined in Table 5.13, the relative difference required for sediment metal or PAH concentrations to have been deemed significantly different from those observed upstream of Donald Creek was large, ranging from 180% for PAH PC1 to >900% for metal PC3 at a power of 80%. The large effect sizes currently detectable by the ANOVAs result from both the limited number of samples available to describe sediment quality at each location and the large within site variability observed at each location, relative to the variation observed among sites. The presence of large within site variability is illustrated, for example, in Figure 5.19 by the high degree of scatter associated with samples collected upstream of Donald Creek.

With increased sampling effort, the projected resolution of the ANOVAs improved, with effect sizes ranging from 94% for PAH PC1 to 672% for metal PC3 at a power of 80% (Table 5.13). These estimates were derived using the same within site variability currently observed in the Athabasca River. However, with increased sampling, it is likely that the estimates of within site variability would decline, resulting in a smaller error term in the ANOVAs. Based on the direct relationship of effect size to the size of the error term, the smaller the error term, the smaller the effect size. Therefore, improvements to the resolution of the ANOVAs used to detect significant spatial variations in the Athabasca River would likely be greater with a greater level of sampling than the levels described herein.

Table 5.13 Resolution of the ANOVA Models Used to Detect Significant Spatial Variations in Metal and PAH Concentrations in the Athabasca River

Parameter	Estimated Effect Size (%) at a Power of 80% [a]		
	With Current Sample Size	Double The Current Sample Size	Triple The Current Sample Size
metals PC1	249	167	131
metals PC2	224	151	118
metals PC3	999	672	525
PAH PC1	180	121	94
PAH PC2	417	280	219

[a] Effect size is expressed as a percentage of the average concentration observed upstream of Donald Creek (i.e., difference between means/average concentration observed upstream of Donald Creek * 100).

5.3.3.3 Conclusions and Recommendations

The Mann-Kendall test for trend requires at least five samples to detect a significant upward or downward trend with a 95% test threshold (i.e., theta = 0.05). More than five samples are required to improve test resolution substantially. Currently, RAMP collects three years of sediment data (one sample per year) to define baseline conditions prior to development (Golder 2002f). It is recommended, based on the data requirements of the Mann-Kendall procedure, that the RAMP Water and Sediment Subgroup of the Technical Subcommittee consider expanding this period of baseline characterization from three to more than five years. This expansion would allow the subcommittee to determine if temporal trends detected after the initiation of development were already occurring under baseline conditions. More than five years of baseline data would also allow for "before and after" comparisons to test for potentially significant step changes, with more reasonable estimates of baseline variance than can be provided with only three baseline samples.

If timelines are such that more than five years are not available for baseline sampling prior to the initiation of development, sediment samples could be collected from multiple seasons in a given year. This type of accelerated sampling schedule would allow for adequate baseline characterization in a shortened period of time. However, caution must be exercised when moving to an accelerated sampling plan since it is important to quantify inter-year variability. The extreme case of collecting all samples in one year would not, for example, be recommended.

This recommendation should not affect the amount of baseline data required to complete the sediment quality component of an EIA. As previously discussed in Section 4.3.3.1, available baseline data can be effectively supplemented by using information from comparable waterbodies and/or probabilistic distributions developed from existing data to predict impacts in an EIA.

With respect to identifying spatial trends, the relative difference required for sediment metal or PAH concentrations to have been deemed significantly different from those observed upstream of Donald Creek ranged from 180% for PAH PC1 to >900% for metal PC3 at a power of 80%. Conservative calculations indicate that effect sizes will decline with increased sampling effort, ranging from 94% for PAH PC1 to 672% for metal PC3 at a power of 80%. However, these results were produced assuming that within-site variability remains unchanged, an unlikely scenario. Therefore, effect sizes are expected to decline to a greater extent than shown here with increased sampling effort. To expedite that rate of data collection, it is recommended that the RAMP Water and Sediment Subgroup of the Technical Subcommittee maintain a consistent sampling schedule with minimal alteration to established sample sites.

5.4 MONITORING TO VERIFY EIA PREDICTIONS

As outlined in recent EIAs (e.g., Shell 1997; TrueNorth 2001; Golder and Cantox 2002), oil sands development is not expected to affect sediment quality in the lower Athabasca River watershed, with respect to metal and PAH content. Whether the information collected by RAMP can be used to verify EIA predictions was addressed through an examination of the following questions:

- Are RAMP sediment sample sites situated in appropriate locations (e.g., at or near EIA water quality assessment nodes and other relevant depositional areas)?
- Does the RAMP sediment analytical test list include all of the parameters discussed in relevant sections of the EIA?
- Is RAMP collecting or otherwise obtaining the type of information required to differentiate natural variability from changes associated with human activities?

5.4.1 Sampling Locations

As outlined in Section 4.4.1, EIA water quality assessment nodes are situated downstream of existing, approved and planned developments within the relevant watershed(s). In tributaries to the Athabasca River, this results in assessment nodes typically being placed at river or creek mouths. Within the Athabasca River, assessment nodes are placed downstream of the incoming tributary(ies) scheduled for development. The RAMP sediment sampling program typically contains sampling locations at the mouth of potentially affected tributaries (see

Table 5.1), consistent with assessment node locations. However, within the Athabasca River, RAMP sediment sampling sites are positioned upstream, not downstream, of selected tributaries and in the Athabasca Delta.

The decision to situate sediment sampling sites upstream of selected tributaries within the Athabasca River was based on having water and sediment samples collected at the same location[3]. Placing the sediment sampling sites upstream of the relevant tributaries does not preclude verification of EIA predictions, because these sites can be used to monitor potential effects from upstream operations. Further, the inclusion of the upstream of the Embarras River and the Delta sites provides data on cumulative effects of all natural events and developments within the basin. Therefore, the answer to the first question is yes, RAMP sediment sample sites are situated in appropriate locations.

5.4.2 Analytical Parameter List

The RAMP parameter list contains all of the PAHs and metals included in relevant sections of recent EIAs (Golder and Cantox 2002). Therefore, the answer to the second question is also yes, the RAMP sediment analytical test list does include all of the parameters discussed in relevant sections of the recent EIAs.

5.4.3 Identifying Changes Related to Human Activity

To establish that instream variation is the result of human activity, one must ascertain that the significant variation is not a reflection of natural conditions. This process is generally completed through comparison to adequate baseline data from that area and/or data from a suitable reference area. In addition, one must also determine that the significant variation does not result from one or more confounding factors (e.g., variations in sediment composition).

With respect to the RAMP sediment monitoring program, the amount of baseline data currently collected (i.e., one sample per year for three years) is insufficient to determine if significant temporal variations are present prior to development. The power to conduct "before and after" comparisons is also limited with only three baseline samples. Hence, it is recommended in Section 5.3.3.1 that the RAMP Water and Sediment Technical Subgroup of the Technical Subcommittee consider expanding this period of baseline characterization from three to more than five years.

[3] The rationale for placing water quality sampling sites in the Athabasca River upstream of selected tributaries is outlined in Section 4.4.1.

5.4.4 Conclusions and Recommendations

RAMP sample sites are located in appropriate locations, and the RAMP parameter list includes all of the parameters discussed in relevant sections of recent EIAs (e.g., TrueNorth 2001; Golder and Cantox 2002). RAMP does not, however, currently collect sufficient baseline data to determine if significant temporal variations can be detected prior to development. Hence, it is recommended in Section 5.3.3.1 that the RAMP Water and Sediment Subgroup of the Technical Subcommittee consider expanding this period of baseline characterization from three to more than five years.

5.5 SUMMARY

5.5.1 Characterizing Existing Variability

The characterization of existing variability in sediment quality within the RAMP study area included an examination of potential parameter correlations within the existing RAMP sediment quality database. This analysis was completed to determine the following:

- if substances of a common nature are typically found together and/or follow consistent patterns (e.g., do sediments with high aluminium content also contain high barium concentration?);
- how sediment chemistry may be affected by sediment composition (e.g., are PAH levels generally higher in sediments with high silt content?); and
- if indicator parameters can be identified to allow for the possible reduction of the standard RAMP sediment test list (e.g., possibly using TRH as an indicator of PAH concentrations).

This analysis was also used to identify key parameters that could be used in subsequent examinations of potential temporal and spatial trends.

Sediment data collected by RAMP between 1997 and 2001 were combined with comparable information collected by Albian (2000) and Golder (1996a) to create a sediment quality data set for the lower Athabasca River watershed. Potential correlations among TOC and the physical parameters, such as percent sand, silt and clay, were examined using explicit pairwise Pearson correlations with Bonferroni adjustments. Principal components analysis was used to evaluate potential correlations among the metals and among the PAHs included in the standard RAMP parameter list (Table 5.2), with the exception of silver, acenaphthylene, C1 and C2 substituted biphenyl, anthracene and dibenzo(a,h)anthracene. The data sets for these parameters contained >70% non-detectable results.

Results of this analysis indicate that sediments collected from the RAMP study area exhibited the following patterns:

- High silt content was generally accompanied by high clay and low sand content.
- Metal concentrations tended to follow consistent, positively correlated trends, whereby sediments containing high levels of, for example, aluminum also generally contained high levels of cobalt, nickel, vanadium and other metals. Exceptions to this general pattern included mercury and molybdenum, although mercury concentrations tended to be high in sediments with high lead levels.
- PAH concentrations tended to follow similar consistent, positively correlated trends, whereby sediments containing high levels of, for example, pyrene also generally contained high levels of fluorene, acenaphthene and other parent and alkylated PAHs. Exceptions to this general pattern included naphthalene and C1 naphthalene, two parameters strongly correlated to each other with weaker correlation to other parameters included in the organics analysis.
- With the possible exception of metals with a high proportion of non-detectable results (beryllium, cadmium, uranium, thallium and molybdenum), sediments with high silt and/or clay content generally contained higher metal levels than those with larger amounts of sand and less silt and/or clay.
- PAH levels were not significantly correlated to sediment composition, with the exception of naphthalene and C1 naphthalene. Concentrations of these two compounds were significantly, positively correlated to silt content.

Other conclusions that can be drawn from the results of this study include the following:

- TOC content could not be used effectively to indirectly monitor PAH levels in sediment.
- It may be unnecessary for RAMP to monitor both TRH and TEH, since they are highly correlated to one another.
- The number of PAHs included in the RAMP parameter list could be reduced, in reflection of the high correlation observed between almost all of the parent and alkylated PAHs included in the organics analysis.

- Comparable reductions in the metals test list could be pursued for similar reasons. However, limited financial gain would result, because metals are generally analyzed using broad spectrum scans. Thus, the incremental cost associated with adding or subtracting elements to the scan is small.
- The strong correlations observed between TRH and almost all of the PAHs (parent and alkylated) included in the organics analysis suggests that TRH could be used as an indicator of PAH content in areas where naphthalene and C1 naphthalene concentrations are not expected to change as a result of development.

Building upon these conclusions, it is recommended that the RAMP Water and Sediment Subgroup of the Technical Subcommittee consider revising the "Organics" and "PAH" portions of the standard sediment parameter list, as well as the 2003 to 2009 study plan described in Golder (2002f). Suggested changes include the following:

- dropping TEH from the parameter list;
- reducing standard PAH testing to naphthalene and C1 naphthalene; and
- using TRH as a surrogate for the remaining PAHs, with more extensive PAH analysis occurring only once every two to three years.

In combination, these changes could results in cost savings of approximately $300 per sample. Based on the 39 samples included in the 2002 sediment sampling program (Golder 2002f), these modifications would reduce the sediment program's analytical costs by approximately $11,700 per year.

5.5.2 Detecting and Assessing Regional Trends

5.5.2.1 Temporal Trends

The investigation into temporal trends in the sediment quality data set included an examination of the temporal variability at the following locations:

- the mouth of the Muskeg River;
- along the east and west banks of the Athabasca River upstream of Donald Creek; and
- along the east and west banks of the Athabasca River upstream of Fort Creek.

The nonparametric Mann-Kendall test for trend was used in combination with Sen's slope estimation procedure (Gilbert 1987) to determine both the magnitude and potential significance of apparent temporal trends. Data from the east and west banks in the Athabasca River were combined and analyzed together to meet the minimum data requirements for a two-tailed test with a level of significance of 0.05.

With the possible exception of metals with a high proportion of non-detectable results (beryllium, cadmium, uranium, thallium and molybdenum), metal and PAH concentrations in sediments collected from the mouth of the Muskeg River and in the Athabasca River upstream of Fort Creek have been declining over time, as have metal and PAH concentrations in sediments collected from the Athabasca River upstream of Donald Creek. Although these trends were not all statistically significant, they suggest that oil sands development within the lower Athabasca River watershed has not resulted in increased sediment metal or PAH concentrations at either downstream location (i.e., mouth of the Muskeg River and in the Athabasca River upstream of Fort Creek) since the initiation of RAMP in 1997.

5.5.2.2 Spatial Trends

The examination of spatial trends in sediment quality within the lower Athabasca River included a general overview of spatial variations in the RAMP study area, as well as a focused analysis of potentially significant variations in metal and PAH concentrations along the length and width of the Athabasca River.

General spatial patterns were examined using sediment distribution figures (i.e., adapted piper plots) and ordination plots derived from the metal and PAH PCAs described in Section 5.2. With respect to the more focused analysis of the Athabasca River, potentially significant variations in metal and PAH concentrations along the width and length of the river were examined using two-way and one-way ANOVAs, respectively. Each ANOVA was constructed as a randomized block design, with year acting as the blocking variable.

Based on the five years of sediment data RAMP has collected since 1997, metal concentrations in sediments from the Muskeg River watershed tend to be lower than those in the Athabasca River, whereas sediment PAH concentrations tend to be comparable between the two systems. Other conclusions that can be drawn from the spatial analysis include the following:

- Mercury, lead and PAH concentrations, excluding naphthalene and C1 naphthalene, are generally lower in Muskeg River watershed sediments than in sediments from the other Athabasca River tributaries sampled by RAMP.

- With the possible exception of metals with a high proportion of non-detectable results (molybdenum, cadmium, beryllium, uranium and thallium), metal concentrations are generally higher in sediments collected upstream of the Embarras River and in the Delta than in samples collected between Fort McMurray and Fort Creek.
- The variation in metal levels in the Athabasca River is a reflection of differing sediment composition (i.e., higher proportion of silt and/or clay upstream of the Embarras River and in the Delta).
- PAH concentrations vary over the length of the Athabasca River, with no clear spatial pattern.
- Shipyard, Kearl and Isadore's lakes sediments generally contain higher metal levels and a greater proportion of silt and clay in comparison to those in the other waterbodies sampled by RAMP.

5.5.2.3 Ability to Detect Change

Temporal Variations

The Mann-Kendall test for trend is a nonparametric test that relies on relative magnitudes of the data rather than absolute values. Significance of a trend is determined by looking at how often and how consistently data collected through time are higher or lower than previously collected data (Gilbert 1987). A minimum of four data points are required for this test. However, if one is interested in looking for either a significant upward or downward trend with a 95% test threshold (i.e., theta = 0.05), then at least five data points are required. More than five samples are required to improve test resolution substantially.

As the program is currently designed, RAMP collects three years of sediment data (one sample per year) to define baseline conditions prior to development (Golder 2002f). Based on the data requirements and resolution of the Mann-Kendall procedure, it is recommended that the RAMP Water and Sediment Subgroup of the Technical Subcommittee consider expanding this period of baseline characterization from three to more than five years. This expansion would allow the subcommittee to determine if temporal trends detected after the initiation of development were already occurring under baseline conditions. More than five years of baseline data would also allow for "before and after" comparisons to test for potentially significant step changes, with more reasonable estimates of baseline variance than can be provided with only three baseline samples.

If timelines are such that more than five years are not available for baseline sampling prior to the initiation of development, sediment samples could be collected from multiple seasons in a given year. This type of accelerated sampling schedule would allow for adequate baseline characterization in a shortened period of time. However, caution must be exercised when moving to an accelerated sampling plan since it is important to quantify inter-year variability. The extreme case of collecting all samples in one year would not, for example, be recommended.

This recommendation should not affect the amount of baseline data required to complete the sediment quality component of an EIA. As previously discussed in Section 4.3.3.1, available baseline data can be effectively supplemented by using information from comparable waterbodies and/or probabilistic distributions developed from existing data to predict impacts in an EIA.

Spatial Variations

The current program's ability to detect significant spatial variations in sediment quality was examined using power analysis. The focus of the power analysis was to determine the effect size, or relative difference, that could be detected (i.e., deemed significant) based on the data collected to date and with increased sampling effort. Using the procedures outlined in Zar (1984), the relative difference required for sediment metal or PAH concentrations to have been deemed significantly different from those observed upstream of Donald Creek was estimated to range from 180% for PAH PC1 to >900% for metal PC3 at a power of 80%.

Conservative calculations indicate that effect sizes will decline with increased sampling effort, ranging from 94% for PAH PC1 to 672% for metal PC3 at a power of 80%. However, these results were produced assuming that within site variability remains unchanged, an unlikely scenario. Therefore, effect sizes are expected to decline to a greater extent than shown here with increased sampling effort. To expedite that rate of data collection, it is recommended that the RAMP Water and Sediment Subgroup of the Technical Subcommittee maintain a consistent sampling schedule with minimal alteration to established sample sites.

5.5.3 Monitoring to Verify EIA Predictions

As outlined in recent EIAs (e.g., Shell 1997; TrueNorth 2001; Golder and Cantox 2002), oil sands development is not expected to affect sediment quality in the lower Athabasca River watershed, with respect to metal and PAH content. The issue of whether the information collected by RAMP can be used to verify

EIA predictions was addressed through an examination of the following questions:

- Are RAMP sediment sample sites situated in appropriate locations (e.g., at or near EIA water quality assessment nodes and other relevant depositional areas)?
- Does the RAMP sediment analytical test list include all of the parameters discussed in relevant sections of the EIA?
- Is RAMP collecting or otherwise obtaining the type of information required to differentiate natural variation from changes associated with human activities?

RAMP sample sites are located in appropriate locations, and the RAMP parameter list includes all of the parameters discussed in relevant sections of recent EIAs (e.g., TrueNorth 2001; Golder and Cantox 2002). RAMP does not, however, currently collect sufficient baseline data to detect significant temporal trends prior to development. Hence a recommendation was made that the RAMP Water and Sediment Subgroup of the Technical Subcommittee consider expanding this period of baseline characterization from three to more than five years.

6 BENTHIC INVERTEBRATES

6.1 INTRODUCTION

6.1.1 Program Overview

During the first five years of RAMP, the benthic invertebrate program has concentrated largely on the three major tributaries of the Athabasca River in the Oil Sands Region (MacKay, Muskeg and Steepbank rivers) and, more recently, on Kearl and Shipyard lakes (Table 6.1; Figure 6.1). The Athabasca River was sampled once (fall 1997; Golder 1998), but further work was suspended pending development of a suitable approach to monitor this river. A decision regarding benthic invertebrate monitoring in the Athabasca River is anticipated, based on an independent evaluation of possible monitoring approaches to be commissioned in 2003.

The design of the annual monitoring program is determined each year by committee using a consensus approach. The benthic program has evolved during the first five years as a result of changes in the RAMP subcommittee structure (i.e., a Subgroup of the Technical Subcommittee dedicated to the benthic invertebrate component was established in 1999), stakeholder input, program funding and increases in the number of approved and planned oil sands developments. As a consequence, only two years or less of data have been collected using the same sampling design and methods at the end of the first five-year period of monitoring (Table 6.1).

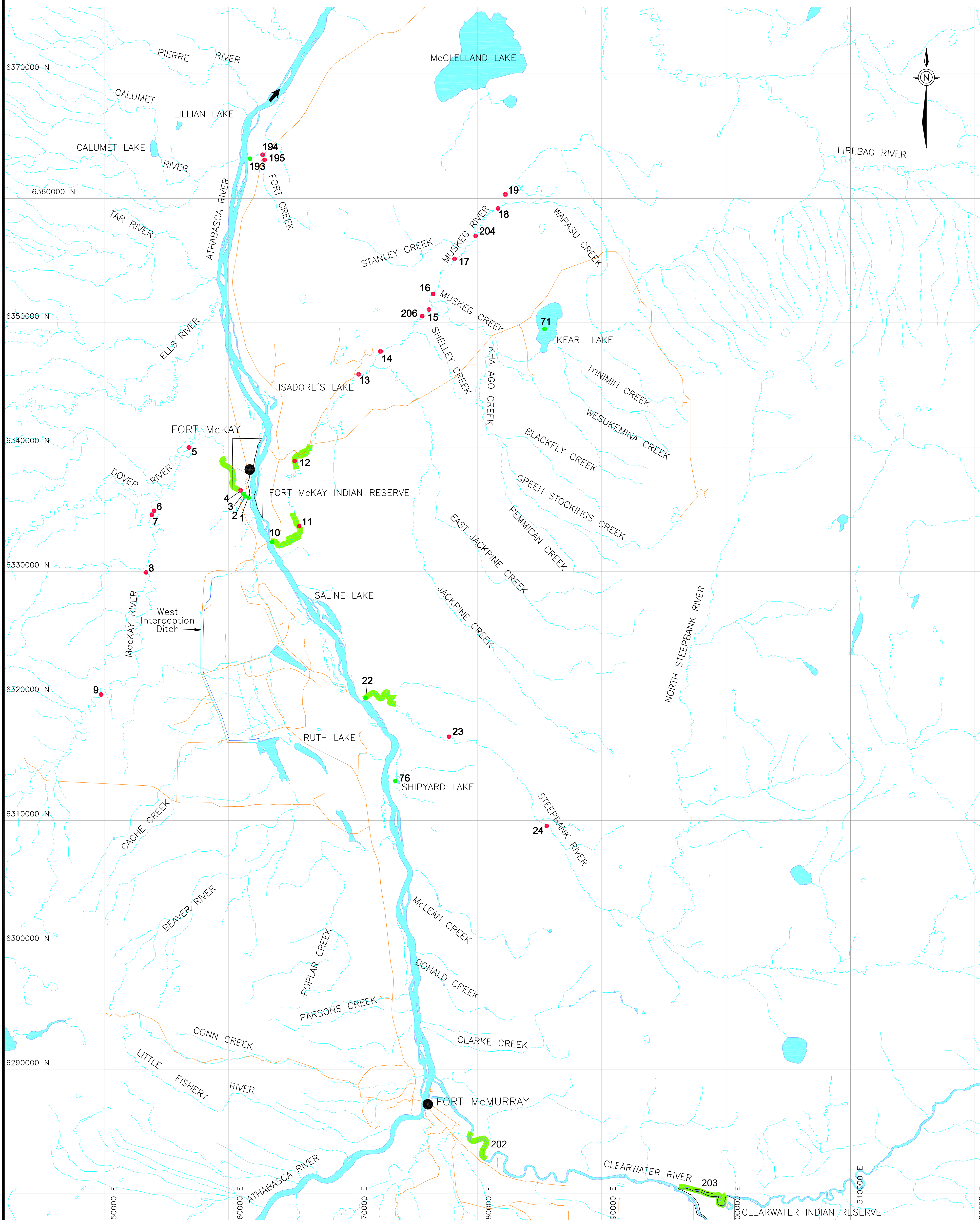
The continued expansion of this component underscores the necessity to develop a program that is cost-efficient and appropriately designed. The benthic program has undergone a considerable expansion in 2002 (eight river reaches and one lake were added), which represents an approximate doubling of the program (Table 6.2). Another expansion of similar scope is planned for 2003 (eight additional river reaches) (Table 6.2). Therefore, one of the most important objectives of this report is to critically evaluate the benthic invertebrate program and provide recommendations to maximize efficiency. This Five Year Report also provides an opportunity to assess whether the RAMP monitoring data meet RAMP's needs, as identified by the current RAMP objectives and the Benthic Invertebrate Subgroup of the Technical Subcommittee.

Table 6.1 Overview of the RAMP Benthic Invertebrate Program from 1997 to 2001

Waterbody	1997	1998	1999	2000	2001
Athabasca River	six sites upstream and six sites downstream of oil sands area	n/s	n/s	n/s	n/s
Clearwater River	n/s	n/s	n/s	n/s	one depositional reach upstream of Fort McMurray and one depositional reach upstream of Christina River
MacKay River	n/s	three erosional sites near mouth	n/s	one erosional reach near mouth	one erosional reach near mouth
Muskeg River	n/s	three erosional sites near mouth	n/s	one erosional reach near mouth and one depositional reach in lower reach	one erosional reach near mouth and one depositional reach in lower reach
Steepbank River	n/s	three erosional sites near mouth	n/s	one erosional reach near mouth	one erosional reach near mouth
Fort Creek	n/s	n/s	n/s	n/s	one depositional reach near mouth
Kearl Lake	n/s	n/s	n/s	n/s	nine samples throughout lake
Shipyard Lake	n/s	n/s	n/s	10 samples throughout lake	10 samples throughout lake
Summary	**two river reaches**	**three river reaches**	**no sampling**	**three river reaches** **one lake**	**seven river reaches** **two lakes**

Note: n/s = Not sampled.

R:\CAD\2300\022-2301\6350\5yr Report\ Drawing file: Benthic Invertebrate Sampling.dwg   Mar 06, 2003 - 3:03pm



LEGEND

ROADWAYS
RIVERS AND STREAMS
1 SITES SAMPLED BY RAMP
4 SITES SAMPLED BY OTHER STUDIES
REACHES SAMPLED BY RAMP IN 2000 AND 2001

5 0 5
SCALE KILOMETRES

REFERENCE

DIGITAL DATA SETS 74D, 74E, 74I, 84A AND 84H FROM RESOURCE DATA DIVISION ALBERTA ENVIRONMENTAL PROTECTION 1997. DATUM: NAD83. PROJECTION: UTM ZONE 12.

PROJECT

RAMP FIVE YEAR REPORT

TITLE

BENTHIC INVERTEBRATE SAMPLING LOCATIONS INCLUDED IN THE RAMP FIVE YEAR REPORT

Golder Associates
Calgary, Alberta

PROJECT No. 022-2301.6350			FILE No. Benthic Invertebrate	
DESIGN	ZK	11/12/02	SCALE AS SHOWN	REV. 0
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CHECK				
REVIEW				

Table 6.2 Overview of the 2001 and 2002 RAMP Benthic Invertebrate Programs, and Planned Work for 2003

Waterbody	2001	2002	Planned for 2003
Calumet River	n/s	one depositional reach near mouth	one depositional reach near mouth; one upstream depositional reach
Clearwater River	one depositional reach upstream of Fort McMurray; one depositional reach upstream of Christina River	one depositional reach upstream of Fort McMurray; one depositional reach upstream of Christina River	one depositional reach upstream of Fort McMurray; one depositional reach upstream of Christina River
Christina River	n/s	one depositional reach near mouth; one upstream depositional reach	one depositional reach near mouth; one upstream depositional reach
Ells River	n/s	one depositional reach near mouth	one depositional reach near mouth; one upstream depositional reach
Firebag River	n/s	n/s	one erosional reach near mouth; one upstream erosional reach
Hangingstone River	n/s	n/s	one erosional reach near mouth
Jackpine Creek	n/s	one depositional reach near mouth	one depositional reach near mouth; one upstream depositional reach
MacKay River	one erosional reach near mouth	one erosional reach near mouth; one upstream erosional reach	one erosional reach near mouth; one upstream erosional reach
Muskeg River	one erosional reach near mouth; one depositional reach in lower reach	one erosional reach near mouth; one depositional reach in lower reach; one depositional reach upstream of Stanley Creek	one erosional reach near mouth; one depositional reach in lower reach; one depositional reach upstream of Stanley Creek
Steepbank River	one erosional reach near mouth	one erosional reach near mouth	one erosional reach near mouth; one upstream erosional reach
Tar River	n/s	one depositional reach near mouth	one depositional reach near mouth; one upstream depositional reach
Fort Creek	one depositional reach near mouth	one depositional reach near mouth	one depositional reach near mouth
Kearl Lake	nine samples throughout lake	10 samples throughout lake	10 samples throughout lake
McClelland Lake	n/s	10 samples throughout lake	10 samples throughout lake
Shipyard Lake	10 samples throughout lake	10 samples throughout lake	10 samples throughout lake
Summary	**seven river reaches** **two lakes**	**15 river reaches** **three lakes**	**23 river reaches** **three lakes**

Note: n/s = Not sampled.

The data collected by RAMP represent a small proportion of the total amount of benthos data available for the Oil Sands Region. A listing of previous studies (Table 6.3) reveals that all waterbodies monitored by RAMP except the Clearwater River have been sampled for invertebrates in the past. The Benthic Invertebrate Subgroup of the Technical Subcommittee recognized the importance of historical baseline data and has undertaken a summary of available historical data. This summary will be presented in a forthcoming report (Golder in prep.; to be released in 2003). In the present report, historical data were summarized along with RAMP data to facilitate evaluations of long-term trends.

In the interest of clarity, consistent terminology was used in this chapter to refer to sampling locations and to describe spatial hierarchy. The following bullets provide descriptions of the terms used:

- **Waterbody:** Any body of water, regardless of size or presence of flow (i.e., river, stream, lake or pond).
- **Reach:** A reach is a several km long section of river. Reach lengths of 3 to 5 km are common in RAMP surveys. Statistical tests were used in this document to compare reach means of benthic community variables among years (e.g., 2000 versus 2001) or locations (e.g., upstream reach versus downstream reach).
- **Site:** The site represents a small area of approximately uniform habitat within a river or stream (e.g., an individual riffle or run). The site is usually a relatively short section of river (<50 m), within which one or a number of samples may be collected. When applied to standing waters, the site represents a defined, small area of the lake (e.g., 10 x 10 m). In statistical tests comparing reaches, the site is the unit of replication. Most of the historical data were collected at the resolution of site rather than reach.
- **Sample:** The sample corresponds to invertebrates removed from a unit area of the bottom of a waterbody, corresponding to the bottom area of the sampling device used (e.g., contents of an individual Ekman grab). Data from all samples collected at a site may be pooled as the mean to arrive at a representative estimate for a benthic community variable (e.g., total abundance). Individual samples collected from the same site do not represent replicates in the statistical sense because they are not independent. Widely-spaced samples from a reach (each sample representing a site) were used as replicates to compare reaches.

The sampling design adopted by RAMP is intended to characterize rivers at the reach scale. During a sampling event, 15 sites are sampled within a 3 to 5 km reach in similar habitat. The habitat selected for sampling is the dominant habitat type within the reach. The two possible habitat types are erosional (primarily riffles) and depositional (slow runs, pools or backwaters). One sample is collected at each site for a total of 15 samples per reach. Similarly, lakes are sampled at the scale of the entire lake, stratified by depth. Ten randomly selected sites are sampled in a lake within a specified depth range. One sample is collected at each site for a total of 10 samples per sampling event. These sampling designs were used during the 2000, 2001 and 2002 RAMP cycles.

Table 6.3 Historical Data Available for Rivers, Streams and Lakes Monitored by RAMP During the First Five Years

Waterbody	Historical Data	Study References
Athabasca River	13 studies from 1975 to 2001; 72 sites (excluding 2001 data, which have not been released to date)	McCart et al. (1977); Barton and Wallace (1980); Noton (1979); Noton and Anderson (1982); Boerger (1983); IEC Beak (1983); Corkum (1984; unreleased); Ouellet and Cash (1996); Anderson (1991); EVS (1986); Dunnigan and Millar (1993); EVS (1996); Jacques Whitford (2002)
Clearwater River	none	none
MacKay River	1977 (three sites)	McCart et al. (1978)
	1984 (four sites)	RL&L and AA Aquatic Research (1985)
Muskeg River	1976 (four sites)	Barton and Wallace (1980)
	1979 (three sites)	Crowther and Lade (1980)
	1985 (five sites)	Beak (1986)
	1988 (six sites)	RL&L (1989)
	1995 (three sites)	Golder (1996a)
	1997 (three sites)	Golder (1998)
	2001 (two sites)	Golder (2002c)
Steepbank River	1976 (10 sites)	Barton and Wallace (1980)
	1995 (three sites)	EVS (1996)
Fort Creek	1999 (three sites)	TrueNorth (2001)
Kearl Lake	1985 (one site)	Beak (1986)
	1988 (one site)	RL&L (1989)
	1995 (one site)	Golder (1996a)
Shipyard Lake	1996 (three sites)	Golder (1996b)

Note: Some sites were sampled more than once.

6.1.2 Objectives

Of the eight overall RAMP objectives listed in the 2001 RAMP annual report (Golder 2002c), the following three are applicable to this report:

- collecting scientifically defensible baseline and historical data to characterize variability in the oil sands area;

- monitoring aquatic environments in the oil sands area to detect and assess cumulative effects and regional trends; and
- collecting data against which predictions contained in environmental impact assessments (EIAs) can be verified.

Each data point represents the cumulative effect of all changes (e.g., natural events, project impacts) in each reach on each date. The entire data set analyzed in this report is, in this sense, a cumulative effects data set. Therefore, the assessment identified by the second broad objective will focus on the determination of regional trends.

Based on these objectives and input from the RAMP Benthic Invertebrate Subgroup of the Technical Subcommittee, the following specific objectives are addressed in this report:

- to characterize spatial variation in benthic community structure in the rivers and lakes monitored by RAMP, and identify factors that may account for the observed variation;
- to define baseline ranges for key benthic invertebrate community variables in rivers and lakes monitored by RAMP;
- to investigate temporal trends in benthic community structure in rivers and lakes monitored by RAMP, incorporating historical data;
- to compare benthic community structure between 2000 and 2001 (i.e., the years with data collected using consistent methods) for rivers and lakes monitored by RAMP;
- to compare riverine benthic community structure between reaches located upstream and downstream of oil sands developments, where possible;
- to evaluate whether the data collected by RAMP will be appropriate to verify EIA predictions in the future; and
- to evaluate the appropriateness and statistical aspects of the current study design (i.e., effect size, power, sample size and representativeness, adequacy of supporting data, potential confounding factors and efficiency of design) and recommend improvements, if applicable.

The first six of these objectives relate to the three broad program objectives as outlined in Table 6.4. The seventh objective (i.e., evaluate appropriateness of study design) applies to all three major program objectives. Therefore, it is addressed in several sections.

Table 6.4 Relationship of the Specific Objectives to RAMP's Overall Objectives

Overall Program Objectives	Relevant Component-Specific Objectives
characterize existing variability	characterize spatial variation in benthic community structure
	define baseline ranges for key benthic community variables
detect and assess cumulative effects and regional trends	investigate long-term trends in benthic community structure
	compare benthic community structure between 2000 and 2001
	compare benthic community structure between upstream and downstream reaches
collect data that can be used to verify EIA predictions	evaluate the usefulness of RAMP data to verify EIA predictions
all three overall objectives	evaluate the appropriateness and statistical aspects of the current study design

6.1.3 Scope of Work

6.1.3.1 Scope Limitations Applicable to all Objectives

The benthic invertebrate section of this report is limited to lakes and tributaries of the Athabasca River sampled by RAMP, up to and including the 2001 program (the 2002 data were not available at the time of writing). Therefore, the following waterbodies were included:

- Kearl Lake;
- Shipyard Lake;
- Clearwater River;
- MacKay River;
- Muskeg River;
- Steepbank River; and
- Fort Creek.

Available data for the Athabasca River have already been summarized in the historical data report (Golder in prep.; to be released in 2003) and are therefore not summarized here.

In addition to including data collected by RAMP, this report also includes quantitative historical data available for each of these waterbodies (data sources are listed in Table 6.3). Inclusion of the historical data was intended to facilitate examination of potential long-term trends that may have begun before the period monitored by RAMP.

In terms of sampling season, the scope is restricted to the fall. All RAMP benthic sampling to date was done during the fall low-flow period and it is anticipated that all future work will be done in this same season. Within the historical data set (Table 6.3), fall samples account for 81% of the total samples collected from the two lakes, and 74% of the total samples collected from rivers and streams sampled by RAMP during the first five years. Inclusion of only fall data removed a major potential source of variation (i.e., seasonal variation) from analyses of spatial and temporal trends, thereby simplifying the interpretation of results. Seasonal variation is discussed in the forthcoming RAMP historical data summary report (Golder in prep; to be released in 2003).

6.1.3.2 Characterizing Existing Variability

There are no additional scope limitations relevant to the first specific objective (i.e., spatial variation in benthic community structure).

The work under the second specific objective (i.e., baseline ranges for key benthic community variables) consisted of summarizing data for river reaches sampled by RAMP to allow use of reach means rather than site means for each year. Historical surveys sampled single sites within these reaches and were thus not relevant at the reach-scale sampled by RAMP. The lower erosional reaches of the MacKay, Muskeg and Steepbank rivers, which had three years of data, were included.

6.1.3.3 Detecting and Assessing Regional Trends

Examination of long-term trends was limited to graphical presentation of benthic community variables for sites with multiple years of data. A formal trend analysis was not done for the following reasons:

- The maximum number of years of data for any lake or river reach was five.
- Sampling designs have changed over time; for example, historical data and 1998 RAMP data were collected at individual sites with closely-spaced replicate samples, whereas subsequent RAMP surveys concentrated on several km long reaches, with single replicates at each site.

- Where data were available for a given reach for up to five years, the exact same locations were not resampled. Rather, one or more different locations within a several-km reach were sampled in different years. This can be expected to result in increased variability among years, reducing the ability to detect trends over time.

The comparisons of community structures between 2000 and 2001 were conducted using RAMP data collected using the same sampling design and methods in both years. The MacKay, Muskeg and Steepbank rivers, and Shipyard Lake were included in the comparison. The Clearwater River, Fort Creek and Kearl Lake were not included because only the 2001 RAMP data were available for these waterbodies at the time of writing.

The analysis of upstream-downstream trends was done using the Clearwater River data collected in 2001, to statistically test for existing differences before the start-up of in situ oil sands developments in the Christina River basin. Upstream and downstream reaches in similar habitats were not sampled by RAMP in other rivers until the 2002 program. However, a number of historical studies sampled several sites along the length of the MacKay, Muskeg and Steepbank rivers. Results of these studies were presented graphically, if at least three relatively widely-spaced sites were sampled along the length of a river.

6.1.3.4 Collecting Data to Verify EIA Predictions

The scope under this objective consisted of investigating whether the data collected by RAMP are appropriate for use in verifying EIA predictions. The evaluation included an examination of RAMP sampling locations (past and future) relative to waterbodies that have been assessed in EIAs.

The type of EIA prediction has some bearing on the necessity to monitor a waterbody. Two general types of predictions were made in oil sands EIAs regarding fish habitat and benthic invertebrates. The first includes predictions of losses of entire waterbodies due to development, followed by compensation in the form of creating new habitat or improving existing habitat. These predictions were not considered relevant to RAMP because it was assumed that specific monitoring programs will be developed to verify them on a case-by-case basis. The second type involves predicted effects on aquatic habitat in waterbodies that will persist during and after development. These predictions were considered relevant to RAMP. In addition, predictions of effects on benthic invertebrates due to air emissions (primarily acidic deposition) were not relevant to this evaluation because it was assumed that those predictions will be verified by the RAMP Acid Sensitive Lakes Program.

6.1.3.5 Appropriateness of the Study Design

The analysis performed to address this objective was relevant to the specific objectives addressed using statistical analysis, or that will be addressed using statistical tests. These include assessments of long-term trends, among year comparisons and upstream-downstream comparisons.

Recommendations for improving the monitoring program were limited to adjustments to the existing program consisting of traditional time trend and upstream-downstream (or control-impact) monitoring, rather than suggesting radical changes to program design. The Benthic Invertebrate Subgroup of the Technical Subcommittee has considered the application of the Reference Condition Approach (RCA) to regional-scale benthic monitoring in the Oil Sands Region and concluded that it prefers the traditional approaches described in this document.

6.2 CHARACTERIZING EXISTING VARIABILITY

6.2.1 Spatial Variation in Benthic Community Structure

6.2.1.1 Methods

This objective was addressed via an exploratory multivariate analysis of RAMP data and historical data, to examine variation in community structure within and among waterbodies. A secondary objective of the analysis was to investigate whether physical or chemical variables can explain the variation in the biological data.

The biological data set consisted of abundances of benthic invertebrates converted to the family level to account for varying levels of taxonomy among studies, expressed as numbers/m^2. In addition to converting genus level data to the family level, taxa identified to varying levels by different studies were converted to the "most common" level of identification (e.g., Amphipoda, Oligochaeta, Hydracarina and Ostracoda). Nearly all of the data were collected using 180 or 250 µm mesh sampling nets (there were three sites sampled in the MacKay River using a 600 µm mesh). Non-benthic taxa (i.e., Cladocera, Copepoda other than Harpacticoida, *Chaoborus*), terrestrial insects and pupae were deleted before analysis. To standardize the level of spatial resolution at the site level, the abundance data were expressed as site means for data consisting of a number of replicate samples from a site. Abundances in individual samples were used for RAMP data, which consisted of single replicates from a number of sites within a reach.

Principal Component Analysis (PCA) was used to transform the large lake and river data sets into low-dimensional data sets with independent variables called principal components (PCs). Since the first few PCs generally account for a large proportion of the total variance in the original data set, they can be used to simplify subsequent analyses with minimal loss of information. As such, PCA is a tool to simplify, and better understand, the variance in complex data sets, but further analysis is required to determine the sources of the variance. PCA is explained in more detail in Section 4.2.1.1.

Plotting the first factors derived from the entire data set revealed large differences in benthic community composition between the erosional and depositional/lake data sets, which may have partly originated from differences in sampling methods (Ekman grab in depositional rivers and lakes; Neill cylinder, Hess sampler or Surber sampler in erosional rivers). Therefore, the data set was divided into three subsets for ordination: lake data, depositional river data and erosional river data. The number of sites included in each set were 32, 77 and 113, respectively.

To reduce the number of zero abundance values in the data used for ordination, rare taxa were deleted using a cumulative percentage criterion of 98% and if they were present at <10% of total sites. To achieve the 98% criterion, taxa contributing to a cumulative percentage of 98% of total abundance in the data set were retained, based on taxa sorted in descending order of abundance across all sites. This procedure ensured that overall, close to 98% of the original total abundance represented in each data set was included in the analysis. The number of remaining taxa were 10, 10 and 21 for lakes, depositional sites and erosional sites, respectively. The original numbers of taxa were 24, 60 and 67 at the family level. The data reduction step also ensured that the number of sites included in the ordination was at least three times the number of variables.

PCA was run on the reduced, log (x+1) transformed data, based on the covariance matrix using the SYSTAT 10 statistical software package (SPSS 2000). Since PCA on the covariance matrix does not produce loadings in the form of correlation coefficients between PCs and the original variables, the relationship between the original biological variables and the new PCs were evaluated by generating Pearson correlation coefficients (Sokal and Rohlf 1995), as also done by Sprules (1981). Ordination plots of PC1 versus PC2 scores were examined for grouping of sites, rivers or lakes.

Environmental data matrices were assembled from a variety of studies to allow an exploration of physical and chemical factors that may influence benthic community structure. As a consequence of the limited amount of supporting data reported by most historical studies, these variables represented a minimum set.

The physical variables chosen represented habitat conditions at the reach scale (discharge, reach gradient, distance from mouth) and the local scale (current velocity, depth, substrate and wetted width). Water quality variables were applicable at both reach and site scales, and served as indicators of salinity (conductivity), nutrients (total phosphorus [TP], total nitrogen [TN], dissolved organic carbon [DOC]), acidity (pH) and sediment load (total suspended solids [TSS]). Environmental variables for rivers included the following:

- distance from mouth, measured on digital maps using Geographic Information System (GIS) software, or on topographic maps using a map wheel;
- wetted width;
- reach gradient, as provided by Sekerak and Walder (1980) for the MacKay, Muskeg and Steepbank rivers, or measured on 1:50,000 topographic maps for the Clearwater River and Fort Creek;
- discharge, as mean open-water discharge and mean 30-day discharge before the sample date using daily discharge data from Environment Canada and RAMP hydrometric stations; discharge in upper river reaches was estimated by subtracting major tributary discharges from discharge measured near the mouth;
- current velocity;
- water depth;
- substrate as % silt plus clay and total organic carbon (TOC) in bottom sediments at depositional sites, and as the weighted average index (WAI; Fernet and Walder 1986) of particle size for erosional sites; and
- water quality, including pH, conductivity, TP, TN, DOC and TSS.

Environmental variables for lakes included the following:

- water depth;
- bottom sediment TOC;
- % silt plus clay in bottom sediments; and
- water quality, including pH, conductivity, TP, TN, DOC and TSS.

Environmental PCAs were run separately for erosional sites (MacKay, Muskeg and Steepbank rivers) and depositional sites (Muskeg River), based on the correlation matrices. Due to the low sample size (three sites) and different physical characteristics of Fort Creek from all other rivers, it was excluded from the analysis of relationships between biological and environmental data sets.

Clearwater River sites were not included in the environmental PCA of depositional sites because of substantial differences between the Muskeg and Clearwater rivers in terms of physical characteristics, which resulted in an initial analysis accentuating differences between rivers. Additionally, many of the environmental variables for the Clearwater River were essentially two-state variables (i.e., one value for each of the upstream and downstream reaches for flow-related variables, and water chemistry). Therefore, they were not useful to investigate variation among sites. Due to low variation among sites and low sample sizes, DOC, TSS and TN were excluded from the environmental PCA of Muskeg River sites.

Because PCA cannot be run on incomplete data matrices, it was necessary to fill in missing data with best estimates using approaches recommended by Tabachnick and Fidell (1996). In cases where a variable with missing data was highly correlated to another variable (e.g., wetted width and mean open-water discharge), linear regression was used to estimate the missing values. In cases where a strong relationship was not apparent with other variables, the river mean or the grand mean for the variable with the missing value was used as an estimate of the missing data. Since missing data accounted for a very small proportion of the environmental data matrices, these estimates were not anticipated to influence results of the analysis. Certain variables were available for the reaches sampled, rather than individual sites (e.g., river discharge and water chemistry). In these cases, the same value was assigned to all sites within a reach.

The relationships between scores on the first biological PC (lakes and depositional sites in rivers) or the first two biological PCs (erosional sites in rivers) and environmental variables were examined by generating Spearman rank correlation coefficients (Sokal and Rohlf 1995) and checking scatter-plots for significant correlations. Either the raw environmental variables (lakes and the Clearwater River) or PC scores generated from the environmental data set (depositional sites in the Muskeg River and erosional sites) were used in these correlations.

6.2.1.2 Results and Discussion

Lakes

The first two PCs derived by PCA of the benthic invertebrate data for lakes explained close to 64% of the total variation in the data set (Table 6.5). Abundances of nearly all taxa included in the analysis were significantly correlated with PC1. Taxa associated with PC2 were a subset of the PC1 taxa. The caddisfly family Polycentropodidae had a slightly higher correlation with PC1 than with PC2, but neither of the correlation coefficients was significant, based on the Bonferroni-adjusted critical value of *r*=0.526 for considering a correlation significant (α=0.05 was adjusted for 20 comparisons, resulting in α=0.0025). Taxa representing 99.5% of total invertebrates included in the analysis were associated with PC1. Therefore, only PC1 was used in further analysis of environmental factors accounting for variation in benthic community structure.

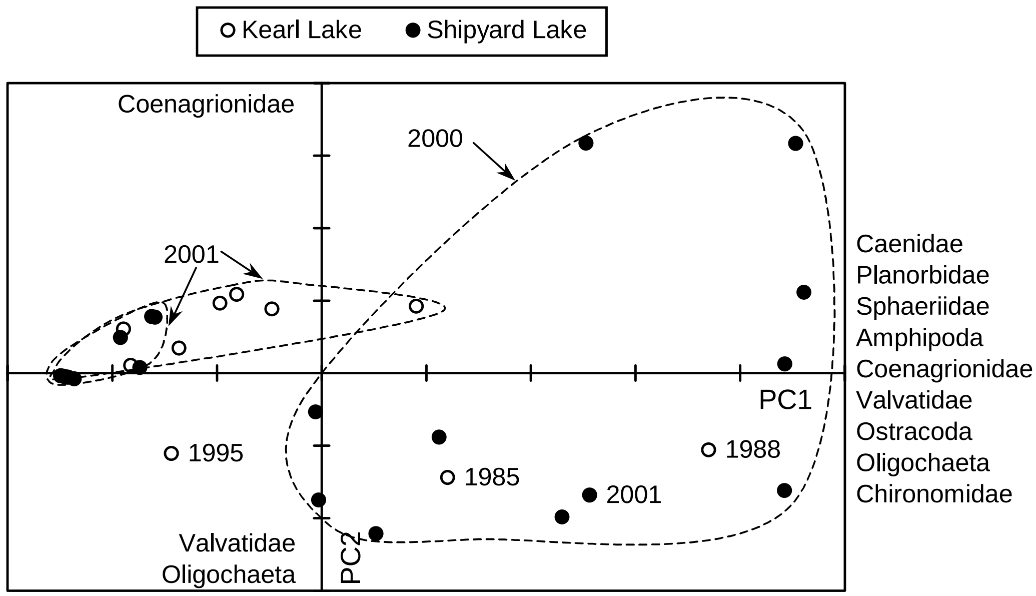
Table 6.5 Summary of Biological PCA Results for Lakes

Variable	Pearson Correlations Between Original Variables and PC Scores	
	PC1	**PC2**
Caenidae	**0.843**	0.095
Planorbidae	**0.829**	-0.182
Sphaeriidae	**0.758**	0.095
Amphipoda	**0.748**	0.151
Coenagrionidae	**0.673**	**0.572**
Valvatidae	**0.609**	**-0.546**
Ostracoda	**0.606**	0.365
Oligochaeta	**0.540**	**-0.688**
Chironomidae	**0.538**	-0.093
Polycentropodidae	0.489	0.450
Eigenvalue	5.902	1.609
% of variance explained	50.4	13.7
% of total abundance represented by taxa with correlation coefficients >0.5	99.5	9.4

Note: Correlation coefficients >0.5 are in bold. Coefficients representing significant correlations (*P*<0.002, n=32) are shaded.

On the ordination plot of PC1 versus PC2 (Figure 6.2), sites from both lakes were widely distributed along both axes, without an apparent grouping by lake. Shipyard Lake sites sampled in 2000 were widely scattered, while the 2001 sites from both lakes formed a relatively tight group with one high outlier from each lake along PC1. These results suggest that communities in 2001 were generally similar within lakes. Communities found in 1985, 1988 and 1995 in Kearl Lake varied widely along PC1 and were different from the 2001 communities. Overall, the analysis revealed some consistency in community structure within years, but wide variation among years, with generally lower abundances in 2001.

Figure 6.2 Ordination Plot of Biological Data for Lake Sites



Ranges of values of environmental variables were indicative of some differences between lakes (Table 6.6). Ranges in water depth and water quality variables were similar in both lakes with the exception of conductivity. Kearl Lake had slightly coarser bottom sediments with higher organic content, slightly higher pH and lower conductivity than Shipyard Lake.

Table 6.6 Ranges of Environmental Variables Selected for Lakes

Variable	Units	Kearl Lake		Shipyard Lake	
		Range	*n*	Range	*n*
water depth	m	1.5 - 2.4	12	1.2 - 2.8	20
bottom sediment TOC	%	29.4 - 38.7	9	4.49 - 15.4	20
% silt and clay in bottom sediments	%	80 - 95	9	94 - 99	20
pH	-	7.3 - 8.4	4	6.8 - 7.9	20
conductivity	µS/cm	125 - 176	4	321 - 380	20
TP	mg/L	0.013 - 0.037	4	0.016 - 0.031	2
TN	mg/L	0.7 - 1.5	3	1.2 - 1.3	2
DOC	mg/L	19 - 23.1	2	18 - 22	2
TSS	mg/L	1 - 4	4	3 - 15	2

Correlations between PC1 and environmental variables were examined for both lakes combined and for each lake individually, using environmental variables with sufficient sample sizes for analysis. Significant correlations were found between PC1 and water depth (both lakes combined), and between PC1 and pH (both lakes combined and Shipyard lake) (Table 6.7). Scatter-plots revealed that these relationships were generally weak (Figure 6.3). In particular, the range in pH was low (less than one unit) once the two extreme points were removed. Scatter-plots of PC1 versus variables with low sample sizes suggested there were no relationships between PC1 and TP, TN and TSS; however, there was an apparent relationship between PC1 and DOC (Figure 6.3), largely due to the single low DOC measurement of 18 mg/L in Shipyard Lake.

The analysis of lake data has shown that most taxa vary in a similar manner among sites in Kearl and Shipyard lakes. Variation among years tends to be large in both lakes, but within-year variation was lower, with some conspicuous outliers. Benthic community structure was weakly related to depth, which is frequently a major controlling factor of benthic communities in standing waters (Wetzel 1983). Relationships with pH and DOC were also weak and less likely to be of ecological significance, due to the limited ranges in these variables.

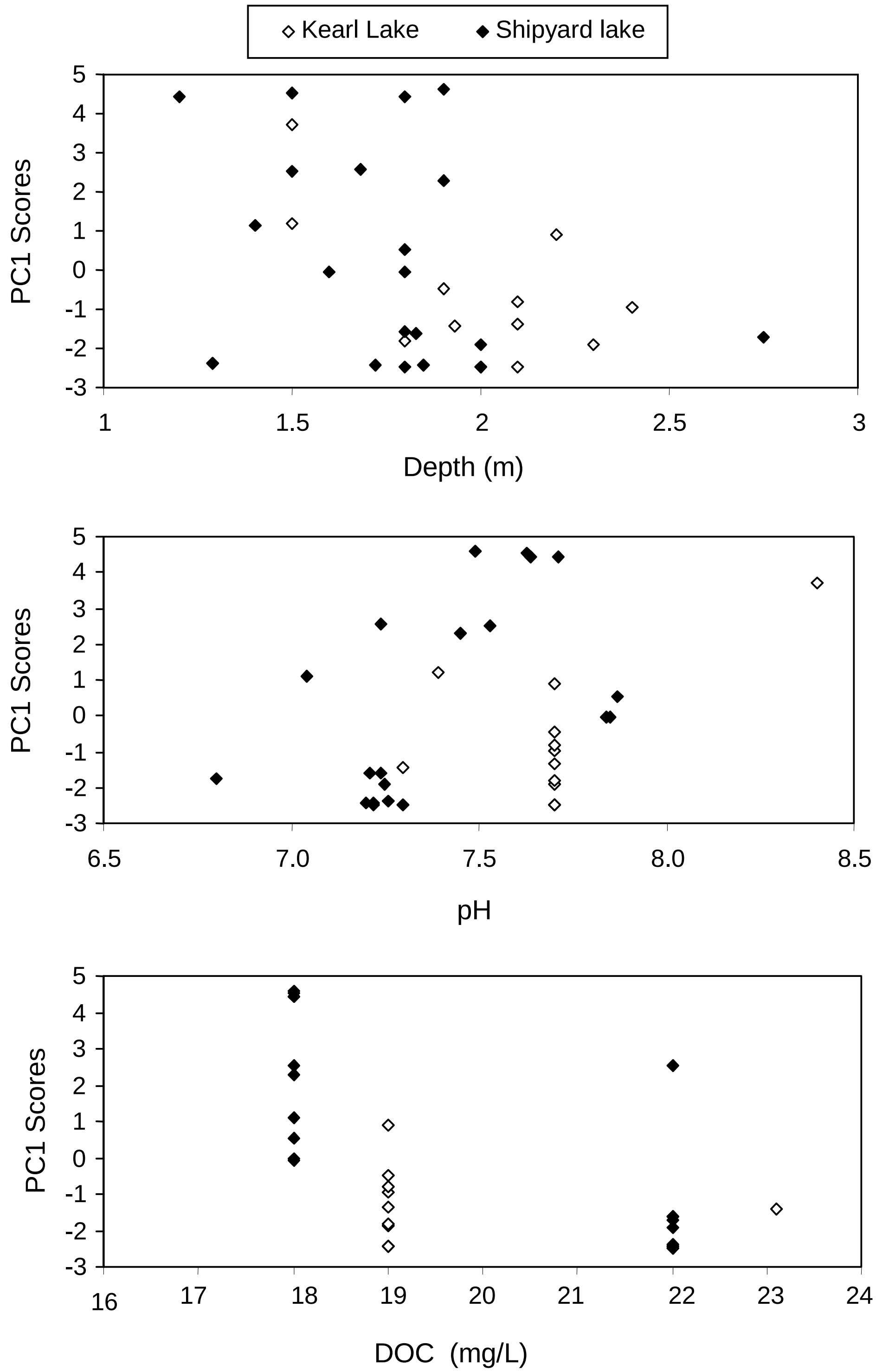
Table 6.7 Spearman Rank Correlations Between Environmental Variables and Biological PC1 Scores for Lakes

Lake	Water Depth	Bottom Sediment TOC	% Silt+Clay in Bottom Sediments	pH	Conductivity
both lakes combined (*n*=22 to 32)	**-0.422***	-0.285	0.282	**0.541****	-0.354
Shipyard Lake (*n*=20)	-0.353	-0.152	0.102	**0.477***	-0.381
Kearl Lake (*n*=9 to 12)	-0.350	-0.201	0.515	[a]	[a]

Note: Significant correlations are identified by bold font; *=*P*<0.05; **=*P*<0.01.

[a] Insufficient data (*n*=4).

Figure 6.3 Relationships Between Depth, pH, DOC and PC1 Scores for Lakes



Erosional Sites in Rivers

The first two PCs generated by ordination of erosional benthic invertebrate data explained about 40% of the total variation in the data set (Table 6.8). Most of the abundant taxa in the erosional data set were associated with PC1. Taxa with high correlations to PC1 (operationally defined as a correlation coefficient >0.5) accounted for about half of the total abundance across all sites. Taxa highly correlated with PC2 included bristle worms (Oligochaeta) and the stonefly family Taeniopterygidae, constituting 13% of total abundance. Additional PCs represented one or two minor taxa accounting for <5% of total invertebrates, and were thus not retained for further analysis.

There was no consistency in terms of habitat preferences among the taxa associated with the first two PCs. For example, depositional taxa (Sphaeriidae) and erosional taxa (Hydropsychidae) were both highly correlated with PC1 scores (Table 6.8), and the two groups with high correlations to PC2 scores (Oligochaeta and Taeniopterygidae) tend to have opposite habitat preferences. The relatively low amount of variation explained by the analysis and the inconsistency in habitat preferences among taxa associated with individual PCs suggest that the interpretation of environmental factors responsible for community structure is unlikely to be straight forward.

Positions of rivers along PC1 (Figure 6.4) were consistent with differences in total abundance among rivers: Muskeg River communities had the highest total abundance, followed by the MacKay and Steepbank rivers. The ordination plot indicated that Muskeg River communities were distinct from communities in the MacKay and Steepbank rivers (Figure 6.4). There were two exceptions, consisting of the farthest downstream site (at the mouth) sampled in the Muskeg River in 2001 and the farthest upstream site (24 km from the mouth) sampled in the Steepbank River in 1995. The unusual Muskeg River site had a low score on PC1 due to very low abundances of all taxa, whereas the Steepbank River site scored high because it supported an unusually large number of midges. MacKay River sites tended to score higher on PC2 than sites in the other two rivers, reflecting higher abundances of taxa associated with PC2, especially bristle worms. Steepbank River sites clustered with MacKay River sites sampled in 1984 and 1977, and with occasional sites sampled by subsequent RAMP studies. The two Fort Creek sites clustered with the MacKay and Steepbank river sites.

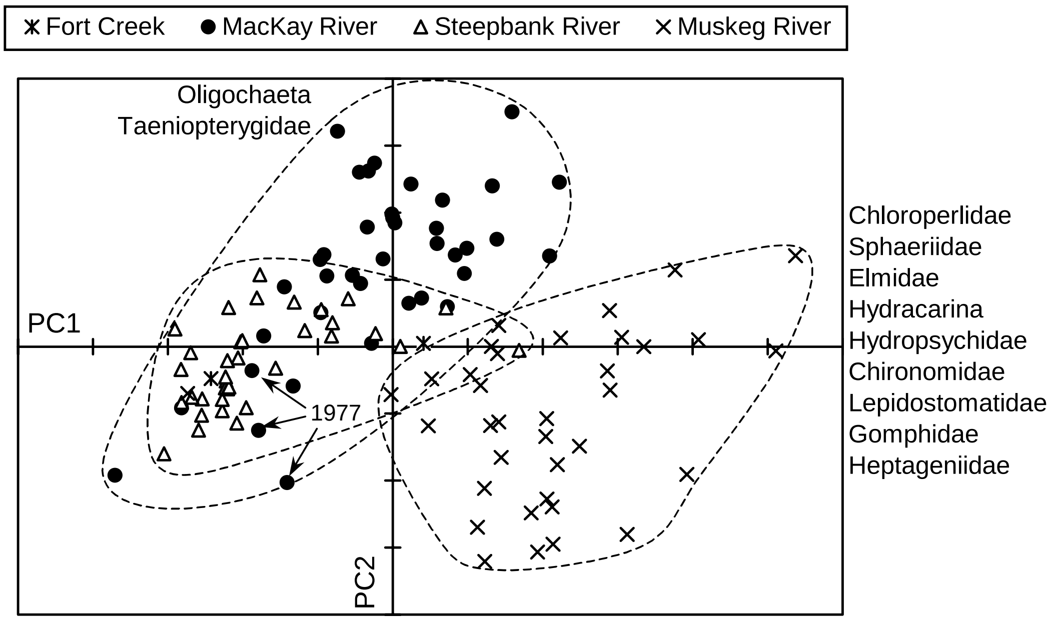
The positions of the 1977 sites on the ordination plots were probably influenced by the larger mesh size used, as indicated by low scores on both PCs due to the low abundances of small-sized taxa (especially Nematoda, Oligochaeta, Hydracarina and Chironomidae) (Figure 6.4). These sites were excluded from correlation analysis of the biological versus environmental data.

Table 6.8 Summary of Biological PCA Results for Erosional Sites

Variable	Pearson Correlations Between Original Variables and PC Scores	
	PC1	PC2
Chloroperlidae	**0.793**	-0.083
Sphaeriidae	**0.754**	-0.377
Elmidae	**0.753**	-0.489
Hydracarina	**0.679**	0.141
Hydropsychidae	**0.628**	-0.150
Chironomidae	**0.610**	0.306
Lepidostomatidae	**0.583**	-0.228
Gomphidae	**0.572**	0.338
Heptageniidae	**0.532**	-0.013
Baetidae	0.462	0.082
Empididae	0.396	0.392
Ancylidae	0.334	0.271
Oligochaeta	-0.097	**0.698**
Taeniopterygidae	0.238	**0.658**
Nematoda	0.193	0.469
Perlodidae	0.321	0.463
Ceratopogonidae	0.421	0.442
Ephemerellidae	0.033	-0.138
Tricorythidae	-0.181	0.441
Plecoptera	0.332	-0.113
Ostracoda	0.420	0.259
Eigenvalue	3.988	1.994
% of variance explained	26.1	13.1
% of total abundance represented by taxa with correlation coefficients >0.5	51.4	12.3

Note: Correlation coefficients >0.5 are in bold. Coefficients representing significant correlations (*P*<0.001) are shaded.

Figure 6.4 Ordination Plot of Biological Data for Erosional Sites



Ranges in values of environmental variables revealed some differences among rivers, mostly in reach-scale variables (Table 6.9). Spatial coverage differed among rivers, with the longest reach sampled in the MacKay River and the shortest in the Muskeg River. The MacKay River data set was characterized by a greater range of wetted width, lower gradient and higher open-water discharge than the Muskeg and Steepbank rivers. In contrast, mean 30-day discharge before sampling and local-scale physical variables (i.e., current velocity, depth and substrate) had similar ranges in all three rivers. Of the water quality variables, pH and conductivity had similar ranges. Sample sizes for other water quality variables were low and, therefore, were not necessarily representative of full ranges.

Ranges in most environmental variables were wide enough to expect an influence on benthic communities with the exception of water depth. Variation in water depth was low because traditional erosional benthic sampling devices are only useful within a narrow depth range.

Table 6.9 Ranges of Environmental Variables Selected for Erosional Sites

Variable	Units	All Rivers Combined		MacKay River		Steepbank River		Muskeg River	
		Range	*n*	Range	*n*	Range	*n*	Range	*n*
distance from mouth	km	0.1 - 56.9	111	0.2 - 56.9	39	0.1 - 23.9	36	0.1 - 12.2	36
wetted width	m	8 - 60	108	9 - 60	39	8 - 31	33	9 - 25	36
reach gradient	m/km	0.6 - 4.4	111	0.6 - 1.9	39	2.7 - 4.4	36	1 - 3.5	36
mean open water discharge	m^3/s	3.4 - 24.34	20	9.35 - 24.34	10	4.41 - 10.04	4	3.4 - 9.33	6
mean 30-day discharge	m^3/s	0.45 - 10.93	20	0.45 - 10.48	10	0.55 - 9.36	4	0.49 - 10.93	6
current velocity	m/s	0.15 - 1.35	106	0.15 - 1.35	36	0.17 - 1.17	36	0.19 - 1.13	34
water depth	m	0.17 - 0.55	111	0.17 - 0.46	39	0.21 - 0.46	36	0.22 - 0.55	36
substrate particle size (WAI)	-	1.6 - 7	111	1.6 - 7	39	2.3 - 4.9	36	2 - 5	36
pH	-	7.1 - 8.7	81	7.1 - 8.7	25	7.7 - 8.7	36	7.7 - 8.5	20
conductivity	µS/cm	143 - 620	106	202 - 576	36	143 - 510	36	208 - 620	34
TP	mg/L	0.008 - 0.054	15	0.01 - 0.054	5	0.008 - 0.054	6	0.008 - 0.023	4
TN	mg/L	0.2 - 3.2	13	0.7 - 3.2	7	0.2 - 2.4	3	0.6 - 0.9	3
DOC	mg/L	11 - 46	17	20 - 46	7	11 - 23	6	11 - 24	4
TSS	mg/L	0.4 - 60	17	2 - 26	7	0.4 - 60	6	2 - 3	4

The first two PCs generated by ordination of the environmental data for the MacKay, Muskeg and Steepbank rivers explained slightly more than 50% of the total variation in the data set (Table 6.10). The third and subsequent components represented mostly single variables and were therefore not interpreted. Reach-scale variables (i.e., discharge and gradient), wetted width and three water quality variables (i.e., TP, conductivity and DOC) were associated with PC1. Variables with high loadings on PC2 included distance from mouth, pH and water depth. The remaining variables (i.e., TSS, current velocity, TN and substrate) were not strongly associated with either component.

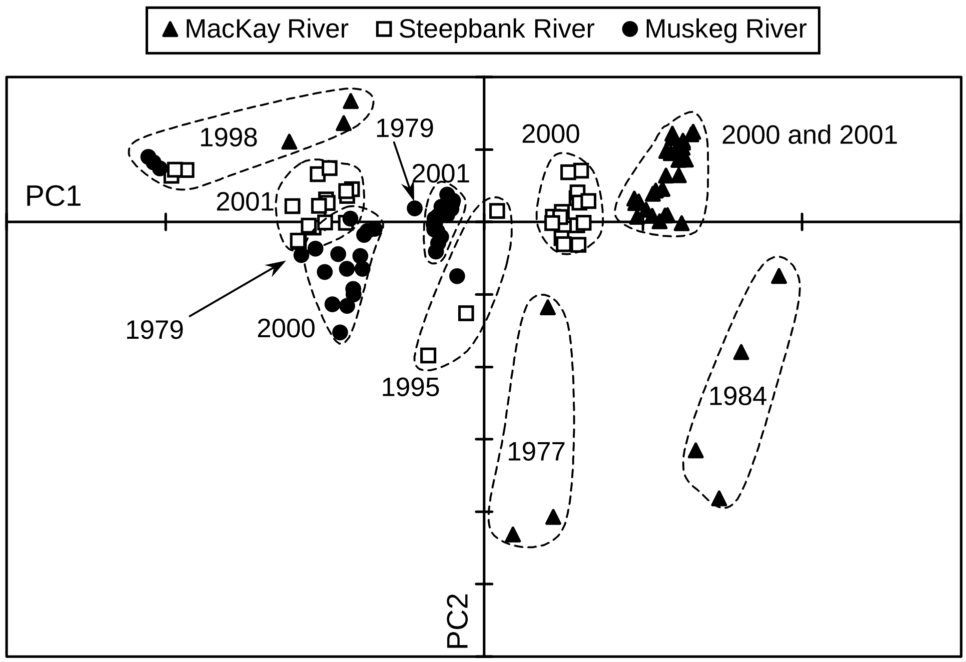
Table 6.10 Summary of Environmental PCA Results for Erosional Sites

Variable	Component Loadings	
	PC1	PC2
TP	**0.916**	0.053
mean 30-day discharge	**0.845**	0.170
mean open water discharge	**0.840**	0.197
conductivity	**-0.749**	0.098
DOC	**0.742**	-0.456
reach gradient	**-0.687**	-0.129
wetted width	**0.647**	0.361
distance from mouth	0.148	**-0.800**
pH	-0.404	**0.733**
water depth	0.150	**-0.570**
TSS	0.402	0.128
current velocity	0.254	0.096
TN	0.247	0.142
substrate particle size (WAI)	-0.281	-0.434
Eigenvalue	4.914	2.523
% of variance explained	35.1	18.0

Note: Loadings >0.5 are in bold.

The ordination plot of environmental PC1 versus PC2 shows grouping of sites sampled within years (Figure 6.5). In the MacKay River, sites sampled in both 2000 and 2001 formed a tight group. With the exception of the 1977 and 1984 data, most of the variation in the environmental data set was along PC1. Sites sampled during recent surveys occupied the same range on PC2. The 1977 and 1984 sites were located farther upstream on the MacKay River, which accounts for their positions on the ordination plot (i.e., sites located farther upstream have lower scores on PC2). Some of the sites sampled in 2000 in the Muskeg River were farther upstream than those sampled in 2001, resulting in lower positions along PC2. The relatively high positions of the 1998 RAMP sites reflect site position (at river mouths), lower depth and higher pH relative to other years' data.

Figure 6.5 Ordination Plot of Environmental Data for Erosional Sites



The environmental PCA results suggest that PC2 is unlikely to be useful to investigate correlations between the biological and environmental data sets in the Muskeg River, because of the relatively short reach with available data. In all three rivers, correlations of biological variables with PC2 would most likely result from upstream-downstream trends and pH because of limited variation in depth among sites in the erosional data set.

Combining all three rivers, biological PC2 was significantly correlated with both environmental PCs (Table 6.11, scatter-plot in Figure 6.6, on lower right). The stronger relationship was with environmental PC2 (distance from mouth and pH) and sites from each river tended to form groups along the x-axis. The same relationship was also significant for the MacKay River sites alone, as may be expected from the greatest river distance included in the data for this river. Based on the scatter-plot (Figure 6.6, lower left), the overall relationship between biological PC2 and environmental PC1 (flow and related variables) was weak and grouping of sites by river was less apparent. The same relationship was not significant within any of the rivers when analyzed separately (Table 6.11).

Overall, distance from mouth and pH appeared to influence abundances of PC2-associated taxa to a greater extent than flow-related variables.

Table 6.11 Spearman Rank Correlations Between Environmental and Biological PC Scores for Erosional Sites

River and Biological PC	Environmental PC1	Environmental PC2
All Rivers (*n*=108)		
PC1	-0.188	-0.071
PC2	**0.379*** **	**0.515*** **
MacKay River (*n*=36)		
PC1	-0.265	**0.439***
PC2	-0.164	**0.595*** **
Muskeg River (*n*=36)		
PC1	-0.296	0.249
PC2	-0.307	-0.055
Steepbank River (*n*=36)		
PC1	**-0.499** **	-0.230
PC2	-0.205	-0.199

Note: Significant correlations are identified by bold font; ***=*P*<0.001; **=*P*<0.005; *=*P*<0.01.

Only two of the eight correlations involving biological PC1 were significant (Table 6.11), despite a pattern suggested by the biological PC1 versus environmental PC1 plot (Figure 6.6, upper left). Steepbank River sites appeared to diverge from the linear trend formed by sites in the Muskeg and MacKay rivers. Significant correlations within individual rivers included those with environmental PC1 in the Steepbank River and with environmental PC2 in the MacKay River. Both of these represented the longest gradients along environmental PCs, suggesting the amount of environmental variation may have been too narrow in the other rivers to influence benthic communities.

Relationships with flow (the underlying factor represented by environmental PC1) were further examined using reach means by river, to illustrate trends along this gradient alone. Mean discharge was calculated for each river and each year with available benthic community data, based on daily flows from July 15 to the sampling date in the fall (usually a two month period). This period was considered relevant for the following reasons:

- It excludes the spring freshet and early summer high flows from which communities present in the fall may have recovered previously.
- It represents the time elapsed since emergence and subsequent egg deposition by insects with the slow seasonal life cycle (as described for

the Oil Sands Region by Barton and Wallace [1980]). These include a number of common mayflies, which were a major component of the benthic communities of the rivers included in the analysis, as documented by fall surveys.

- It encompasses one to several generations of midges, which constitute another major component of the benthic communities of the rivers included in the analysis.

The graphs in Figure 6.7 are limited to sites at river mouths, where the most reliable flow data were available, and means were calculated for reaches subject to the same discharge. Only single sites per reach were available for years before RAMP, which accounts for the lack of error bars for historical data. Declining trends in PC1 scores with increasing flows were suggested by Figure 6.7 for all three rivers. Trends with PC-2 were not apparent, with the possible exception of the Steepbank River. Removing the point corresponding to the lowest discharge value would result in a very shallow trend (Steepbank and Muskeg rivers) or no trend (MacKay River). Therefore, although the results suggest the potential for an influence of flow, the data at this time are insufficient (i.e., only four levels of flow are available) to allow a confident assessment.

Figure 6.6 Relationships Between Environmental and Biological Principal Component Scores for Erosional Sites

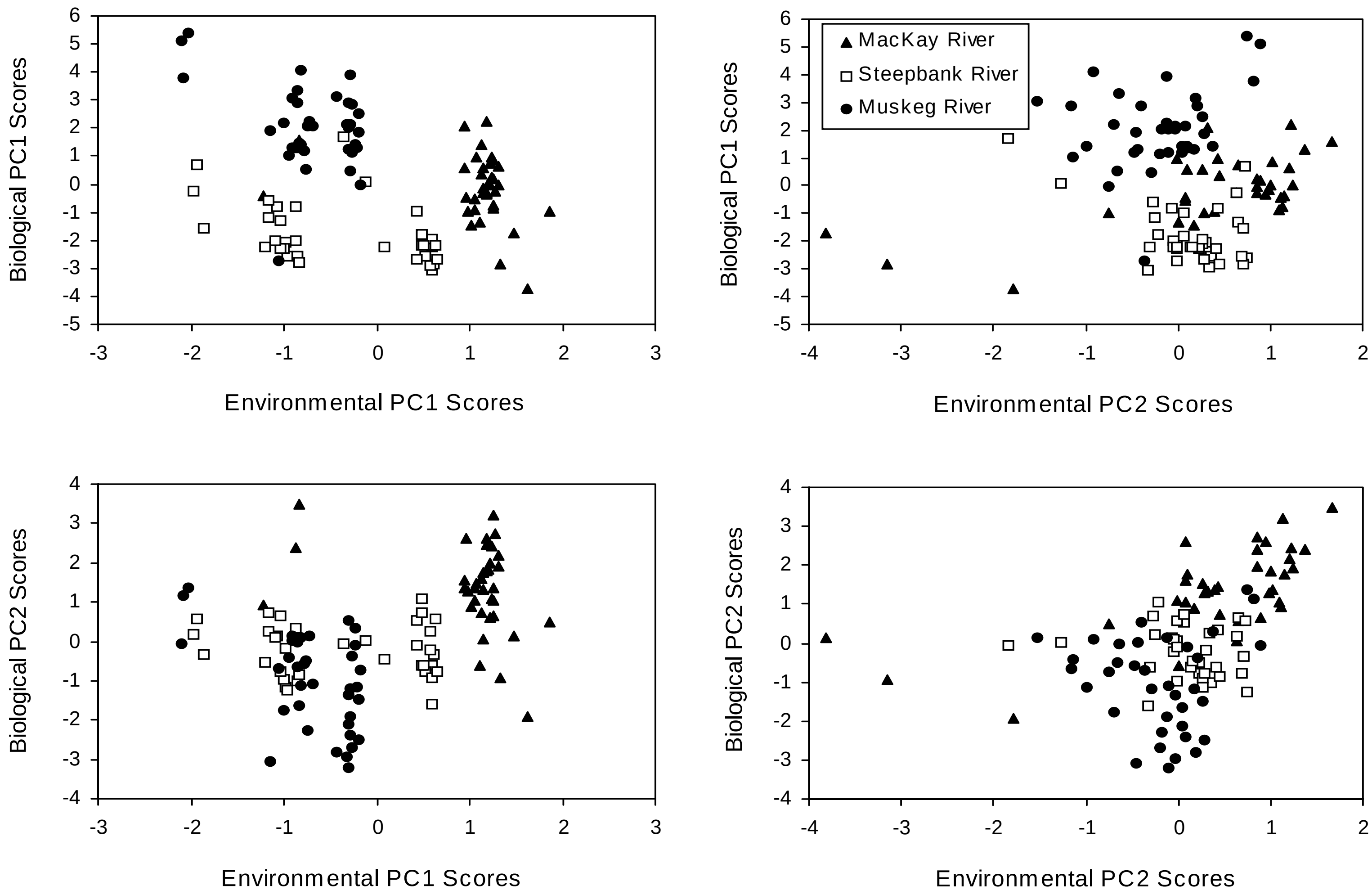
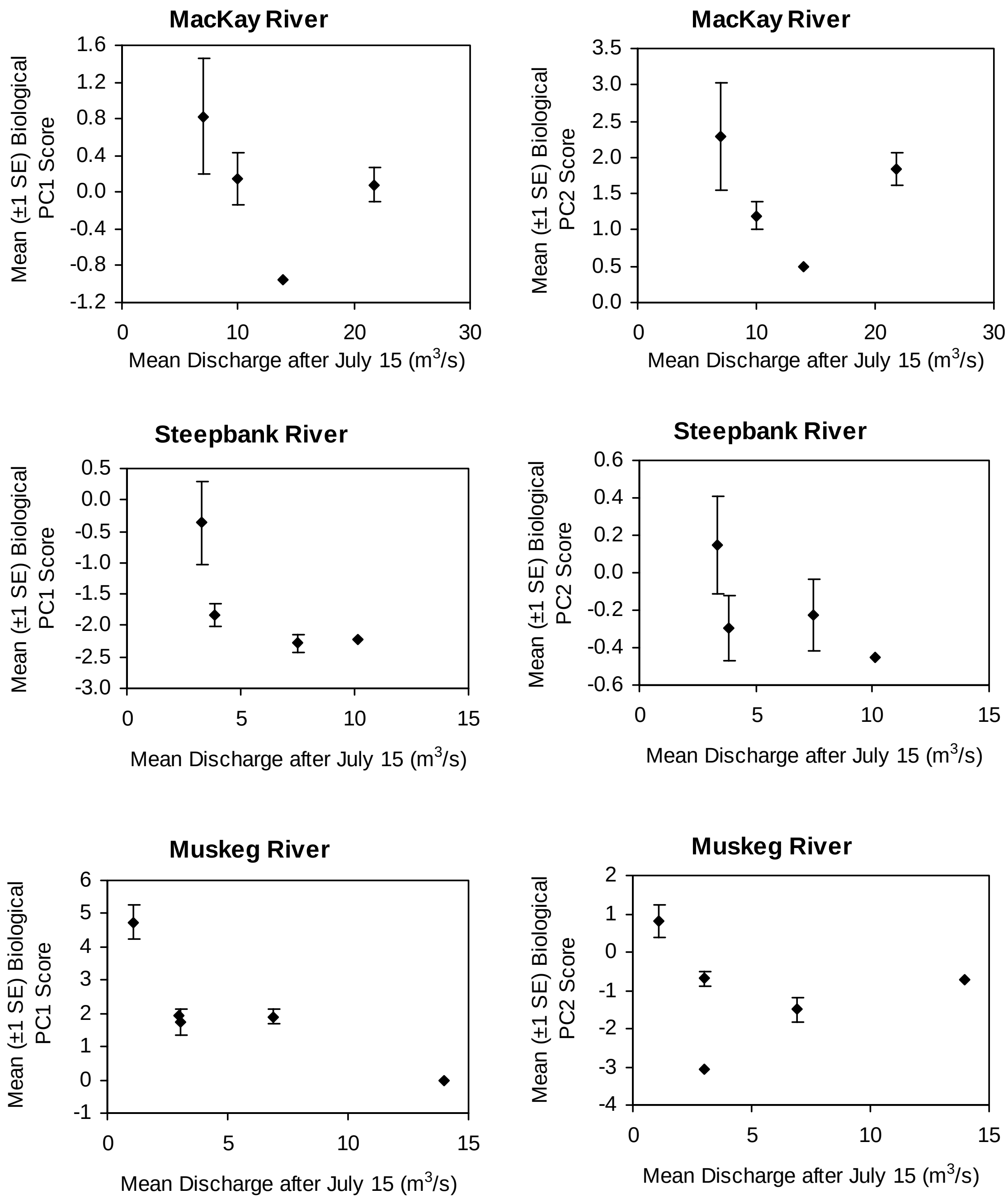


Figure 6.7 Relationships Between River Discharge and Means of Biological Principal Component Scores for Erosional Sites at River Mouths



Note: SE=Standard Error

Analysis of the erosional data set identified differences in community structure among rivers. In particular, Muskeg River communities were different from communities in the MacKay and Steepbank rivers. The PCs generated by the analysis of the biological data set were inconsistent with habitat associations of taxa represented by ordination axes. The analysis did not highlight major factors that influence benthic community structure. A possible reason for this finding is the relatively few years of data available at this time, which represent a limited number of levels of the major factor affecting benthic communities (i.e., flow).

Depositional Sites in Rivers

The first two PCs generated by ordination of depositional benthic invertebrate data explained close to 50% of the total variation in the data set (Table 6.12). Most of the abundant taxa were associated with PC1. Taxa with high correlations to PC1 accounted for 74% of the total abundance across all sites. Only ostracods (2.5% of total abundance) were highly correlated with PC2. Additional PCs also represented individual taxa. Therefore, only PC1 was retained for further analysis. Since two abundant depositional groups, Oligochaeta (15.6%) and Sphaeriidae (6.2%), were not associated with either of the first two PCs, they were also included in further analysis.

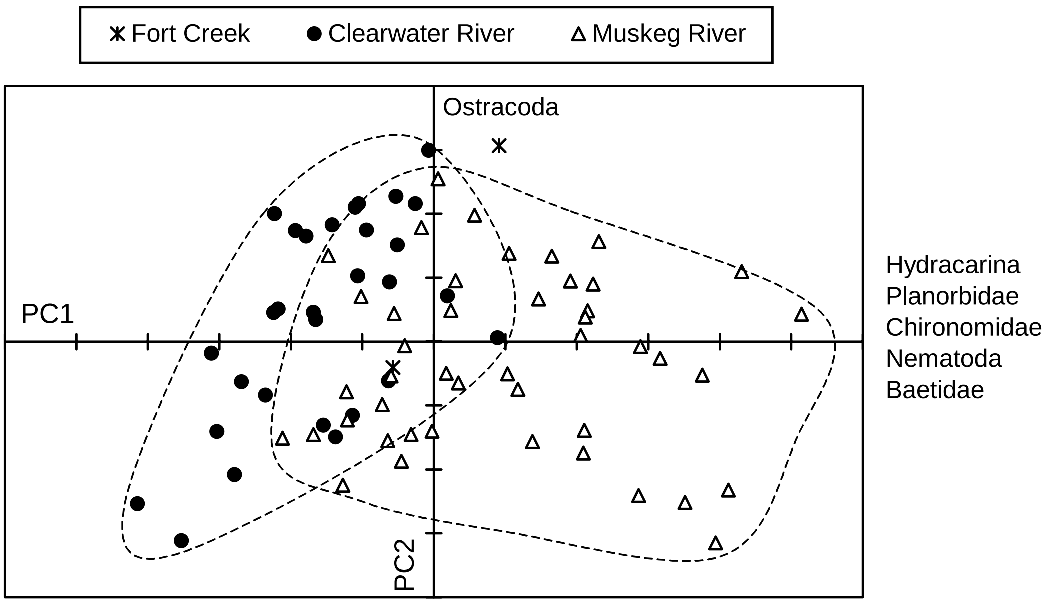
Table 6.12 Summary of Biological PCA Results for Depositional Sites in the Muskeg River

Variable	Pearson Correlations Between Original Variables and PC Scores	
	PC1	PC2
Hydracarina	**0.752**	-0.301
Planorbidae	**0.735**	-0.192
Chironomidae	**0.694**	0.228
Nematoda	**0.666**	0.147
Baetidae	**0.644**	-0.223
Ceratopogonidae	0.486	0.144
Leptophlebiidae	0.424	-0.185
Ostracoda	0.194	**0.872**
Oligochaeta	0.039	0.470
Sphaeriidae	0.145	0.340
Eigenvalue	4.032	2.305
% of variance explained	29.5	16.8
% of total abundance represented by taxa with correlation coefficients >0.5	74.3	2.5

Note: Correlation coefficients >0.5 are in bold. Coefficients representing significant correlations (*P*<0.002) are shaded.

PC1 represented depositional taxa, with the exception of the Baetidae (Table 6.12). Although Muskeg River sites sampled in 2000 and 2001 tended to have higher scores on PC-1, there was a partial overlap between Muskeg River and Clearwater River sites on the ordination plot (Figure 6.8). The two Fort Creek sites were intermediate between these rivers. There was no separation of rivers along PC2.

Figure 6.8 Ordination Plot of Biological Data for Depositional Sites



Ranges in reach-scale environmental variables differed substantially between the Muskeg and Clearwater rivers (Table 6.13). Ranges in a number of other variables (i.e., current velocity, sediment composition, pH, conductivity, TP, TN and TSS) exhibited considerable overlap between the two rivers. Because of the low sample sizes for reach-scale environmental variables for the Clearwater River, only the Muskeg River sites were included in the PCA of environmental data and the analysis of relationships between environmental and biological data was limited to local-scale variables for the Clearwater River.

Table 6.13 Ranges of Environmental Variables Selected for Depositional Sites in the Clearwater and Muskeg Rivers

Variable	Units	Clearwater River		Muskeg River	
		Range	*n*	Range	*n*
distance from mouth	km	6.5 - 35.5	30	12.2 - 48.7	45
wetted width	m	175	2	5.5 - 28	44
mean open water discharge	m^3/s	101.1 - 142	2	1.64 - 10.07	17
mean 30-day discharge	m^3/s	60.3 - 84.7	2	0.15 - 10.93	17
current velocity	m/s	0 - 0.69	30	0 - 0.45	43
water depth	m	0.2 - 0.8	30	0.25 - 2	45
sediment TOC	%	0.01 - 2.9	30	0.2 - 24	32
% fine sediments	%	3 - 77	30	5 - 48	32
pH	-	8.1	2	7.1 - 8.3	45
conductivity	µS/cm	198 - 274	5	200 - 460	45
TP	mg/L	0.032 - 0.035	2	0.021 - 0.052	14
TN	mg/L	0.2 - 0.3	2	0.7 - 2.2	14
DOC	mg/L	6 - 8	2	19 - 27.3	15
TSS	mg/L	7 - 8	2	2 - 9	15

In the Clearwater River, biological PC1 scores were not correlated with local-scale environmental variables, but a number of significant correlations were found between environmental variables, and abundances of bristle worms and fingernail clams (Table 6.14). The directions of significant correlations were consistent with habitat associations of these organisms as well as expected intercorrelations among environmental variables.

Table 6.14 Spearman Rank Correlations Between Environmental and Biological Variables for Depositional Sites in the Clearwater River

Biological Variable	Current Velocity	Water Depth	Bottom Sediment TOC	% Silt and Clay in Bottom Sediments
PC1	-0.165	0.008	0.176	0.097
Oligochaeta	**-0.614*** **	-0.352	**0.629*** **	**0.702*** **
Sphaeriidae	**-0.623*** **	-0.058	**0.606*** **	**0.683*** **

Note: Correlation coefficients representing significant correlations are in bold; *n*=30; ***=*P*<0.001.

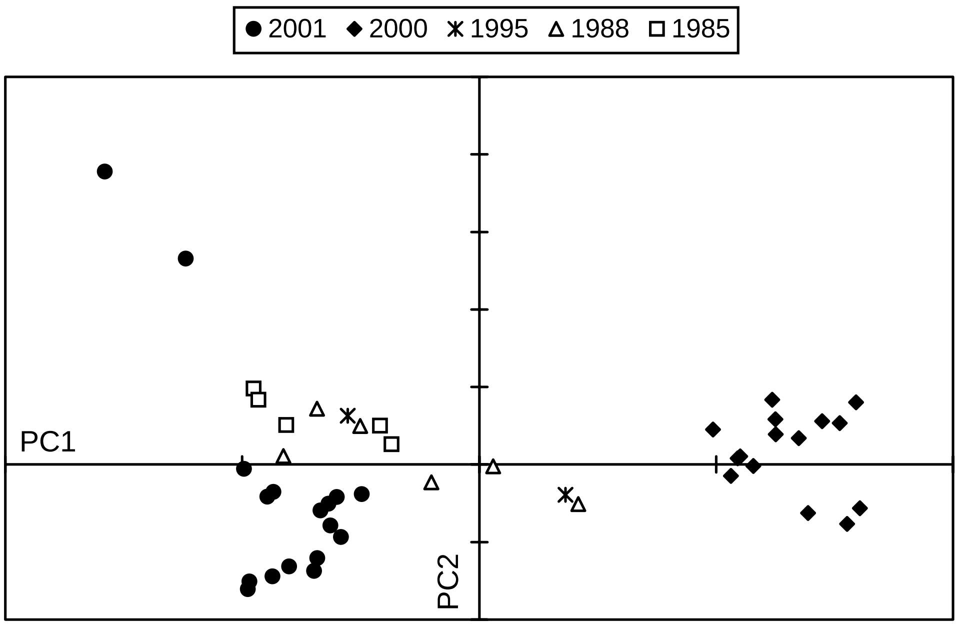
The first two ordination axes produced by the PCA summarizing the environmental data set for the Muskeg River explained about 65% of the total variation in the data set (Table 6.15). All variables except water depth were strongly associated with the first or second PC. Flow-related variables and water quality variables were associated with PC1. Variables with high loadings on PC2 included sediment composition and distance from mouth. As also seen for the erosional data set, sites sampled within years tended to form clusters on the ordination plot, with the conspicuous exception of two sites sampled in 2001 in the mid-reaches of the river (Figure 6.9), which had high PC1 scores due to a high percentage of fine sediments and TOC in bottom sediments. The first two environmental PCs and water depth were used in further analysis to investigate relationships between the benthic community and environmental variation.

Table 6.15 Summary of Environmental PCA Results for Depositional Sites in the Muskeg River

Variable	Component Loadings	
	PC1	PC2
TP	**-0.932**	-0.174
conductivity	**-0.908**	-0.270
mean 30-day discharge	**0.887**	-0.058
wetted width	**0.849**	0.126
mean open water discharge	**0.803**	-0.385
current velocity	**0.755**	0.054
pH	**0.504**	0.186
% silt and clay in bottom sediments	0.0003	**0.856**
TOC in bottom sediments	-0.218	**0.792**
distance from mouth	-0.447	**0.569**
water depth	0.427	0.326
Eigenvalue	5.098	2.097
% of variance explained	46.3	19.1

Note: Loadings >0.5 are in bold.

Figure 6.9 Ordination Plot of Environmental Data for Depositional Sites in the Muskeg River



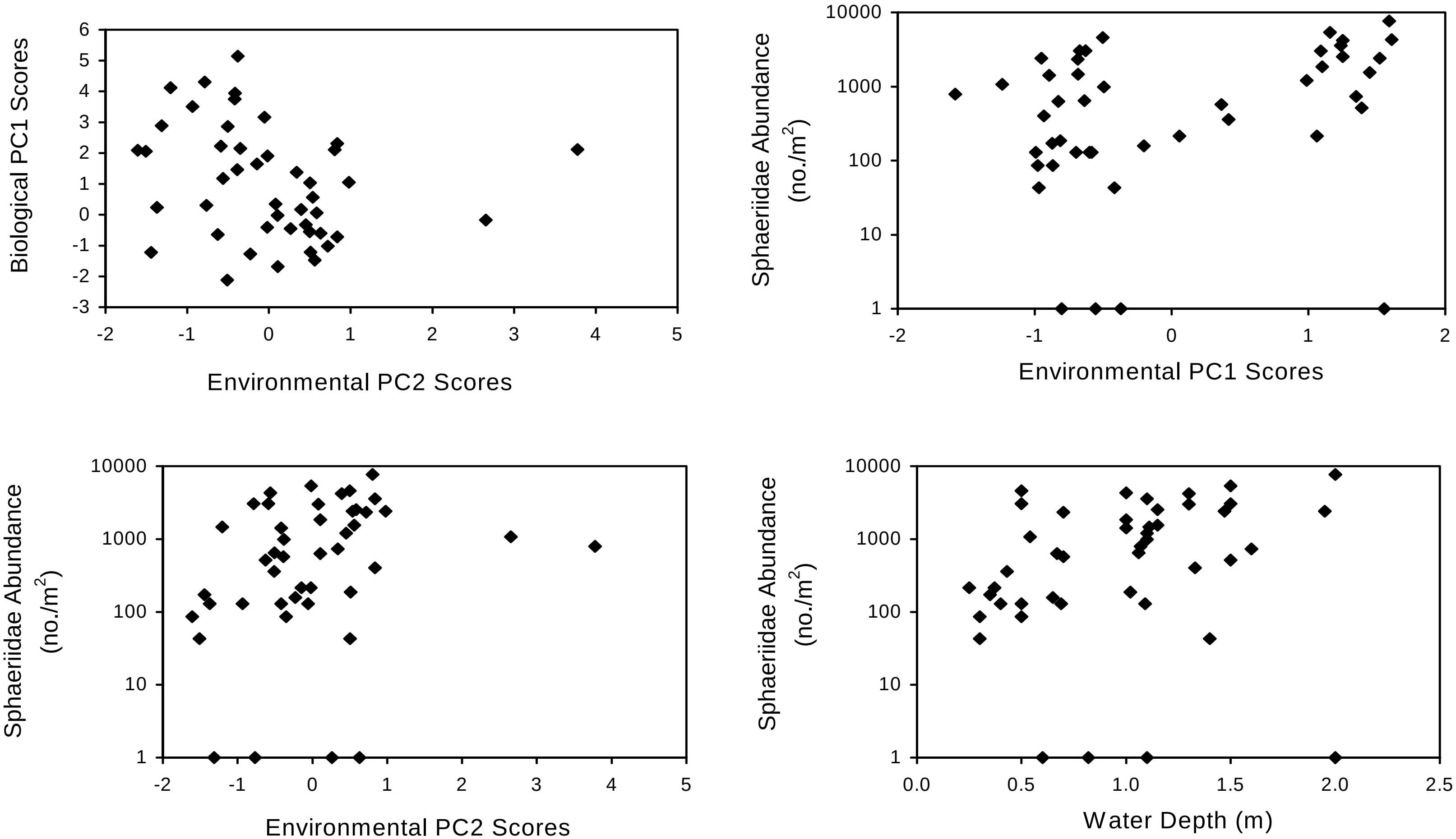
In the Muskeg River data set, significant correlations were found between biological PC1 and environmental PC2, and between Sphaeriidae abundance and all three environmental variables (Table 6.16). However, scatter-plots revealed that none of the significant correlations represented strong relationships (Figure 6.10).

Table 6.16 Spearman Rank Correlations Between Environmental and Biological Variables for Depositional Sites in the Muskeg River

Biological Variable	Environmental PC1	Environmental PC2	Water Depth
PC1	-0.171	**-0.334***	0.011
Oligochaeta	0.290	0.100	0.203
Sphaeriidae	**0.367***	**0.368***	**0.390****

Note: Significant correlations are identified by bold font; *n*=45; *=*P*<0.05; **=*P*<0.01.

Figure 6.10 Relationships Between Environmental and Biological Variables for Depositional Sites in the Muskeg River



Note: Zero abundances are plotted as 1 on graphs with log-transformed y-axes.

Exploratory analysis of the depositional benthic invertebrate data has found some differences between the benthic communities of the Muskeg and Clearwater rivers. In the Clearwater River, local-scale environmental variables were correlated with abundances of bristle worms and fingernail clams. The variation in community structure in the Muskeg River did not appear strongly related to the local or reach-scale variation in environmental variables included in the analysis.

6.2.1.3 Conclusions and Recommendations

Exploratory analysis of benthic invertebrate data generated by RAMP between 1997 and 2001, and available historical data has revealed differences among benthic communities of individual waterbodies, but did not detect strong correlations between community structure and environmental variables. Based on the biological data, sites were usually grouped by river, implying that each river has characteristic communities. Grouping of sites by lake was not apparent. Significant but weak correlations were found between benthic community and local habitat variables in lakes (depth) and the Clearwater River (substrate and current velocity), but not in the Steepbank, MacKay and Muskeg rivers. There was some indication that flow may be an important controlling factor in erosional sections of rivers, but there was insufficient data to demonstrate this with certainty.

These results in part reflect the amount of available data (only a few years) and the variable spatial coverage among years. At most, five years of data are available for a waterbody at this time, representing only a few levels of potential factors affecting benthic communities (e.g., flow). Trends along environmental gradients may also be difficult to detect because of relatively short gradients (i.e., limited ranges in environmental variables due to sampling similar habitats) and added variation originating from collecting single samples at each site (discussed in Section 6.3.2.4).

The findings of characteristic communities in each river implies that it is unlikely that data from one river could be used as reference site data for detecting effects in other rivers.

The analysis was exploratory, taking advantage of the available data to look for patterns. Hence, there are no specific recommendations arising from this component.

6.2.2 Baseline Ranges for Key Benthic Community Variables

6.2.2.1 Methods

The variation in total abundance, richness and abundances of dominant invertebrate groups was examined to derive preliminary baseline ranges at the reach-scale, based on year-to-year variation. The lower erosional reaches of the MacKay, Muskeg and Steepbank rivers were included in this analysis, based on data collected by RAMP in 1998, 2000 and 2001. Previous surveys sampled single sites within these reaches; thus, they were not relevant at the reach-scale sampled by RAMP. Sufficient data were not available from depositional reaches for this type of analysis.

Data for the three sites sampled by RAMP in 1998 (i.e., before converting to the present sampling design) were averaged to arrive at mean values applicable to the reaches sampled. The sampling effort was the same in the three years included in this section, although spatial coverage was greater during 2000 and 2001 (about 4 km in each river) than in 1998 (<1 km).

The evaluation was limited to key benthic community variables, including the following:

- total abundance;
- richness; and
- abundances of dominant invertebrate groups, including the Chironomidae, Oligochaeta, Hydracarina and the combined abundance of the pollution-sensitive orders Ephemeroptera, Plecoptera and Trichoptera (EPT).

Baseline ranges were estimated as the mean ±2 standard deviations (SDs), based on the three years of data available at the reach scale. Given a normal distribution, the mean ±2 SD would encompass 95% of the data, thereby providing a reasonable estimate of the range. Two standard deviations were expressed as a percentage of the mean for each variable in each river. Use of 2 SD as the effect size for evaluating effects on benthic communities was recommended by Environment Canada (1998, 2002) for pulp mill and metal mining aquatic Environmental Effects Monitoring (EEM).

Only three years of data are available at this time, which limits this approach to providing rough approximations only. Nevertheless, the calculated percentages may provide an approximate indication of the among-year differences that might be considered the limits of natural variation, thereby aiding development of critical effect sizes for statistical tests and power analysis during future RAMP cycles.

6.2.2.2 Results and Discussion

Means and 2 SDs for total abundance were similar in the MacKay and Muskeg rivers, while both values were about 50% lower in the Steepbank River (Table 6.17). When expressed as a percentage of the mean, 2 SDs were similar in all three rivers (110 to 130%). Richness (i.e., the total taxa in all samples combined from a reach) was highest in the Muskeg River and was similar in the other two rivers. The year-to-year variation in richness was low in all three rivers, with 2 SDs ranging from 6 to 21% of the mean.

Invertebrate abundances in major groups were more variable among rivers and years than total abundance (Table 6.17). Compared to the maximum range of 2.5-fold variation in total abundance among rivers, the range in variation for abundance of major groups was 1.6-fold (EPT abundance) to 6.1-fold (Hydracarina abundance). The range in 2 SD expressed as a percentage of the mean was between 100 and 200%.

Table 6.17 Means ± 2 Standard Deviations for Total Abundance, Richness and Abundances of Dominant Invertebrate Groups for River Reaches Based on RAMP Data

River/Lake	Variable	Mean ± 2 SD (n=3)	2 SD as % of the Mean
MacKay River (lower erosional reach)	total abundance	8,320 ± 10,821	130
	richness	57.7 ± 9.5	16
	Oligochaeta	1,241 ± 1,573	127
	Hydracarina	208 ± 122	58
	EPT	2,258 ± 3,181	141
	Chironomidae	4,003 ± 7,230	181
Muskeg River (lower erosional reach)	total abundance	10,848 ± 12,365	114
	richness	73.7 ± 4.6	6
	Oligochaeta	767 ± 1,749	228
	Hydracarina	1,266 ± 2,085	165
	EPT	3,641 ± 3,824	105
	Chironomidae	3,285 ± 4,410	134
Steepbank River (lower erosional reach)	total abundance	4,385 ± 5,616	128
	richness	59.3 ± 12.2	21
	Oligochaeta	511 ± 523	102
	Hydracarina	227 ± 373	164
	EPT	2,220 ± 3,076	139
	Chironomidae	1,173 ± 2,150	183

Note: SD = standard deviation.

These ranges are not standardized for among-year variation in environmental factors (e.g., flow) which can be expected to result in wide ranges. Once sufficient data are available to quantitatively express relationships with environmental factors, adjusted values of biological variables would provide more realistic estimates of baseline variation. Those estimates can then be used to derive critical effect sizes to be detected by statistical tests comparing benthic communities among years.

6.2.2.3 Conclusions and Recommendations

Preliminary estimates of baseline ranges in benthic community variables were similar in all three rivers, when expressed as percentages of the mean. Abundance variables had greater ranges (±100 to 200% of the mean) than richness (±6 to 21%). Invertebrate abundances in major groups were more variable among rivers and years than total abundance.

Once sufficient data are available to quantitatively express relationships with environmental factors, adjusted values of biological variables would provide more realistic estimates of baseline variation in abundances. Those estimates can then be used to derive critical effect sizes to be detected by statistical tests comparing benthic communities among years.

There are insufficient data to derive definitive baseline ranges at this time. Therefore, estimates of baseline ranges should be updated in future years as RAMP accumulates more data. It is recommended that using information on baseline ranges, the Benthic Invertebrate Subgroup of the Technical Subcommittee of RAMP develop critical effect sizes for benthic community variables that will be used in future evaluations of monitoring data.

6.3 DETECTING AND ASSESSING REGIONAL TRENDS

6.3.1 Long-Term Trends

6.3.1.1 Methods

Long term trends were examined graphically as plots of site means over time for each waterbody and benthic community variable (i.e., total abundance, richness and abundances of dominant invertebrate groups). This analysis focused on sites with multi-year data, in most cases located near the mouths of major tributaries of the Athabasca River. Differences in sampling designs among studies are discussed below.

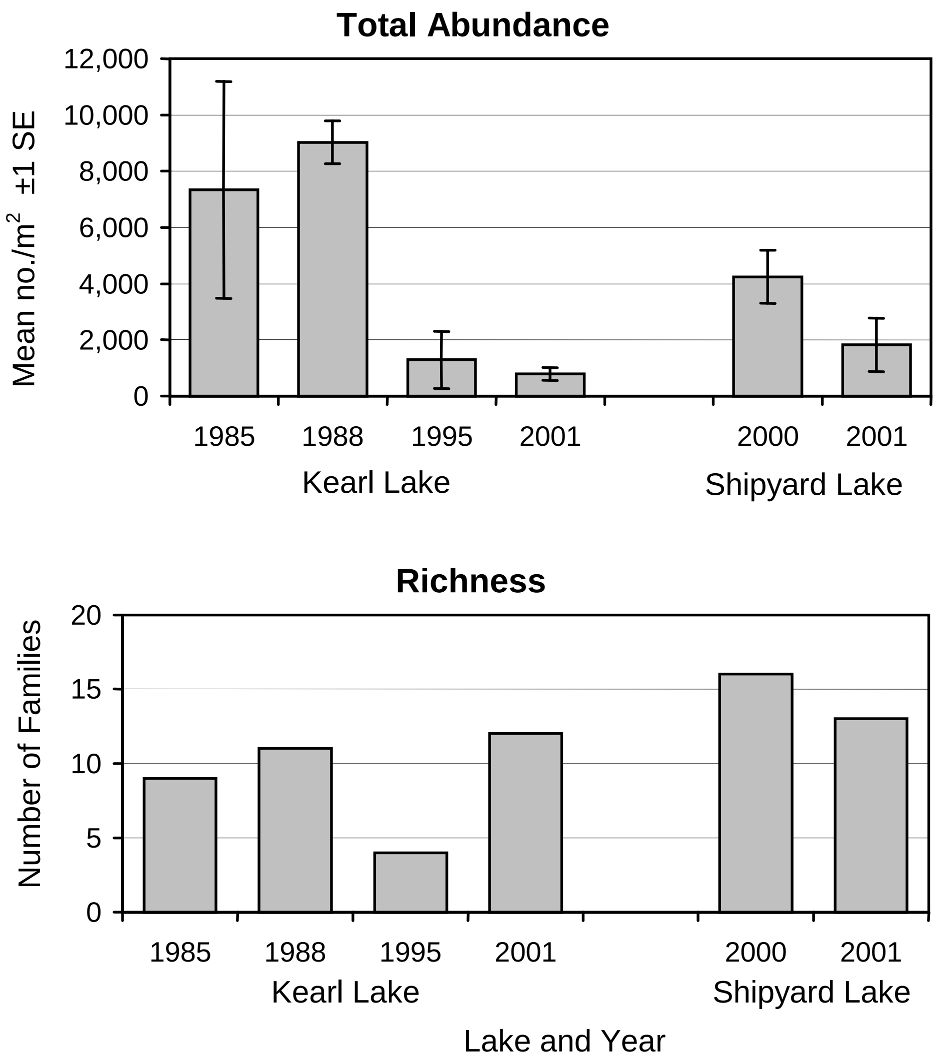
6.3.1.2 Results and Discussion

Kearl and Shipyard Lakes

Total invertebrate abundance has varied widely among years in Kearl Lake (Figure 6.11). There was an approximately two-fold variation between 2000 and 2001 in Shipyard Lake. The Kearl Lake data from 1985, 1988 and 1995 were collected using similar methods (i.e., three to five Ekman grabs from one site per lake) and are therefore directly comparable. RAMP data collected in Kearl Lake, and in 2000 and 2001 from both lakes, were also collected using consistent methods (i.e., single Ekman grabs from 10 locations per lake).

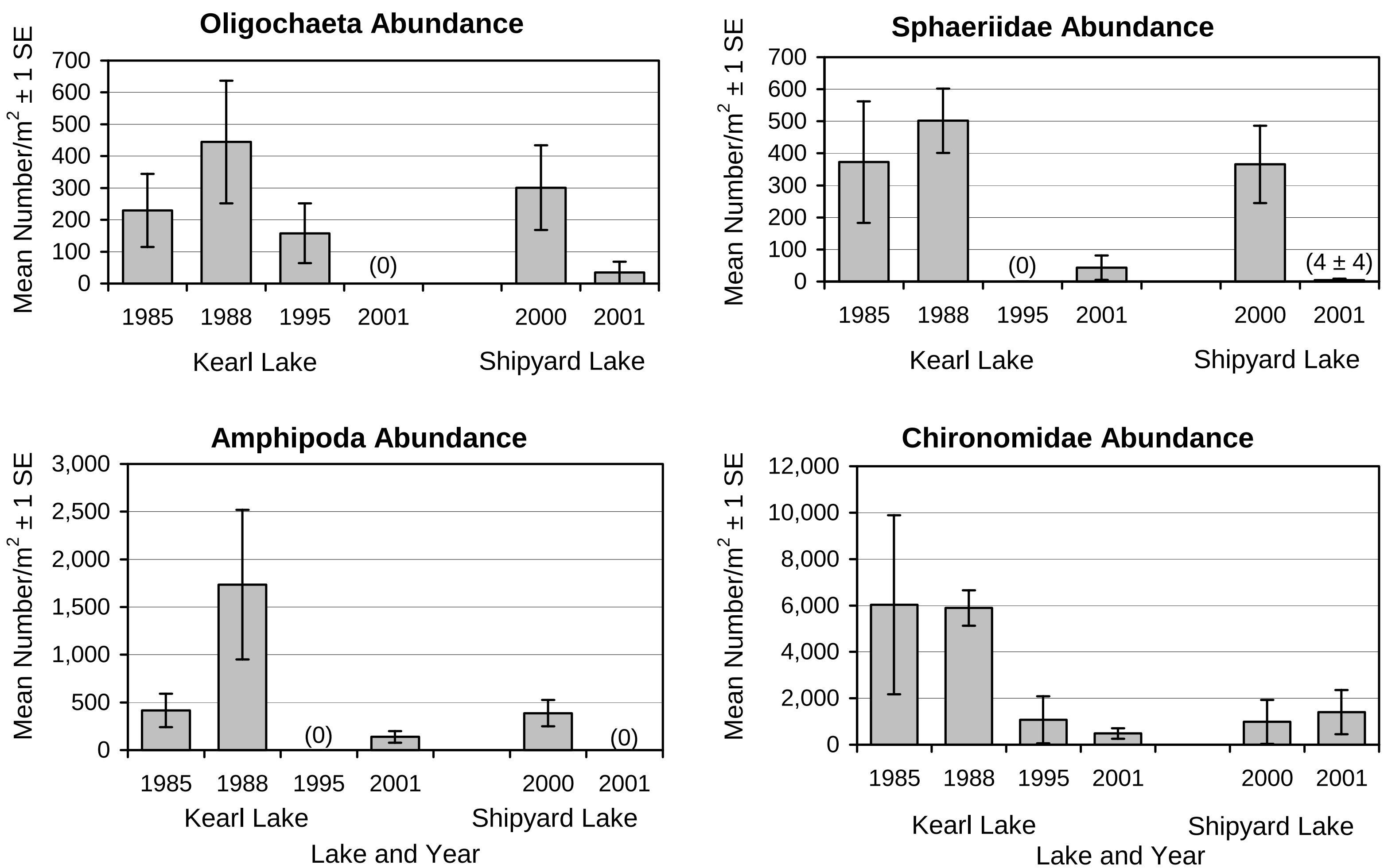
Richness varied somewhat less than total abundance, with an overall two-to-three fold range in Kearl Lake and a lower degree of variation in Shipyard Lake (Figure 6.11). The larger number of families found in 2000 and 2001 was most likely a function of the greater number of samples collected during these years. Abundances of oligochaete worms, sphaeriids, amphipods and chironomids were also highly variable among years in both lakes (Figure 6.12). Available data for these lakes are insufficient to evaluate long-term trends because at most three years of data were collected using the same sampling design.

Figure 6.11 Year-to-Year Variation in Total Invertebrate Abundance and Richness in Kearl and Shipyard Lakes



Note: SE=Standard error.

Figure 6.12 Year-to-year Variation in Abundances of Dominant Invertebrate Groups in Kearl and Shipyard Lakes



MacKay River

Total invertebrate abundance at erosional sites in the lower reach of the MacKay River was highly variable among years (Figure 6.13). Comparability among years is reduced by the larger mesh size used in 1977, which probably accounts for the low abundance reported in that year, and the difference in sampling design after 1998. 1998 and previous data represent individual sites, whereas post-1998 data pertain to approximately 4-km reaches. The change after 1998 was made by the RAMP Technical Subcommittee, to allow monitoring at the reach scale. On Figure 6.13 and subsequent figures showing temporal trends, three bars are shown for 1998, because three individual sites were sampled during that year. The single bars for 2000 and 2001 represent means calculated based on all samples collected in a reach.

Richness was considerably less variable and appeared to suggest an increasing trend over time (Figure 6.13). However, the trend is more likely an artifact of the changes in mesh size and sampling design. The lower sampling mesh used in 1977 may have resulted in reduced richness. Conversely, the greater spatial coverage in 2000 and 2001 most likely accounts for the larger number of families encountered in those years.

Abundances of oligochaete worms varied without an apparent trend over time (Figure 6.13). Combined abundances of the EPT orders and chironomid abundance reflected the pattern in total abundance (Figure 6.14), since these groups contributed the majority of total invertebrates.

The higher abundances observed in 1998 relative to all other years with available data cannot be attributed to any single factor with certainty, although they may reflect among-year variation in river flows or, possibly, the smaller spatial scale of the 1998 survey. During the years with benthos data, discharge in all three major tributaries (MacKay, Muskeg and Steepbank rivers) was the lowest during the late summer and early fall. The analysis described in Section 6.2.1.2 suggested an influence of flows on total abundance, as illustrated in Figure 6.7. For all three rivers examined in that section, the highest abundances were observed during the year with the lowest flows during late summer and early fall (i.e., maximum abundances in Figure 6.7 were in 1998). However, the available data at this time are limited to four or five years, which does not allow a definitive conclusion regarding flow relationships. Additionally, the 1998 data represent a <1 km reach in all three rivers, rather than the 4 to 5 km reaches sampled by subsequent surveys. This change in reach length also introduces uncertainty regarding the observed relationships between invertebrate abundances and flows.

Figure 6.13 Year-to-Year Variation in Total Invertebrate Abundance, Richness and the Abundance of Oligochaeta in the Lower MacKay River

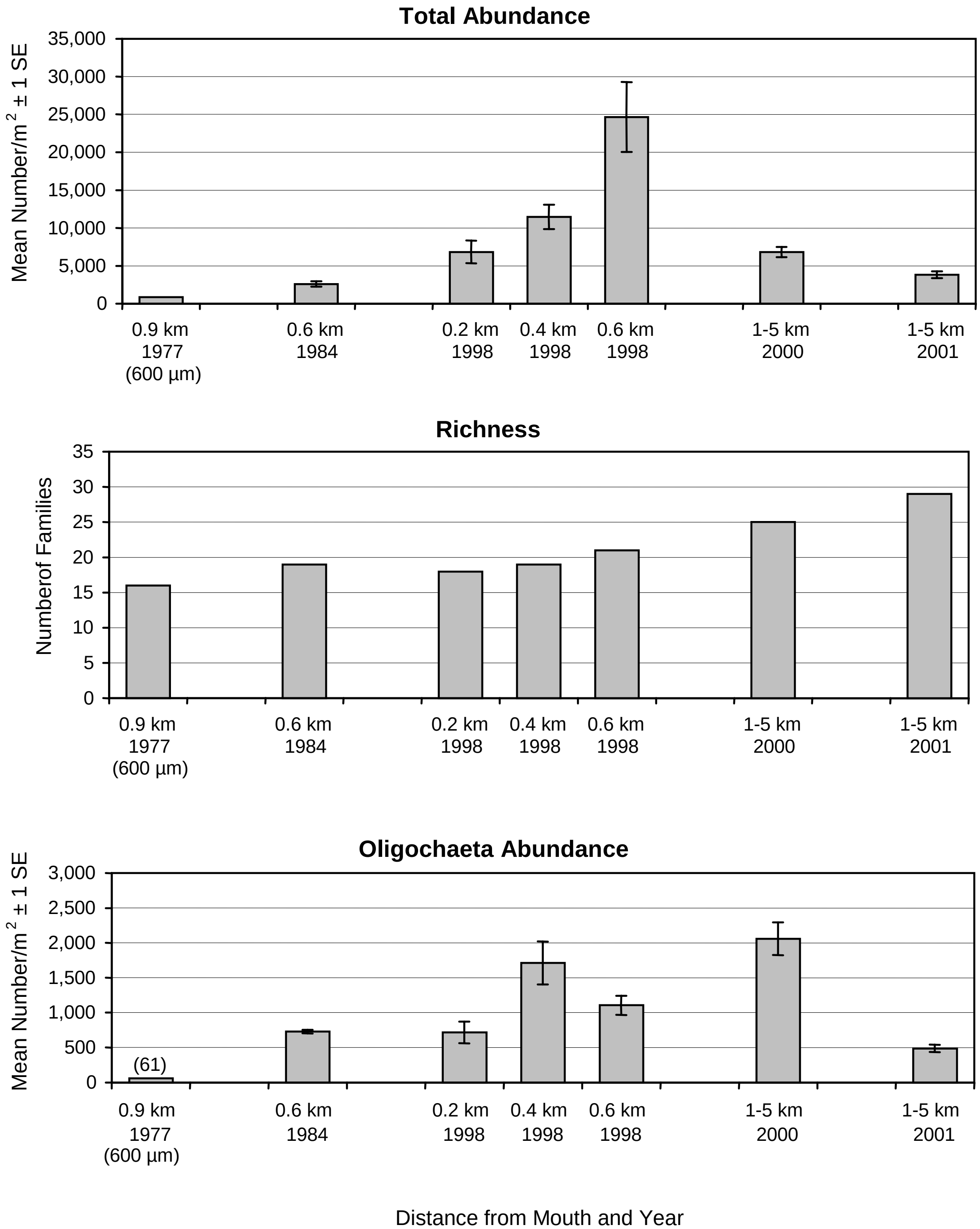
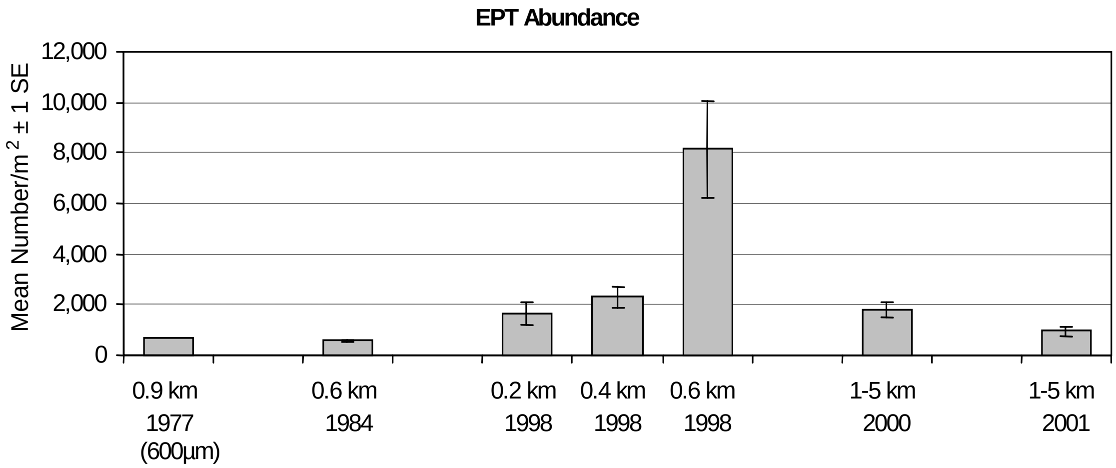
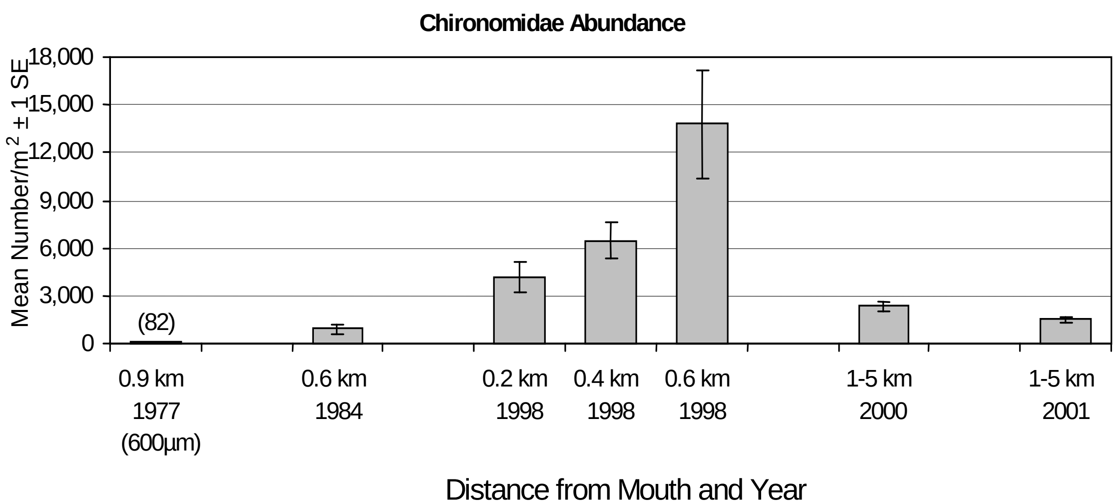


Figure 6.14 Year-to-Year Variation in Abundances of EPT and Chironomidae in the Lower MacKay River





Muskeg River

Within the lower erosional reach of the Muskeg River, total abundance was highly variable among years (Figure 6.15), but less variable among closely spaced sites in 1998 than in the MacKay River (Figure 6.13). As in the MacKay River, the slight increasing trend in richness was most likely an artifact of the change in sampling design after 1998. The higher abundances in 1998 may be due to low river discharge, or the shorter reach sampled.

Abundances of oligochaete worms, water mites (Figure 6.15) and the EPT orders (Figure 6.16) varied among years without an apparent trend. The pattern in chironomid abundance reflected the pattern in total abundance (Figure 6.16).

At most, two years of data were available for sites in the middle to upper depositional reaches of the Muskeg River. The lower part of the middle reach was sampled by RAMP in 2000 and 2001 using consistent methods (i.e., single Ekman grabs from 15 sites within a 4-km reach). A number of sites farther upstream were sampled in both 1985 and 1988, and one site was sampled in both 1988 and 1995. Before 2000, three to five replicate samples were collected at each site.

The RAMP data show low variation in total abundance and richness; however, differences between 1985 and 1988, and between 1988 and 1995 were considerably greater (up to 10-fold in total abundance at the 36.8 km site; Figure 6.17). Richness was slightly lower in 1985 than in 1988 at all sites sampled in both years. There was an approximately two-fold difference in richness between 1988 and 1995 at one site (14.9 km, Figure 6.17) despite similar sampling methods and levels of taxonomy.

Abundances of dominant invertebrate groups were more variable between years than total abundance (Figure 6.17 and Figure 6.18). The direction of differences between 1985 and 1988 were consistent among sites for three of the five variables examined, as demonstrated by significant differences in paired t-tests comparing the two years across all sites (i.e., total abundance, P=0.027; richness, P=0.009; Chironomidae abundance, P=0.05; paired t-tests). The consistency of differences across all sites in these variables suggests the existence of a common environmental factor that influenced communities along the length of the river. As suggested by the analysis under the first objective, variation in stream flow among years is a likely factor influencing year-to-year variation in community structure.

Figure 6.15 Year-to-Year Variation in Total Invertebrate Abundance, Richness and the Abundance of Oligochaeta at Erosional Sites in the Lower Muskeg River

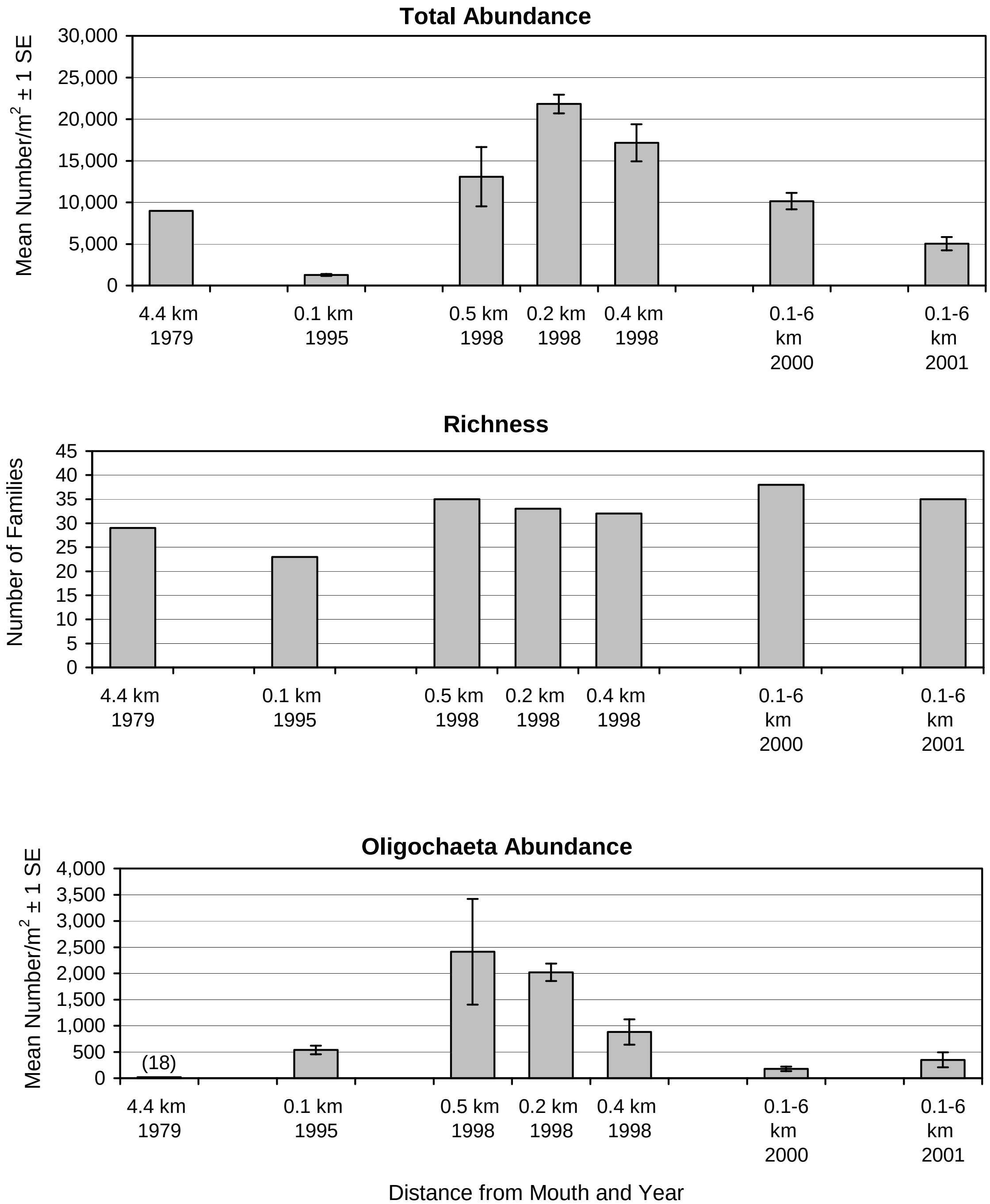


Figure 6.16 Year-to-Year Variation in Abundances of EPT and Chironomidae at Erosional Sites in the Lower Muskeg River

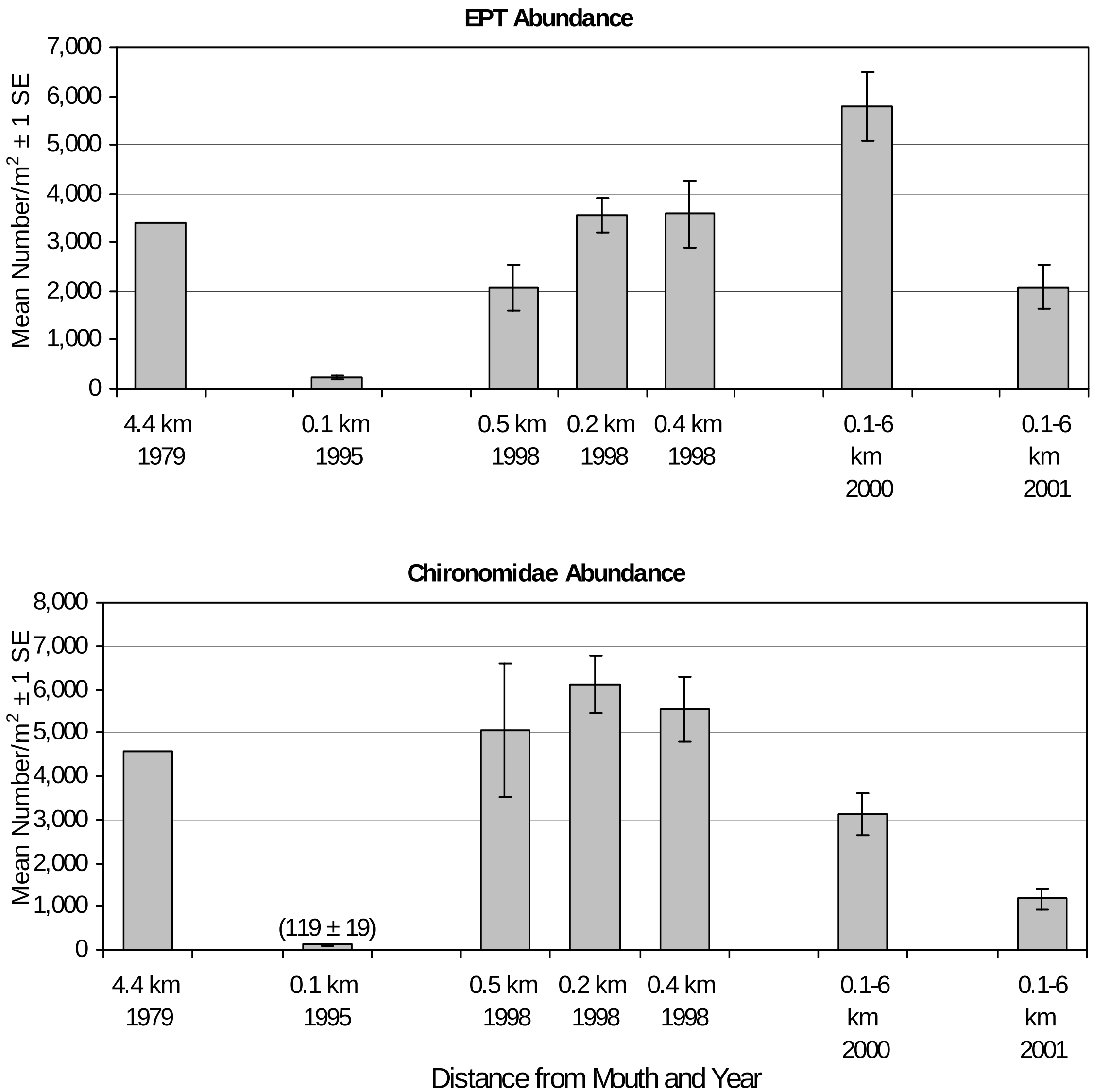


Figure 6.17 Year-to-Year Variation in Total Invertebrate Abundance, Richness and the Abundance of Oligochaeta at Depositional Sites in the Muskeg River

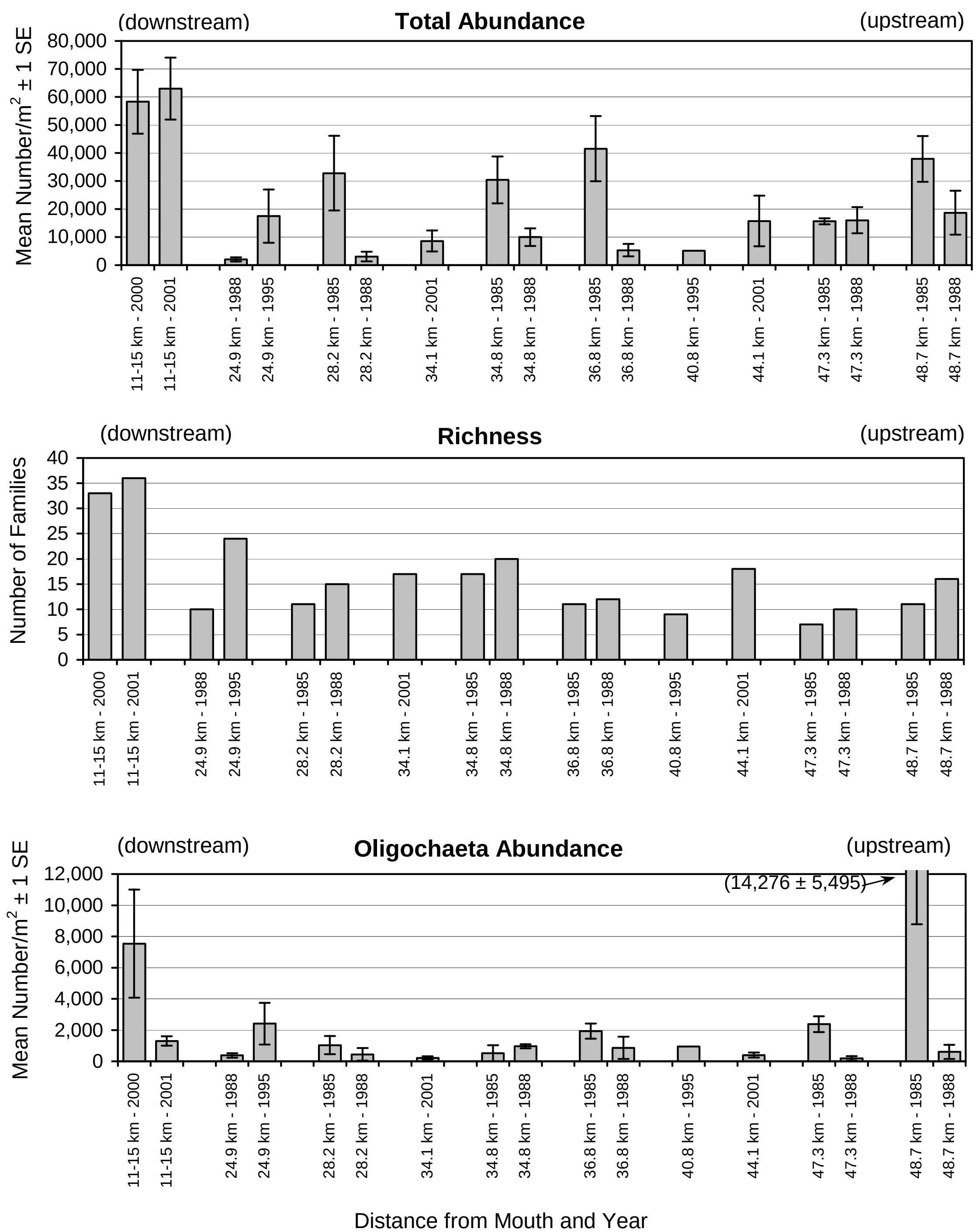
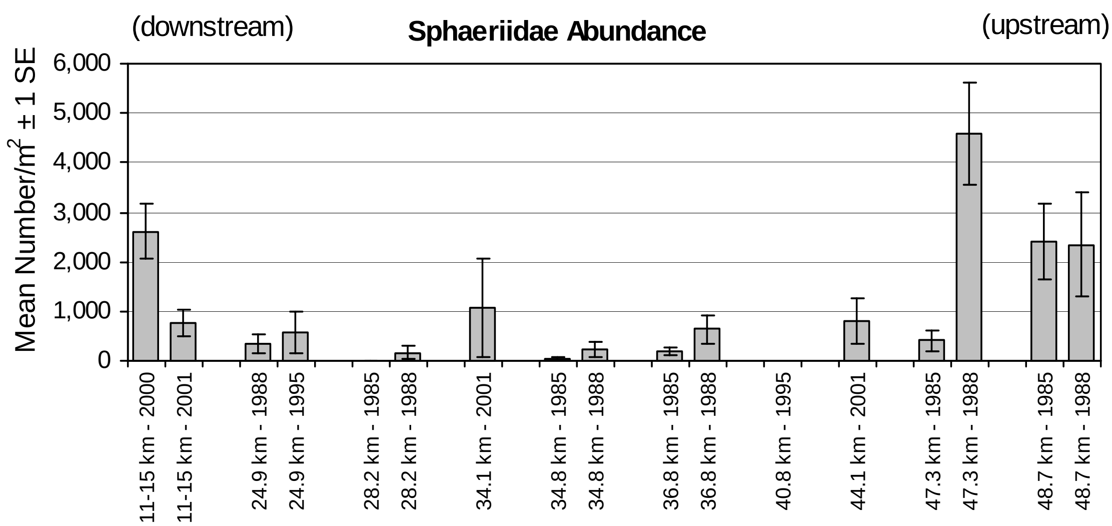
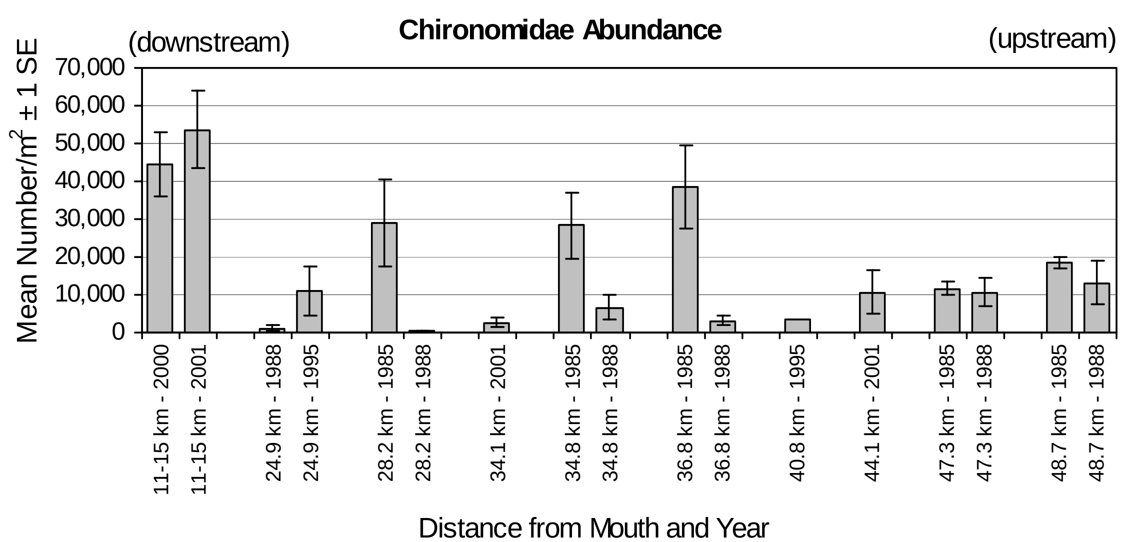


Figure 6.18 Year-to-Year Variation in Abundances of Sphaeriidae and Chironomidae at Depositional Sites in the Muskeg River





Steepbank River

At erosional sites in the lower reach of the Steepbank River, total invertebrate abundance was moderately variable among years (Figure 6.19). Comparability among years is reduced by the difference in sampling design after 1998. Pre-1998 data represent individual sites, whereas post-1998 data pertain to approximately 5-km reaches. Richness was less variable and the apparent increasing trend also reflected the change in sampling design after 1988. Abundances of oligochaete worms suggested an increasing trend over time (Figure 6.19). EPT and chironomid abundances generally reflected the pattern in total abundance (Figure 6.20), since these groups contributed the majority of total invertebrates. As in the other two rivers, the higher abundances in 1998 may reflect low river discharge, or the shorter reach sampled.

Summary

Visual assessment of the available data for locations with multi-year data did not detect long-term trends in major tributaries of the Athabasca River, other than apparent trends that may be the result of changes in sampling design. At this time, there are insufficient data to statistically test for long-term trends.

6.3.1.3 Appropriateness of the Study Design

Analysis of long-term trends requires collection of consistent data over time. RAMP has been gathering data for five years and has developed a standardized design. Only two years of consistent data are available at this time, which is insufficient to detect long-term trends. Since the benthic program is limited to the fall, data for analysis of long-term trends will accumulate at the slow rate of one data point/river/year. Thus, detection of long-term trends will not be possible for some time yet. The approach adopted by the Benthic Invertebrate Subgroup of the Technical Subcommittee is to collect five years of baseline data in each reach and then adjust the frequency according to development schedules.

Since there will be a potential for the appearance of long-term trends unrelated to oil sands developments (e.g., due to climate change or long-term hydrological cycles), monitoring to detect long-term trends should incorporate at least one reference river. Although the analysis described in Section 6.2.1.2 suggests that each river is unique in terms of its benthic community, it is possible that long-term trends unrelated to development would be similar in all regional rivers. This would allow the consideration of time-trends observed in reference rivers in the interpretation of data from potentially affected rivers. Based on the extent of planned oil sands development in the region and its hydrological features, finding reference rivers is problematic. Therefore, if significant long-term trends are found by future assessments without corresponding reference river data, the possibility of factors other than oil sands developments causing the observed trends will need to be considered, possibly by evaluating the consistency of trends among rivers monitored throughout the region.

Figure 6.19 Year-to-Year Variation in Total Invertebrate Abundance, Richness and the Abundance of Oligochaeta at Erosional Sites in the Lower Steepbank River

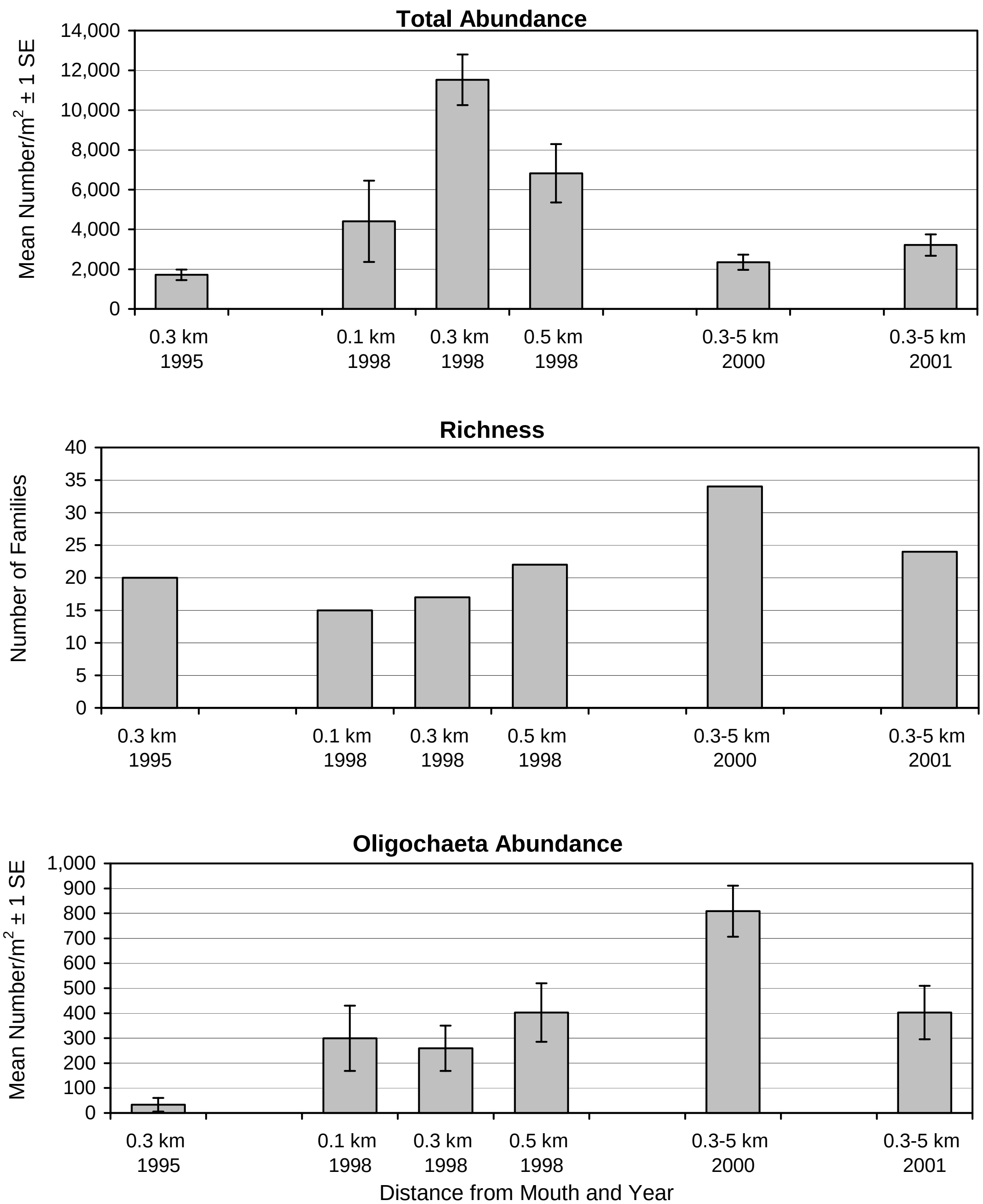
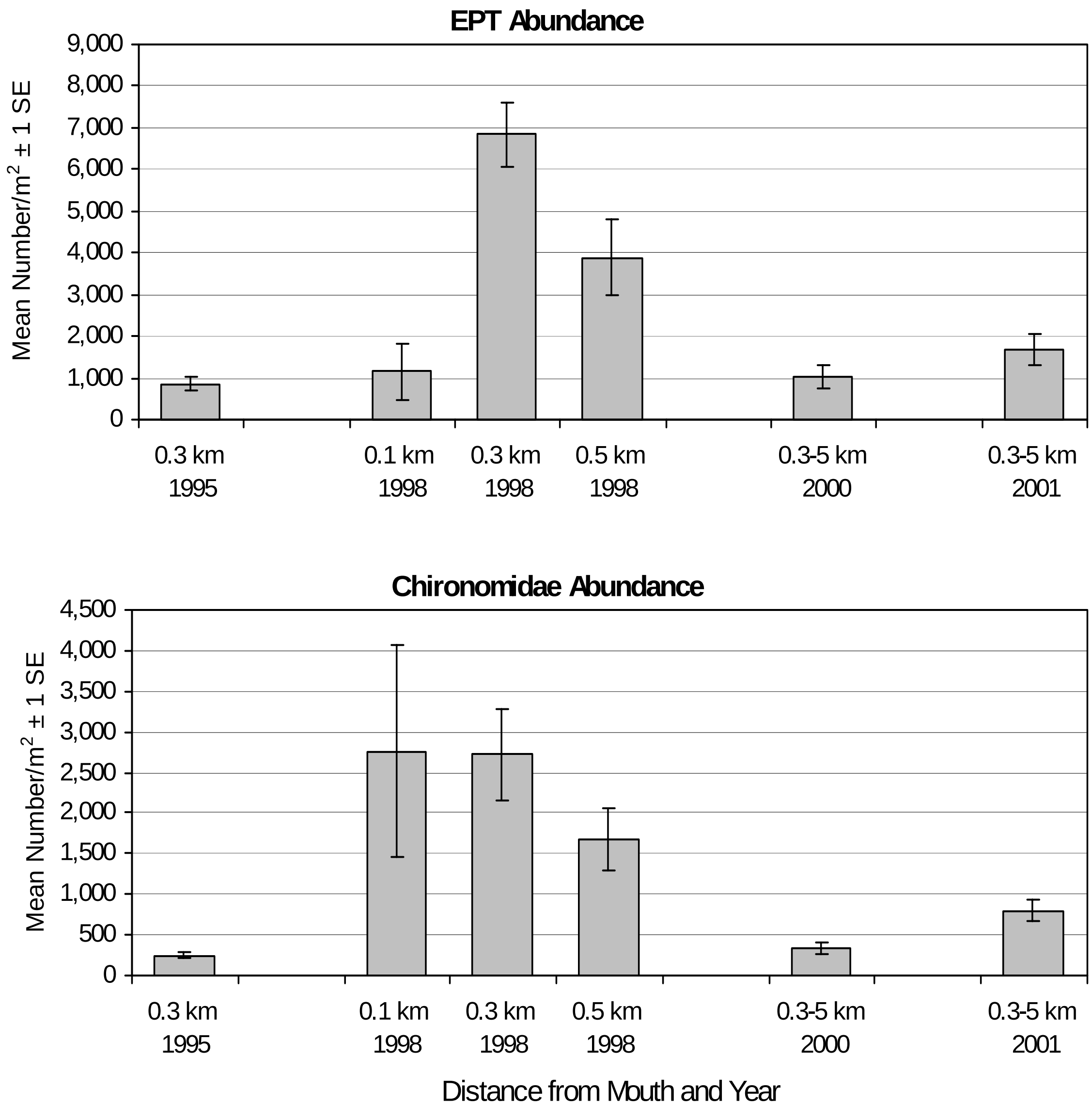


Figure 6.20 Year-to-Year Variation in the Abundances of EPT and Chironomidae at Erosional Sites in the Lower Steepbank River



Due to the phased nature of open-pit oil sands developments, effects in the form of step-trends are more likely than long-term trends. For example, the initial phase of muskeg and overburden dewatering usually results in releases of large amounts of drainage waters to surface waters, which may affect benthic communities. Following this phase, effects are less likely due to substantially lower water releases (or, in most cases, no planned water releases), until the establishment of tailings ponds which may release seepages to nearby streams. Therefore, it is essential that the study designs employed by RAMP be able to detect among-year differences (discussed in Section 6.3.2), while detection of long-term trends is of lower importance, especially during the initial phase of monitoring.

6.3.1.4 Conclusions and Recommendations

Detection of temporal trends requires consistent sampling over time at fixed locations. The RAMP committees that design monitoring components are aware of this requirement and are striving to satisfy it. As the program is still in a relatively early stage, adjustments suggested in other sections can be made without greatly compromising future ability to detect time trends. There are no specific recommendations arising from this section.

6.3.2 2000 Versus 2001 Comparisons

6.3.2.1 Methods

Data collected by RAMP were compared between 2000 and 2001 using one-way analysis of variance (ANOVA) or analysis of covariance (ANCOVA). Since positions of sites within reaches were different in each year, use of paired tests was not appropriate. Comparisons were made for the MacKay, Muskeg and Steepbank rivers, and Shipyard Lake. Analysis of covariance was used to compare PC1 scores between years in the Steepbank River, where significant correlations were found between PC1 scores and substrate composition summarized as the WAI in both years. All other comparisons were made using ANOVA. Significant correlations demonstrated in previous sections did not necessarily result in the use of covariates, because (1) covariates were selected based on local-scale environmental variables (reach-scale variables had insufficient ranges for use as covariates), (2) only subsets of the total available data were used in statistical tests, and (3) correlations were run individually for each reach being compared.

Benthic community variables compared between years included total abundance, richness and PC scores on the first (lakes and depositional rivers) or first two (erosional rivers) axes. Abundances of Oligochaeta and Sphaeriidae were also included in the analysis of the depositional river data set, because these groups were abundant and were not associated with PC1. Abundance variables were log(x+1) transformed to equalize variances and to better approximate normal distributions.

Retrospective power analysis was conducted to estimate the minimum detectable differences for non-significant tests, using methods described by Zar (1999). In addition, sample sizes required to detect a range of effect sizes were estimated using the SYSTAT 10 statistical software package (SPSS 2000) to investigate the possibility of adjusting the number of replicates to increase the sensitivity of statistical tests in future monitoring cycles. Since PC scores represent the abundance data, it was assumed that effect sizes relevant to invertebrate abundance are also appropriate for ordination scores.

6.3.2.2 Results and Discussion

Shipyard Lake

All variables were significantly different between years, with lower values in 2001 (Table 6.18). The difference between means in richness (56%) was larger than the 2 SDs calculated based on river data in Section 6.2.2.2 (6 to 21%). There were no substantial changes in mine activity near the lake, or in mine-related hydrological factors affecting the lake between the two years. There were minor differences in water quality between 2000 and 2001 (Golder 2001a, 2002c), but all parameters were within historical ranges in both years.

There is no obvious explanation for these findings, other than the possibility of a difference in the benthic community due to variation in dissolved oxygen (DO) and aquatic macrophyte cover between the two sampling periods. Dissolved oxygen concentration was lower in 2001 (2.3 to 3.7 mg/L) than in 2000 (7.4 to 10.3), and bottom sediments were anoxic in 2001. Macrophyte cover was close to zero in 2001 at all sites, but was 100% in 2000. These differences are generally consistent with the lower abundances and diversity found during 2001.

Table 6.18 Means, Standard Errors and Results of Statistical Tests for Benthic Invertebrate Variables Compared Between 2000 and 2001 in Shipyard Lake

Variable	2000			2001			% Difference[b]	*P*-value[c]
	Mean	Mean - SE	Mean + SE	Mean	Mean - SE	Mean + SE		
total abundance[a]	3,311	2,592	4,229	792	520	1,208	-76	**0.009**
richness	11.7	10.3	13.1	5.1	3.1	7.1	-56	**0.016**
PC1 scores	2.438	1.816	3.059	-1.649	-2.132	-1.167	-168	**<0.001**

Note: SE = standard error.

(a) Geometric means are shown for total abundance; mean + SE and mean - SE were calculated on log-transformed data and were then back-transformed.

(b) Percent difference between the 2000 and 2001 means, expressed relative to the 2000 mean.

(c) Results of one-way ANOVAs; *P*-values <0.05 are in bold.

MacKay River

Total abundance was significantly lower in 2001 in the MacKay River, but there was only a minor, non-significant difference in richness between years (Table 6.19). The mean PC1 score was 76% higher in 2001, but the difference was not significant. A smaller reduction in PC2 scores in 2001 was found to be significant. Since there was no change in development in the MacKay River basin between these years, the differences may reflect natural variation, possibly related to hydrological factors.

Muskeg River

Results for the lower erosional reach of the Muskeg River were generally similar to those described for the MacKay River. Total abundance and PC2 scores were significantly lower in 2001, with 50 to 60% lower values relative to 2000 (Table 6.20). Only small differences were found in richness and PC1 scores, neither of which was statistically significant.

Farther upstream, just above the change in dominant habitat type from erosional to depositional, differences in community structure between years consisted of a small, non-significant change in total abundance, an increase of 20% in richness, a relatively large increase in PC1 scores, and declines in abundances of Oligochaeta and Sphaeriidae in 2001 (Table 6.21). Differences in richness, PC1 scores, and abundances of Oligochaeta and Sphaeriidae were significant.

Table 6.19 Means, Standard Errors and Results of Statistical Tests for Benthic Invertebrate Variables Compared Between 2000 and 2001 in the MacKay River

Variable	2000			2001			% Difference[b]	*P*-value[c]
	Mean	Mean - SE	Mean + SE	Mean	Mean - SE	Mean + SE		
total abundance[a]	6,360	5,626	7,191	3,456	2,963	4,030	-46	**<0.001**
richness	28.0	26.9	29.1	25.9	24.3	27.6	-7	0.220
PC1 scores	0.084	-0.152	0.320	0.149	-0.195	0.492	76	0.853
PC2 scores	1.838	1.571	2.104	1.197	0.971	1.422	-35	**0.036**

Note: SE = standard error.
(a) Geometric means are shown for total abundance; mean + SE and mean - SE were calculated on log-transformed data and were then back-transformed.
(b) Percent difference between the 2000 and 2001 means, expressed relative to the 2000 mean.
(c) Results of one-way ANOVAs; *P*-values <0.05 are in bold.

Table 6.20 Means, Standard Errors and Results of Statistical Tests for Benthic Invertebrate Variables Compared Between 2000 and 2001 in the Muskeg River (Erosional Habitat)

Variable	2000			2001			% Difference[b]	*P*-value[c]
	Mean	Mean - SE	Mean + SE	Mean	Mean - SE	Mean + SE		
total abundance[a]	9,338	8,094	10,774	3,840	2,855	5,165	-59	**0.003**
richness	31.2	29.4	33.0	28.7	26.6	30.7	-8	0.264
PC1 scores	1.899	1.620	2.177	1.739	1.242	2.235	-8	0.732
PC2 scores	-1.504	-1.879	-1.130	-0.691	-0.930	-0.452	-54	**0.033**

Note: SE = standard error.
(a) Geometric means are shown for total abundance; mean + SE and mean - SE were calculated on log-transformed data and were then back-transformed.
(b) Percent difference between the 2000 and 2001 means, expressed relative to the 2000 mean.
(c) Results of one-way ANOVAs; *P*-values <0.05 are in bold.

Table 6.21 Means, Standard Errors and Results of Statistical Tests for Benthic Invertebrate Variables Compared Between 2000 and 2001 in The Muskeg River (Depositional Habitat)

Variable	2000			2001			% Difference[b]	*P*-value[c]
	Mean	Mean - SE	Mean + SE	Mean	Mean - SE	Mean + SE		
total abundance[a]	41,509	30,261	56,938	45,797	34,154	61,408	10	0.782
richness	24.5	22.7	26.3	29.3	27.4	31.1	20	**0.030**
PC1 scores	0.634	0.289	0.979	2.749	2.236	3.263	334	**<0.001**
Oligochaeta abundance[a]	3,034	1,901	4,844	619	330	1,161	-80	**0.019**
Sphaeriidae abundance[a]	1,192	599	2,373	226	118	432	-81	**0.040**

Note: SE = standard error.

(a) Geometric means are shown for abundance variables; mean + SE and mean - SE were calculated on log-transformed data and were then back-transformed.

(b) Percent difference between the 2000 and 2001 means, expressed relative to the 2000 mean.

(c) Results of one-way ANOVAs; *P*-values <0.05 are in bold.

Steepbank River

Benthic communities in the Steepbank River were similar in 2000 and 2001. None of the variables compared between years differed significantly (Table 6.22). Accordingly, differences between years expressed as percentages of the 2000 means were small, ranging form -2 to 31 %.

Table 6.22 Means, Standard Errors and Results of Statistical Tests for Benthic Invertebrate Variables Compared Between 2000 and 2001 in the Steepbank River

Variable	2000			2001			% Difference[b]	*P*-value[c]
	Mean	Mean - SE	Mean + SE	Mean	Mean - SE	Mean + SE		
total abundance[a]	2,009	1,659	2,434	2,448	1,867	3,208	22	0.472
richness	21.4	19.5	23.3	21.0	19.4	22.6	-2	0.843
PC1 scores	-2.282	-2.452	-2.112	-1.841	-2.066	-1.616	-19	0.212
PC2 scores	-0.224	-0.456	0.008	-0.293	-0.506	-0.081	31	0.788

Note: SE = standard error.

(a) Geometric means are shown for total abundance; mean + SE and mean - SE were calculated on log-transformed data and were then back-transformed.

(b) Percent difference between the 2000 and 2001 means, expressed relative to the 2000 mean.

(c) Results of one-way ANOVAs; *P*-values <0.05 are in bold.

6.3.2.3 Power Analysis Results

Significant statistical tests detected differences of 46 to 76% in total abundance, 20 to 56% in richness and 35 to 334% in PC scores (Table 6.23). Differences in means compared by non-significant tests were in all cases lower. Results of power analysis indicated that non-significant tests comparing total abundance could detect minimum increases of 119 to 175% in means, or decreases of 54 to 64% (Table 6.24). Tests comparing richness could detect differences of 17 to 27% in means and tests comparing PC scores had a wide range in power, with minimum detectable differences ranging between 28 to 1,168% of the 2000 mean.

Although two tests comparing PC scores had low power, most tests had sufficient power to detect differences that may be considered outside of natural variation. Based on the year-to-year variation described in Section 6.3.1 and 2 SDs calculated in Section 6.2.2, detecting effect sizes of 50 to 100% for abundance variables and 10 to 25% for richness seem reasonable goals for statistical analysis of RAMP data, although they will need to be adjusted upon further sampling. Using these criteria, three of the five tests comparing total abundance, four of the five tests comparing richness and six of the eight tests comparing PC scores had adequate power.

In terms of sample sizes necessary to detect specified effect sizes, the tests comparing abundance and PC scores that had low power would require unrealistically large sample sizes, which do not appear warranted based on the results of these comparisons (i.e., actual differences between means were small; Table 6.23). Current sample sizes are generally adequate for sensitive tests comparing richness among years.

Table 6.23 Percentage Differences Between 2000 and 2001 Means for Benthic Community Variables

River/Lake	Total Abundance	Richness	PC1 Scores	PC2 Scores	Oligochaeta abundance	Sphaeriidae abundance
Significant tests						
Shipyard Lake	-76	-56	-168	-[a]	-	-
MacKay River	-46	-	-	35	-	-
Muskeg River (erosional)	-59	-	-	-54	-	-
Muskeg River (depositional)	-	20	334	-	-80	-81
Steepbank River	-	-	-	-	-	-
Non-significant tests						
Shipyard Lake	-	-	-	-	-	-
MacKay River	-	-7	76	-	-	-
Muskeg River (erosional)	-	-8	-8	-	-	-
Muskeg River (depositional)	10	-	-	-	-	-
Steepbank River	22	-2	-19	31	-	-

[a] Not tested, or not applicable due to outcome of test.

Table 6.24 Power Analysis Results for Statistical Tests with Non-significant Results

Variable	Minimum Detectable Difference (n=15, Power=0.8)		Required Sample Size (n) for a Range of Effect Sizes (Power=0.8)[(a)]		
	Increase (%)	Decrease (%)	25% (-20%)	50% (-33%)	100% (-50%)
MacKay River					
richness	17	-17	8	3	2
PC1 scores	1,168	-1,168	29,675	7,800	1,900
Muskeg River - Erosional					
richness	21	-21	11	4	3
PC1 scores	71	-71	114	30	9
Muskeg River - Depositional					
total abundance	178	-64	293	90	32
Steepbank River					
total abundance	119	-54	175	54	20
richness	27	-27	18	6	3
PC1 scores	29	-29	21	6	3
PC2 scores	333	-333	2,460	630	156

(a) Since statistical analysis was done using log-transformed abundance data, effect sizes differ depending on direction, when back-transformed. Differences of 25, 50 and 100% represent increases, and percentages in parentheses represent corresponding decreases relative to the 2000 mean. Richness and PC scores were not transformed for analysis; therefore % increases and % decreases are equal, and percentages in parentheses are not applicable. *n* represents the number of replicate sites required within one reach.

6.3.2.4 Appropriateness of the Study Design

As noted in the previous section, most tests had sufficient power to detect differences that may be considered outside of natural variation. Therefore, from the perspective of statistical power, no adjustments are necessary to the sampling design.

An issue of greater concern regarding the existing study design is the possible lack of representativeness of single samples collected at each site within a reach. Individual samples are often not representative due to patchy distribution of benthic invertebrates on the bottom (as demonstrated by Resh 1979 using samples collected side by side). Non-representative samples can be expected to introduce additional variation to the data, thereby reducing the power of statistical tests and resulting in unreliable results of statistical tests.

Lack of power is not an issue in the case of the RAMP surveys because a relatively large number of samples (n=15) were collected within each reach.

However, collecting fewer representative samples (each consisting of a composite of a number of smaller samples) would be less labour-intensive and therefore less costly, especially considering that the primary means of access to sample sites is by helicopter in most rivers and streams sampled by RAMP. An additional benefit of reducing the number of sites would include reduced cost of supporting laboratory data because fewer sets of supporting data would have to be collected. Increasing the number of samples at each site would also achieve consistency with historical data in terms of spatial resolution. Previous sections have shown that the ability to interpret potential long-term trends was impaired by the lack of consistency in spatial resolution among studies, which could be remedied by adjusting the sampling design.

The approach suggested for adjusting the sampling design is that recommended by Environment Canada (1998, 2000) for Environmental Effects Monitoring (EEM) of pulp mill and metal mining discharges. Briefly, EEM requires sampling a number of sites ("replicate stations", using EEM terminology) in each reach ("area") and collection of a number of samples ("field subsamples") at each site. Statistical tests are used to compare reaches, using the site as the unit of replication. The number of sites is determined based on power analysis to detect an effect of a specified magnitude (2 SD). The number of samples at each site is estimated based on the within-site variation to achieve a specified degree of precision. The recommended rule of thumb for obtaining representative data from a site is to collect the number of samples that will yield a standard error that is ≤20% of the site mean (%SE = 20) for a variable of interest (based on Elliott 1977).

Three to five Neill cylinder or Ekman samples usually satisfy the above requirement for %SE for total abundance and richness, unless productivity is very low. Abundances of individual taxa may require a larger number of samples. Increasing the number of samples at a site and compositing those samples would likely reduce the site-to-site variation (i.e., the basis of the statistical test comparing years) allowing sampling fewer sites in each reach than the 15 sampled in 2000 and 2001. Based on generic power analysis results provided by Environment Canada (1998), five sites are sufficient to detect a difference of 2 SD at a significance level of 0.05, with a power of 0.8.

The issue of sampler size should also be examined to maximize efficiency. Ekman grabs collected from lakes and depositional rivers in the Oil Sands Region tend to contain large amounts of organic material (and bitumen in many cases), resulting in a large effort to process even a single Ekman grab sample. The amount of additional processing effort required for composite samples should be offset by collecting a larger number of smaller samples at each site, rather than a few Ekman grabs. The advantage of collecting many small samples over a few large samples has been examined by a number of investigators (Downing 1979, 1989; Resh 1979; Morin 1985) reviewed by Taylor (1997). All of these investigators concluded that there is a clear advantage to the former approach in terms of cost efficiency and data quality.

Using a different mesh size (i.e., 500 µm rather than 250 µm) would also be of help in controlling laboratory analytical effort. There are, however, a large amount of historical data collected using 250 µm mesh sampling devices, which could not be directly compared with RAMP data. Therefore, switching to a larger mesh size is not recommended.

Sampling fewer sites would also allow standardizing site locations among years. Although attempts were made to re-sample the same locations in 2000 and 2001, it was not possible to do so due to large differences in stream flows between these years. Although this factor could also affect subsequent studies, sampling fewer sites would facilitate standardizing site locations. This would standardize among-site variation to the variation among the same set of sites in all years of monitoring, potentially resulting in greater power to detect differences among years.

These recommendations entail a considerable change to the sampling design used for the benthic invertebrate component. However, since the program is still in its initial phase, adjusting the sampling design would not entail loss of an unacceptably large amount of information. An additional benefit to adjusting the sampling design would be better compatibility with the considerable historical data set.

Data analysis methods should also be revisited once data are available for a larger number of years. Only two years were compared in this report, allowing use of ANOVA or ANCOVA to test for differences between years. However, once the number of years with consistent monitoring data is closer to ten, a simple comparison of all years will not be sufficient, because the objectives of the analysis will be to determine whether each new year’s data are within the baseline range of variation defined by the previous years’ data, and whether there are any long-term trends. Possible additional methods to address these objectives include trend analysis to detect long-term trends and step trends, control charts showing the limits of variation during the baseline period, and multivariate techniques (e.g., ordination) to compare communities sampled in each new year with those documented by previous surveys.

6.3.2.5 Conclusions and Recommendations

Although the current sampling designs of 15 samples collected from a reach and 10 samples collected from a lake have adequate power when analyzed using ANOVA, the benthic program could be adjusted to be more cost-efficient without loss of statistical power. Additionally, adjustments to the current design may be warranted to ensure that representative data are collected at each site within a reach.

The recommended approach is based on study designs used in pulp mill EEM and consists of collecting a larger number of smaller samples at each site (analyzed in the laboratory as composites) and reducing the number of sites based on power analysis results. Additionally, establishing permanent monitoring site locations would standardize among site variation, potentially resulting in greater power to detect differences among years. Because the program is still in its initial phase, adjusting the sampling design would not entail loss of an unacceptably large amount of information. Data analysis methods should also be revisited once data are available for a larger number of years.

6.3.3 Upstream-Downstream Comparisons and Trends

6.3.3.1 Methods

RAMP data and historical data were analyzed to evaluate upstream-downstream differences and trends in major rivers in the Oil Sands Region under baseline conditions. Data collected by RAMP in the Clearwater River upstream and downstream of the mouth of the Christina River were used in these comparisons.

Benthic community variables included total abundance, richness, Oligochaeta abundance, Sphaeriidae abundance and PC scores on the first ordination axis. Abundance variables were log(x+1) transformed before statistical analysis. Comparisons were made using one-way ANOVA, except for tests comparing abundances of Oligochaeta and Sphaeriidae where ANCOVA was used. Log (x+1) transformed abundances of these taxa were significantly correlated with current velocity, % fine sediments and sediment TOC in both reaches. Only % fine sediments was used as the covariate because all three environmental variables were significantly intercorrelated and the strongest correlations between invertebrate abundances and environmental variables were with % fine sediments.

Retrospective power analysis was conducted to estimate the minimum detectable differences for non-significant tests (Zar 1999). In addition, sample sizes required to detect a range of effect sizes were estimated using the SYSTAT 10 statistical software package (SPSS 2000) to investigate the possibility of adjusting the number of replicates to increase the sensitivity of statistical tests in future monitoring cycles.

Historical data collected in the MacKay, Muskeg and Steepbank rivers were examined visually for upstream-downstream trends. The variables examined included total abundance, richness, PC scores and abundances of dominant invertebrate groups.

6.3.3.2 Results and Discussion

Clearwater River

There were significant differences in three of the five benthic community variables between the reaches sampled upstream and downstream of the Christina River, suggesting existing differences in community structure under baseline conditions. Total abundance and Sphaeriidae abundance did not vary significantly between the two reaches, despite nearly 50% or 69% lower abundances in the downstream reach, respectively (Table 6.25). Richness, PC1 scores and Oligochaeta abundance were significantly different between the two reaches (all were lower in the downstream reach). Ranges in local-scale habitat features (e.g., current velocity, depth and substrate) were similar in both reaches and were accounted for by using ANCOVA, suggesting the existing differences may reflect the influence of the Christina River.

Table 6.25 Means, Standard Errors and Results of Statistical Tests for Benthic Invertebrate Variables Compared Between the Upstream and Downstream Reaches Sampled in the Clearwater River

Variable	Upstream of Christina River			Downstream of Christina River			% Difference[b]	*P*-value[c]
	Mean	Mean - SE	Mean + SE	Mean	Mean - SE	Mean + SE		
total abundance[a]	13,639	9,484	19,614	7,099	3,973	12,683	-48	0.253
richness	13.9	12.2	15.6	9.5	8.0	11.0	-32	**0.024**
PC1 scores	-0.999	-1.288	-0.711	-2.104	-2.457	-1.750	-111	**0.006**
Oligochaeta abundance[a]	2,779	1,735	4,453	599	374	959	-78	**0.029**
Sphaeriidae abundance[a]	527	284	977	165	89	307	-69	0.196

Note: SE = standard error.

(a) Geometric means are shown for abundance variables; mean + SE and mean - SE were calculated on log-transformed data and were then back-transformed. Re-analysis after removing an outlier did not affect the outcome of the test. Adjusted means and SEs are shown for Oligochaeta and Sphaeriidae abundances, based on ANCOVA results using % fine sediments as the covariate.

(b) Percent difference between the 2000 and 2001 means, expressed relative to the 2000 mean.

(c) Results of one-way ANOVAs; *P*-values <0.05 are in bold.

Power Analysis Results

Results of the power analysis indicate the tests comparing total abundance and Sphaeriidae abundance had low power, and could only detect large differences (Table 6.26). Adjusting the number of samples to that required to achieve reasonable power is not a viable option, given the very large number of samples indicated by the analysis.

Table 6.26 Power Analysis Results for Statistical Tests with Non-Significant Results

Variable	Minimum Detectable Difference (*n*=15, Power=0.8)		Required Sample Size (*n*) for a Range of Effect Sizes (Power=0.8)[b]		
	Increase (%)	Decrease (%)	25% (-20%)	50% (-33%)	100% (-50%)
total abundance[a]	407 / 292	-80 / -74	740 / 530	225 / 160	78 / 56
Sphaeriidae abundance	1,159	-92	1,820	550	188

(a) Power analysis was done with and without an outlier identified during the analysis; results of the two analyses are separated by "/".

(b) Since statistical analysis was done using log-transformed abundance data, effect sizes differ depending on direction, when back-transformed. Differences of 25, 50 and 100% represent increases, and percentages in parentheses represent corresponding decreases relative to the 2000 mean. *n* represents the number of replicate sites required within a reach.

MacKay, Muskeg and Steepbank Rivers

In the Mackay River, total abundance increased with distance from the mouth in 1977 (Figure 6.21). Although maximum total abundance was observed at the farthest upstream site in 1984 as well, there was no consistent trend that year. Similarly, there were no consistent trends in richness (both years), and abundances of Oligochaeta and Chironomidae in 1977 (Figure 6.22). In 1984, abundances of Oligochaeta, EPT and Chironomidae reflected the pattern in total abundance.

Since all of the erosional data from the Muskeg River were collected at the mouth, upstream-downstream trends cannot be examined in erosional habitat. In addition erosional habitat in this river is restricted to the lower 10 km, which is generally homogeneous in terms of habitat. Therefore, an upstream downstream trend in benthic community structure is unlikely, and is of limited concern regarding effects monitoring. In depositional habitat, trends were inconsistent among years and variables. For example, there were increasing trends in total abundance and Chironomidae abundance with distance upstream in 1988, but there were no trends in 1985 (Figure 6.23 and Figure 6.24). Oligochaete abundance increased in an upstream direction in 1985, but not in 1988. The only consistent trend was found in abundances of Sphaeriidae, which were higher in the upper reach in both years (Figure 6.24).

Total abundance, richness and abundances of nearly all major invertebrate groups increased with distance from the mouth in the Steepbank River in 1995 (Figure 6.25). Abundances of oligochaetes did not follow the same trend.

Based on visual qualitative examination, increasing abundances with distance upstream appear common in major tributaries in the Oil Sands Region. Total abundance showed this trend in at least one year in all three rivers and abundances of major taxa frequently did as well. The same trend was not apparent in richness in the MacKay and Muskeg rivers, but was seen in the Steepbank River. Changes in benthic community structure along rivers have been widely observed (e.g., Wright and Li 2002) and are expected (Vannote et al. 1980), and will need to be considered during data analysis, once RAMP data are available from both upstream and downstream reaches of the major tributaries.

Figure 6.21 Variation in Total Abundance, Richness and Oligochaeta Abundance Along the MacKay River

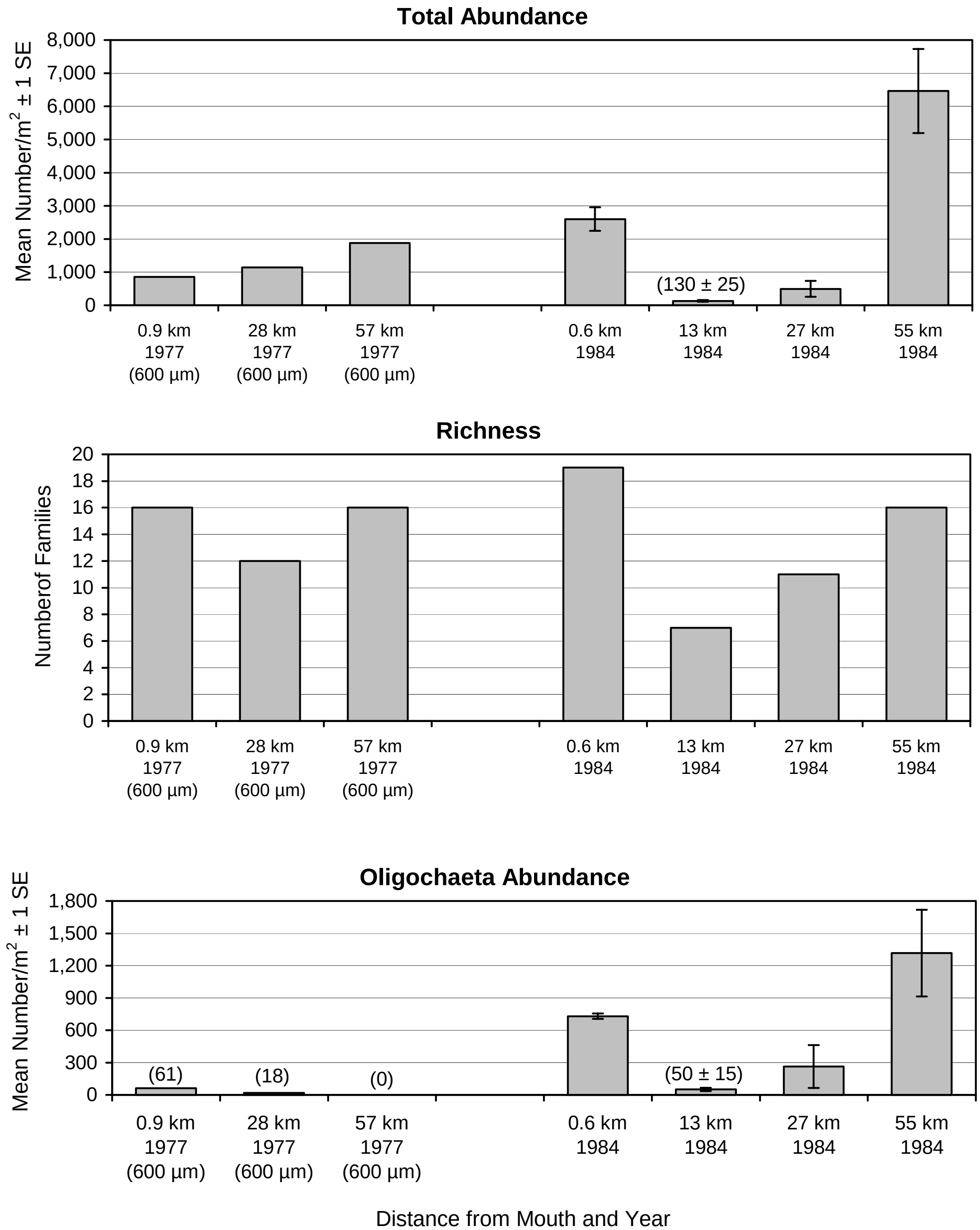


Figure 6.22 Variation in the Abundances of EPT and Chironomidae Along the MacKay River

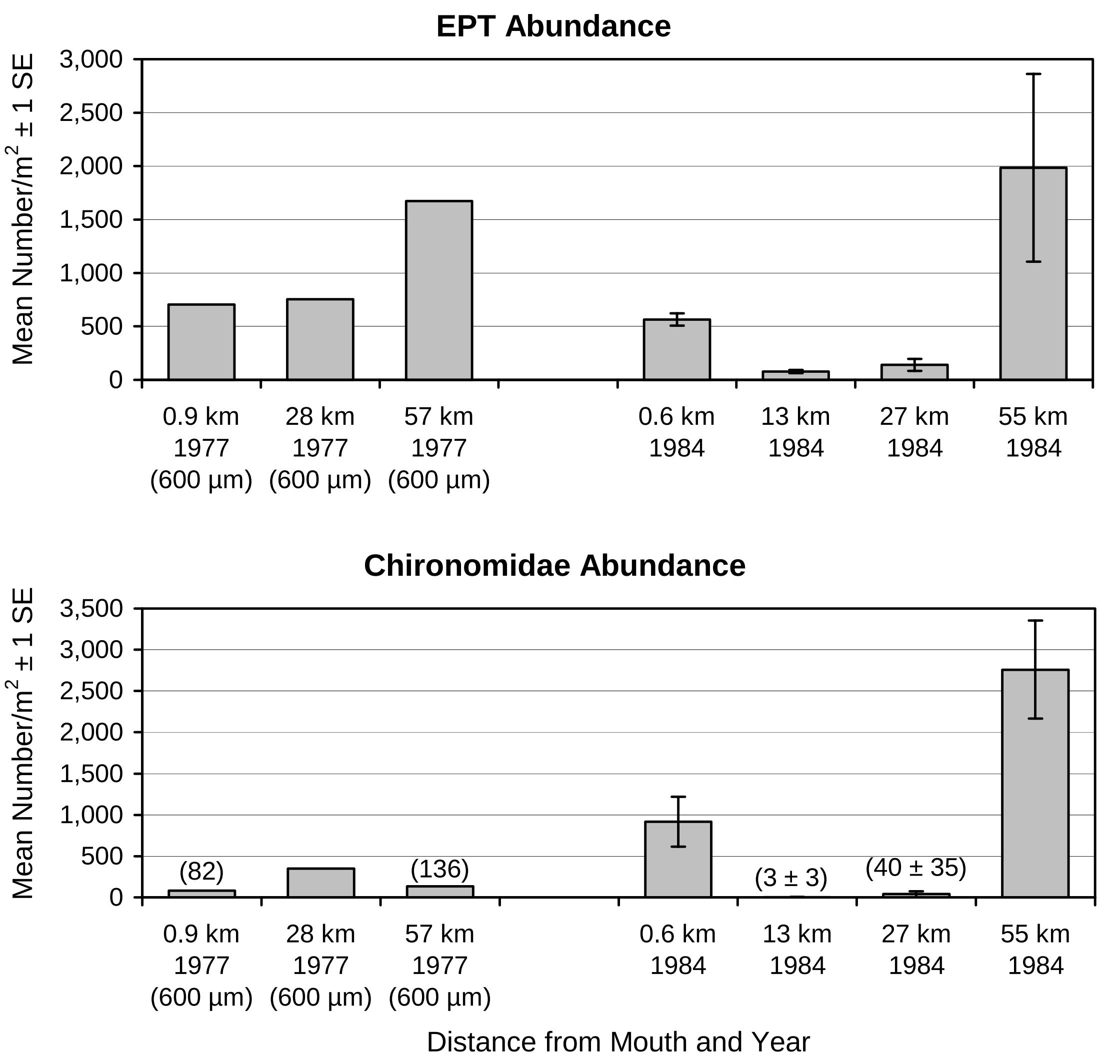


Figure 6.23 Variation in Total Abundance, Richness and Oligochaeta Abundance Along the Muskeg River

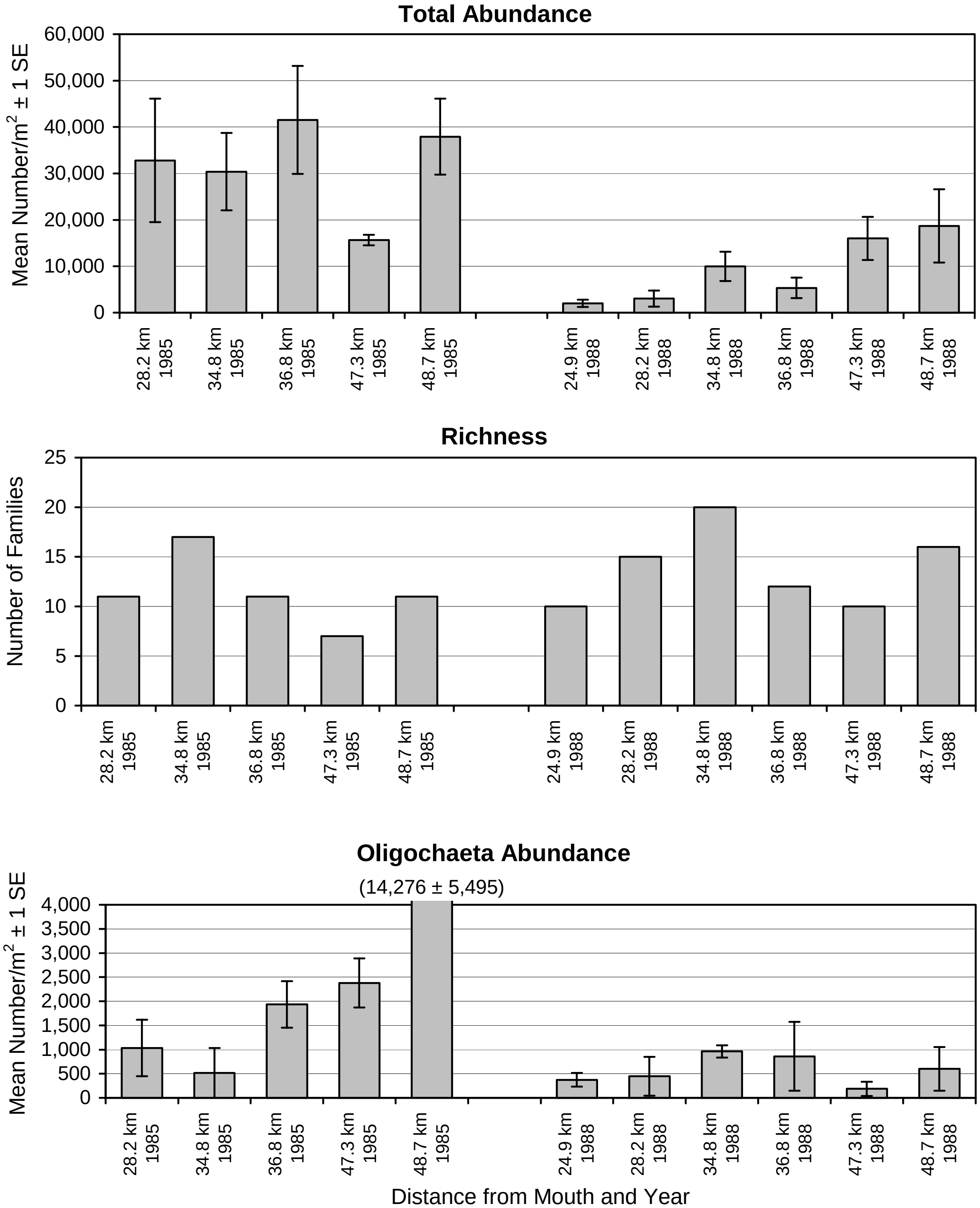
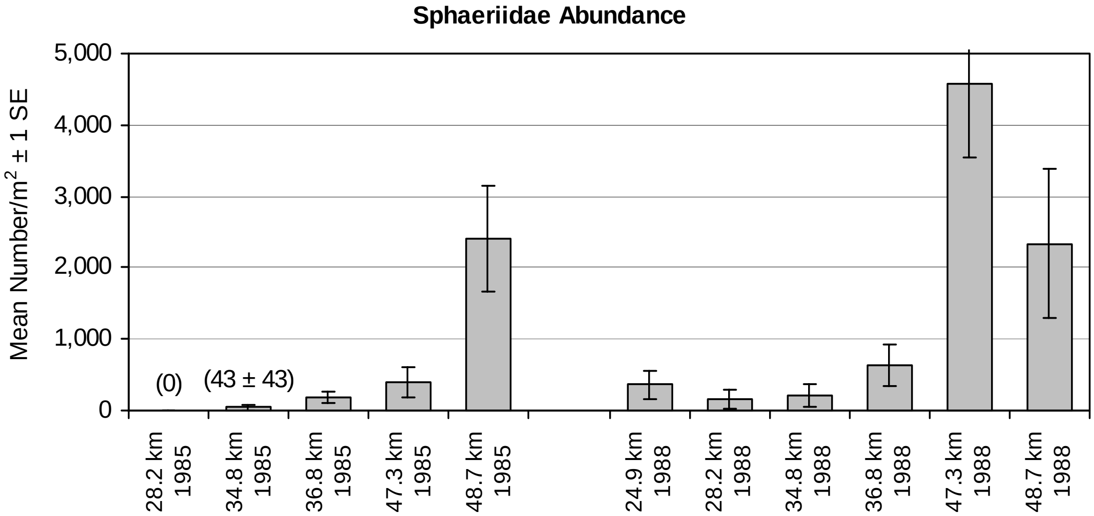


Figure 6.24 Variation in the Abundances of Sphaeriidae and Chironomidae Along the Muskeg River



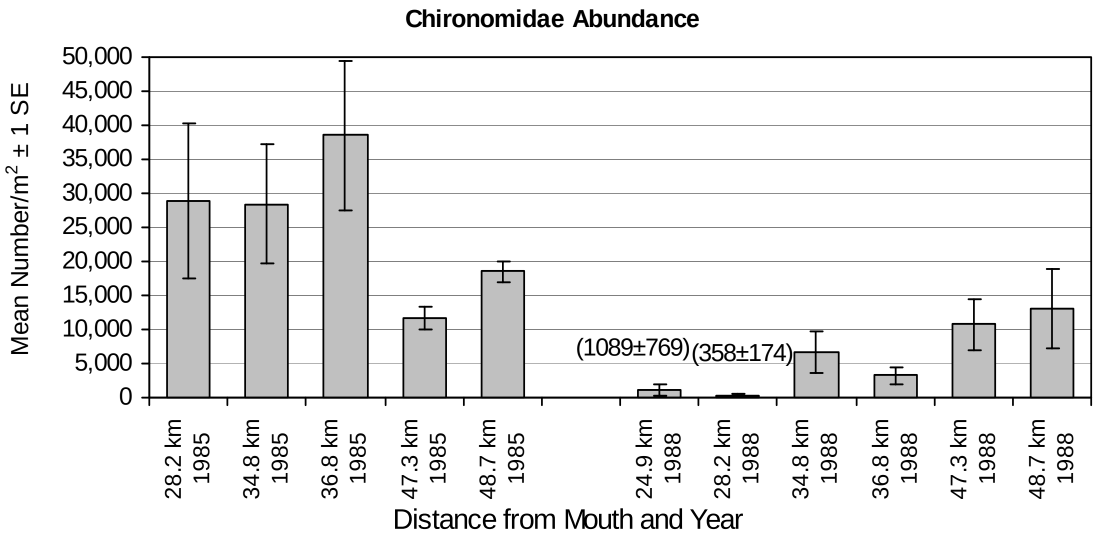
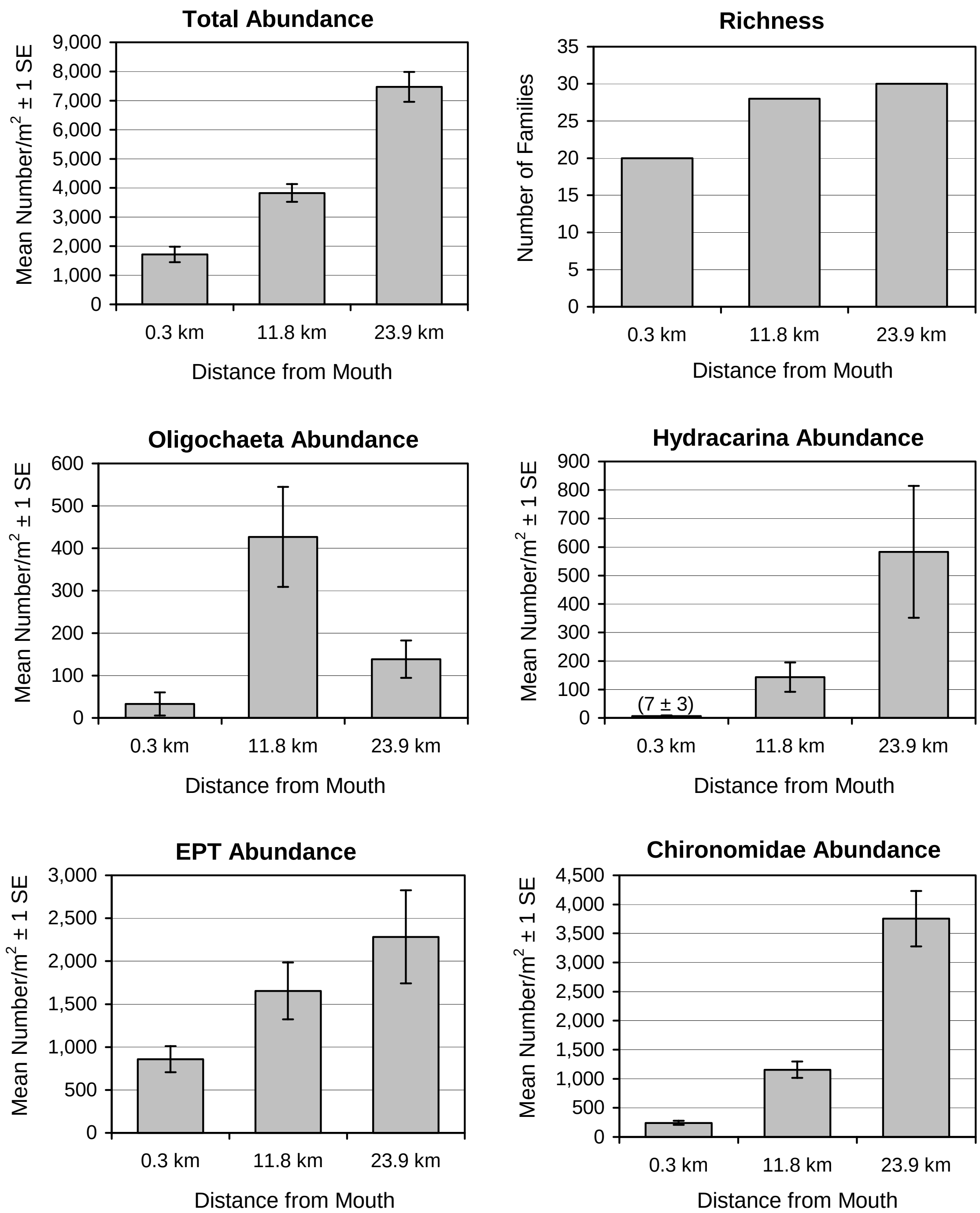


Figure 6.25 Variation in Total Abundance, Richness and Abundances of Dominant Invertebrate Groups Along the Steepbank River in Fall 1995



6.3.3.3 Appropriateness of the Study Design

At this time, upstream-downstream comparisons using RAMP data could only be performed for the Clearwater River. Analysis of the historical data was done to provide context for interpreting data generated by RAMP surveys, but assessment of longitudinal trends is not planned by RAMP. The analysis of the Clearwater River data has shown that there are existing differences in community structure between the reaches sampled upstream and downstream of the Christina River. Two of the three tests had sufficient power to detect ecologically meaningful differences. As in the other rivers sampled by RAMP in 2000 and 2001 (Section 6.3.2.4), the sampling design employed in the Clearwater River should be re-examined to determine whether a greater effort should be expended at each site to collect representative samples, which would likely reduce the number of sites to be sampled, resulting in greater cost-efficiency.

The above recommendation is made if the Clearwater River monitoring reaches are considered essential to RAMP. As pointed out in Section 6.4.1.2 below, the pair of reaches monitored in the Clearwater River is considered superfluous for a number of reasons.

6.3.3.4 Conclusions and Recommendations

Existing differences were found in benthic community structure between the reaches sampled in the Clearwater River upstream and downstream of the Christina River. Recommended changes to the study design are the same as those outlined in Section 6.3.2.4.

6.4 COLLECTING DATA TO VERIFY EIA PREDICTIONS

6.4.1.1 Methods

The appropriateness of current and planned RAMP benthic invertebrate sampling locations was evaluated in relation to waterbodies that have been assessed by oil sands EIAs completed since 1995. The evaluation focused on waterbodies that will persist during and after development. Waterbodies assessed by EIAs were identified based on fish habitat assessments, which included predictions relevant to benthic invertebrates. The 10-year program set forth in the “Program Design and Rationale” document (Golder 2002f) was assumed to represent planned monitoring under RAMP.

Relevant waterbodies and RAMP monitoring locations were summarized in table form and on a map to illustrate the correspondence between assessed waterbodies and RAMP monitoring locations.

6.4.1.2 Results and Discussion

Recent EIAs evaluated potential impacts to a large variety of waterbodies in the Oil Sands Region (Table 6.27 and Figure 6.26). North of Fort McMurray, all regionally significant waterbodies (i.e., larger rivers and lakes) that will persist through development are monitored, or will be monitored by RAMP for benthic invertebrates. Table 6.27 and Figure 6.26 highlight the fact that EIA predictions encompass a considerably larger number of waterbodies than are monitored by RAMP, implying that it will not be possible to verify all predictions. However, for practical reasons, it seems reasonable to limit monitoring to waterbodies of regional significance. An exception to this approach includes having a specific reason to add a smaller stream or lake, such as significance to local stakeholders, or the necessity to collect additional baseline data to facilitate the development of habitat compensation plans. Monitoring of all waterbodies assessed in EIAs would necessitate either a large addition to the program, which is beyond the available resources, or a radical change in monitoring design, such as converting to an RCA-type program.

RAMP monitors some rivers and streams that will be lost to development. Plans for the CNRL Horizon Project entail loss of the lower reaches of the Calumet and Tar rivers, and Fort Creek will be dewatered as part of the TrueNorth Fort Hills Project. Although it is useful to collect baseline data in waterbodies that will be lost to development (e.g., to facilitate measuring the success of habitat compensation in the future), monitoring these watercourses beyond establishing a baseline is unlikely to be of value, as their fate is already known. As well, monitoring reaches upstream of the planned development footprint, as planned in the Calumet and Tar rivers, will be of little value because there will be no future upstream-downstream comparisons. Hence, limiting sampling to the reaches that will be affected appears sufficient.

Current and planned monitoring south of Fort McMurray is of much lower intensity relative to the area to the north (Table 6.27). This is partly justifiable based on the lower density of planned developments and the lower magnitudes of predicted impacts. All planned developments in this area will use in situ methods to extract bitumen, which require substantially less surface disturbance compared to open-pit mining. Impacts to surface water quality and fish habitat were predicted to be predominantly of negligible magnitude, resulting from releases of treated site runoff waters and sewage, small reductions in stream flows and stream crossings (PanCanadian 1998; OPTI 2000; AXYS 2001; Petro-Canada 2001; Rio Alto 2002). Based on these predictions, some monitoring within the potentially affected reaches is warranted, as well as some effort farther downstream to detect cumulative effects.

Table 6.27 Waterbodies Assessed in Oil Sands EIAs Completed since 1995 and RAMP Monitoring Locations

Waterbody[(a)]	Planned Development (EIA reference)	Current and Planned RAMP Monitoring Locations
North of Fort McMurray		
Athabasca River	Suncor Steepbank Mine (Golder 1996a); Syncrude Aurora North and South Mines (BOVAR 1996); Suncor Millennium Mine (Suncor 1998); Albian Muskeg River Mine (Shell 1997); TrueNorth Fort Hills (TrueNorth 2001); CNRL Horizon (CNRL 2002)	monitoring approach being developed
Alsands Drain	Albian Muskeg River Mine (Shell 1997)	none
Blackfly Creek	Syncrude Aurora North and South Mines (BOVAR 1996); Shell Jackpine Mine - Phase 1 (Shell 2002)	none
Calumet Lake (lost and then re-filled)	CNRL Horizon (CNRL 2002)	none
Calumet River (lost)	CNRL Horizon (CNRL 2002)	lower reach near mouth and upstream reach
East Jackpine Creek	Suncor Firebag (Suncor 2000)	none
Ells River	CNRL Horizon (CNRL 2002)	lower reach near mouth and upstream reach
Firebag River	TrueNorth Fort Hills (TrueNorth 2001)	lower reach near mouth and upstream reach
Fort Creek (lost)	Syncrude Aurora North and South Mines (BOVAR 1996); TrueNorth Fort Hills (TrueNorth 2001)	lower reach near mouth
Green Stockings Creek	Syncrude Aurora North and South Mines (BOVAR 1996); Shell Jackpine Mine - Phase 1 (Shell 2002)	none
Isadore's Lake	Albian Muskeg River Mine (Shell 1997)	none
Iyinimin Creek (lost)	Syncrude Aurora North and South Mines (BOVAR 1996)	none
Jackpine Creek	Syncrude Aurora North and South Mines (BOVAR 1996); Albian Muskeg River Mine (Shell 1997); Suncor Firebag (Suncor 2000); Shell Jackpine Mine - Phase 1 (Shell 2002)	lower reach near mouth and upstream reach
Joslyn Creek	CNRL Horizon (CNRL 2002)	
Kearl Lake	Syncrude Aurora North and South Mines (BOVAR 1996); Shell Jackpine Mine - Phase 1 (Shell 2002)	entire lake
Khahago Creek (lost)	Syncrude Aurora North and South Mines (BOVAR 1996); Shell Jackpine Mine - Phase 1 (Shell 2002)	none
Leggett Creek (lost)	Suncor Steepbank Mine (Golder 1996a)	none
Lillian Lake	CNRL Horizon (CNRL 2002)	none
Mackay River	Petro-Canada MacKay River (AXYS 1998)	lower reach near mouth and upstream reach
McClelland Lake	TrueNorth Fort Hills (TrueNorth 2001)	entire lake
McLean Creek	Suncor Millennium Mine (Suncor 1998)	none
Mills Creek	Albian Muskeg River Mine (Shell 1997)	none
Muskeg River	Syncrude Aurora North and South Mines (BOVAR 1996); Albian Muskeg River Mine (Shell 1997); Shell Jackpine Mine - Phase 1 (Shell 2002)	lower reach near mouth, lower to mid-reach and upstream reach
Muskeg Creek (lost)	Syncrude Aurora North and South Mines (BOVAR 1996); Shell Jackpine Mine - Phase 1 (Shell 2002)	none

Table 6.27 Waterbodies Assessed in Oil Sands EIAs Completed since 1995 and RAMP Monitoring Locations (continued)

Waterbody[(a)]	Planned Development (EIA reference)	Current and Planned RAMP Monitoring Locations
North Steepbank River	Suncor Firebag (Suncor 2000)	none
Pemmican Creek	Syncrude Aurora North and South Mines (BOVAR 1996); Shell Jackpine Mine - Phase 1 (Shell 2002)	none
Shelley Creek (lost)	Syncrude Aurora North and South Mines (BOVAR 1996); Shell Jackpine Mine - Phase 1 (Shell 2002)	none
Shipyard Lake	Suncor Millennium Mine (Suncor 1998)	entire lake
Shipyard Creek (lost)	Suncor Millennium Mine (Suncor 1998)	none
Stanley Creek	Syncrude Aurora North and South Mines (BOVAR 1996)	none
Steepbank River	Suncor Steepbank Mine (Golder 1996a); Suncor Millennium Mine (Suncor 1998); Suncor Firebag (Suncor 2000)	lower reach near mouth and upstream reach
Susan Lake drainage (lost)	TrueNorth Fort Hills (TrueNorth 2001)	none
Tar River (lost)	CNRL Horizon (CNRL 2002)	lower reach near mouth and upstream reach
Wapasu Creek (upper reaches lost)	Syncrude Aurora North and South Mines (BOVAR 1996)	none
Wesukemina Creek (lost)	Syncrude Aurora North and South Mines (BOVAR 1996); Shell Jackpine Mine - Phase 1 (Shell 2002)	none
Wood Creek (lost)	Suncor Steepbank Mine (Golder 1996a)	none
unnamed streams, ponds and lakes	all EIAs	none
South of Fort McMurray		
Birch Lake	OPTI/Nexen Long Lake (OPTI 2000)	none
Canoe Lake	OPTI/Nexen Long Lake (OPTI 2000)	none
Caribou Horn Lake	OPTI/Nexen Long Lake (OPTI 2000)	none
Christina River	OPTI/Nexen Long Lake (OPTI 2000); Petro-Canada Meadow Creek (Petro-Canada 2001); ConocoPhilips Surmont (AXYS et al. 2001)	lower reach near mouth and upstream reach
Clearwater River	ConocoPhilips Surmont (AXYS et al. 2001)	upstream and downstream of Christina River
Cottonwood Creek	ConocoPhilips Surmont (AXYS et al. 2001)	none
Engstrom Lake	ConocoPhilips Surmont (AXYS et al. 2001)	none
Frog Lake	OPTI/Nexen Long Lake (OPTI 2000)	none
Gregoire Lake	OPTI/Nexen Long Lake (OPTI 2000); Petro-Canada Meadow Creek (Petro-Canada 2001)	none
Gregoire River	OPTI/Nexen Long Lake (OPTI 2000); Petro-Canada Meadow Creek (Petro-Canada 2001)	none
Hangingstone River	Petro-Canada Meadow Creek (Petro-Canada 2001)	lower reach near mouth
Ipiatik Lake	Rio Alto Kirby (Rio Alto 2002)	none
Island Lake	Petro-Canada Meadow Creek (Petro-Canada 2001)	none
Kettle River	ConocoPhilips Surmont (AXYS et al. 2001)	none
Kiskatinaw Lake	OPTI/Nexen Long Lake (OPTI 2000)	none
Long Lake	OPTI/Nexen Long Lake (OPTI 2000)	none

Table 6.27 Waterbodies Assessed in Oil Sands EIAs Completed since 1995 and RAMP Monitoring Locations (continued)

Waterbody[(a)]	Planned Development (EIA reference)	Current and Planned RAMP Monitoring Locations
Maqua Lake	Petro-Canada Meadow Creek (Petro-Canada 2001)	none
Meadow Creek	ConocoPhilips Surmont (AXYS et al. 2001)	none
Poison Lake	OPTI/Nexen Long Lake (OPTI 2000)	none
Pushup Lake	OPTI/Nexen Long Lake (OPTI 2000)	none
Rat Lake	OPTI/Nexen Long Lake (OPTI 2000)	none
Sucker Lake	OPTI/Nexen Long Lake (OPTI 2000)	none
Sunday Creek	EnCana Christina Lake Thermal (PanCanadian 1998)	none
Surmont Creek	Petro-Canada Meadow Creek (Petro-Canada 2001)	none
Surmont Lake	Petro-Canada Meadow Creek (Petro-Canada 2001)	none
Wiau Lake	Rio Alto Kirby (Rio Alto 2002)	none
unnamed streams, ponds and lakes	all EIAs	none

The monitoring reach planned in the Hangingstone River (Table 6.27) is appropriate, as it will be located downstream of the Petro-Canada Meadow Creek Project (Petro-Canada 2001). However, there is no planned monitoring in the immediate vicinity of four of the five developments that have submitted EIAs. OPTI (2000) predicted small flow reductions in the Gregoire River, which may warrant monitoring in the potentially affected reach. Negligible impacts were predicted to streams draining all other planned developments (PanCanadian 1998; AXYS 2001; Rio Alto 2002). To achieve consistency in monitoring effort among developments, additional monitoring locations would be required in the immediate vicinity of the remaining four planned developments.

The lower Christina River reach is a useful monitoring location to test for cumulative effects, considering that there are four planned in-situ developments in the Christina River basin. The upstream location in this river (upstream of Janvier) is downstream of the Jackfish River draining Christina Lake, which may receive drainage from the EnCana Christina Lake Thermal Project (PanCanadian 1998). Therefore, the location of this monitoring reach should be adjusted by moving it farther upstream.

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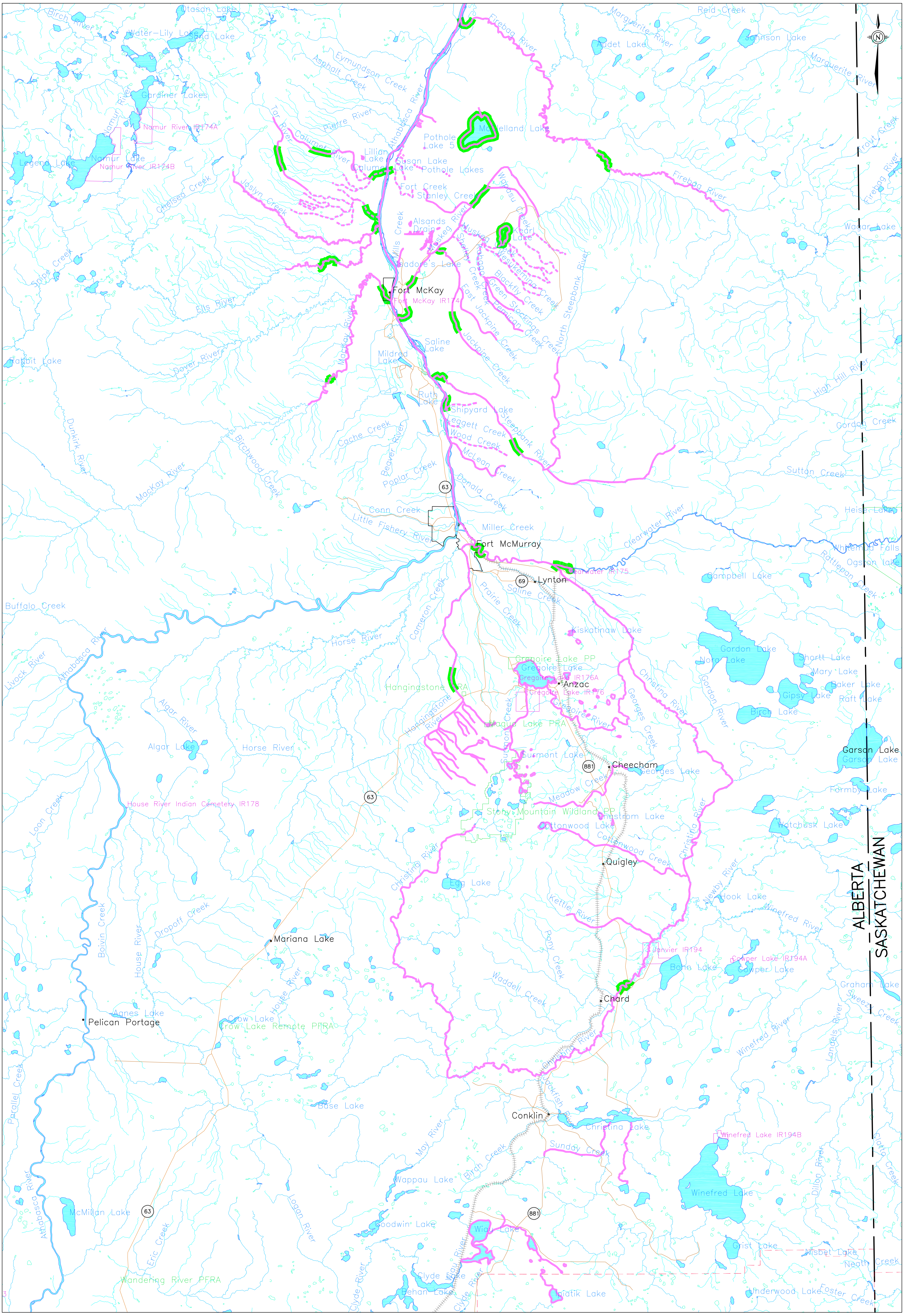

LEGEND

- WATERBODIES ASSESSED IN EIA'S
- WATERBODIES ASSESSED IN EIA'S (WILL BE LOST TO DEVELOPMENT)
- WATERBODIES MONITORED BY RAMP

REFERENCE

ALBERTA NTDB DIGITAL DATA OBTAINED FROM GEOMATICS CANADA, AUGUST 2001. SASKATCHEWAN NTDB DATA OBTAINED FROM ISC, AUGUST 2001.
DATUM: NAD 83 PROJECTION: UTM ZONE 13

15 0 15
SCALE KILOMETRES

RAMP FIVE YEAR REPORT

TITLE

WATERBODIES ASSESSED IN OIL SANDS EIA'S SINCE 1995 AND WATERBODIES MONITORED BY RAMP FOR BENTHIC INVERTEBRATES

Golder Associates
Calgary, Alberta

PROJECT No. 022-2301.6350		
DESIGN	ZK	06/01/03
CADD	AS	06/03/03
CHECK		
REVIEW		

FILE No. OilSands Leases-EIAs
SCALE AS SHOWN REV. 0

FIGURE: 6.26

The downstream reach monitored in the Clearwater River is about 40 km below the mouth of the Gregoire River, which will receive drainage from the OPTI/Nexen Long Lake Project. Because of the long distance from developments, the large dilution capacity of this river and the likelihood of only slight, localized effects from in-situ developments, this location is unlikely to be useful. Furthermore, the monitoring reaches in the Clearwater River are upstream and downstream of the mouth of the Christina River, which is already monitored just above its mouth. Any cumulative effects originating from the southern developments will first be detectable in the smaller Christina River. Therefore, the additional upstream-downstream pair in the Clearwater River is superfluous for a number of reasons. The monitoring effort allocated to this river may be shifted to rivers closer to developments, where monitoring is not planned by RAMP at the present.

The timing of monitoring in relation to the timing of development activities that may cause aquatic effects is an important aspect of monitoring design in a complex program such as RAMP. In most cases, the objective of present monitoring activities is to establish a baseline before large-scale development occurs. Exceptions include Shipyard Lake and the Muskeg River, where new developments are proceeding. As the benthic program of RAMP evolves, it will be important to track the progress of each development to maximize the efficiency of monitoring and the potential to detect effects.

6.4.1.3 Conclusions and Recommendations

The conclusions and recommendations of this section can be summarized as follows:

- North of Fort McMurray, all regionally significant waterbodies that will persist through development are monitored, or will be monitored by RAMP.
- Although EIA predictions encompass a greater number of waterbodies than are monitored by RAMP, practical constraints require that monitoring be limited to waterbodies of regional significance.
- RAMP monitors some rivers and streams that will be lost to development (Calumet and Tar rivers and Fort Creek). Monitoring these watercourses beyond the baseline period is unlikely to be of value and monitoring reaches upstream of planned developments will also be of little value because there will be no future upstream-downstream comparisons.
- Planned monitoring south of Fort McMurray is of much lower intensity relative to the area to the north, which is partly justified by the lower

density of planned developments and lower magnitudes of predicted impacts.

- The monitoring reaches planned in the Hangingstone and Christina rivers are generally appropriate. The location of the upstream monitoring reach in the Christina River should be reconsidered because it is downstream of the EnCana Christina Lake Thermal Project.
- To achieve consistency in monitoring effort among southern in-situ oil sands developments, monitoring locations would be required in the immediate vicinity of all planned developments.
- The reaches monitored in the Clearwater River are superfluous, because they are too far downstream from the sources of potential effects to be useful and represent a duplication of effort. Therefore, the monitoring effort allocated to this river may be shifted closer to developments, where monitoring is currently not planned by RAMP.
- As the benthic program evolves, it will be important to track the progress of each development to maximize the efficiency of monitoring and the potential to detect effects.

6.5 SUMMARY

6.5.1 Characterizing Existing Variability

6.5.1.1 Spatial Variation in Benthic Community Structure

An exploratory multivariate analysis of RAMP data and available historical data, combined with correlation analysis, was conducted to examine variation in community structure within and among waterbodies sampled by RAMP between 1997 and 2001. Kearl and Shipyard lakes, and the MacKay, Muskeg, Steepbank and Clearwater rivers were included in the analysis and separate analyses were conducted for each major habitat type. An additional objective of the analysis was to investigate whether physical or chemical variables can explain the variation in the biological data.

Results of the analysis highlighted differences among benthic communities of individual waterbodies, but did not detect strong correlations between community structure and environmental variables. Based on the biological data, sites were usually grouped by river, implying that each river has characteristic communities. Grouping of sites by lake was not apparent. The findings of characteristic communities in each river implies that it is unlikely that data from one river could be used as reference site data for detecting effects in other rivers.

Significant but weak correlations were found between benthic community and local habitat variables in lakes (depth) and the Clearwater River (substrate and current velocity), but not in the Steepbank, MacKay and Muskeg rivers. There was some indication that flow may be an important controlling factor in erosional sections of rivers, but there were insufficient data to demonstrate this with certainty.

These results in part reflect the amount of available data (only a few years) and the variable spatial coverage among years. At most, five years of data were available for a waterbody, representing only a few levels of potential factors affecting benthic communities (e.g., flow). Trends along environmental gradients may also be difficult to detect because of relatively short gradients and added variation due to differences in methods among studies.

The analysis was exploratory, taking advantage of the available data to look for patterns. Hence, there are no specific recommendations arising from this component.

6.5.1.2 Baseline Ranges for Key Benthic Community Variables

Benthic invertebrate data were summarized for each river reach sampled by RAMP for an analysis of the degree of year-to-year variation to estimate baseline ranges in total abundance, richness and abundances of dominant invertebrate groups. The lower erosional reaches of the MacKay, Muskeg and Steepbank rivers were included in this analysis, based on data collected by RAMP in 1998, 2000 and 2001. Baseline ranges were estimated as the mean ±2 standard deviations (SDs), based on three years of data collected by RAMP at the reach scale.

Preliminary estimates of baseline ranges in benthic community variables were similar in all three rivers, when expressed as percentages of the mean. Abundance variables had greater ranges (±100 to 200% of the mean) than richness (±6 to 21%). Invertebrate abundances in major groups were more variable among rivers and years than total abundance.

There are insufficient data to derive definitive baseline ranges at this time. Once data are available to quantitatively express relationships with environmental factors, adjusted values of biological variables would provide more realistic estimates of baseline variation. Estimates of baseline ranges should be updated in future years as RAMP accumulates more data. It is recommended that using information on baseline ranges, the Benthic Invertebrate Subgroup of the Technical Subcommittee of RAMP develop critical effect sizes for benthic community variables that will be used in future evaluations of monitoring data.

6.5.2 Detecting and Assessing Regional Trends

6.5.2.1 Long-Term Trends

Examination of long-term trends was limited to graphical presentation of benthic community variables for sites with multiple years of data. Kearl and Shipyard lakes, the lower erosional reaches of the MacKay, Muskeg and Steepbank rivers, and depositional sites with two or more years of data in the Muskeg River were included in this analysis. A formal trend analysis was considered inappropriate based on the quantity of data and differences in sampling designs among studies.

Visual assessment of the available data for locations with multi-year data did not identify possible long-term trends in major tributaries of the Athabasca River, other than apparent trends that reflected changes in sampling design. At this time, there are insufficient data to statistically test for long-term trends. Since data for analysis of long-term trends will accumulate at the rate of one data point/river/year, detection of long-term trends will not be possible for some time yet.

Since there will be a potential for the appearance of long-term trends unrelated to oil sands developments (e.g., due to climate change or long-term hydrological cycles), it is recommended that monitoring to detect long-term trends should incorporate at least one reference river. Although the analysis described in Section 6.2.1.2 suggests that each river is unique in terms of its benthic community, it is possible that long-term trends unrelated to development would be similar in all regional rivers. This would allow the consideration of time-trends observed in reference rivers in the interpretation of data from potentially affected rivers.

Detection of temporal trends requires consistent sampling over time at fixed locations. The RAMP committees that design monitoring components are aware of this requirement and are striving to satisfy it. As the program is still in a relatively early stage, adjustments suggested in other sections can be made without greatly compromising future ability to detect time trends. There are no specific recommendations arising from this section.

6.5.2.2 2000 Versus 2001 Comparisons

Comparisons of community structures between 2000 and 2001 were conducted using RAMP data collected using the same sampling design and methods in both years. The MacKay, Muskeg and Steepbank rivers, and Shipyard Lake were included in the comparison. Benthic community variables included total abundance, richness and PC scores, and abundances of Oligochaeta and Sphaeriidae in depositional habitat in the Muskeg River.

All variables were significantly different between years in Shipyard Lake, with lower values in 2001. There were no substantial changes in mine activity near the lake, or in mine-related hydrological factors affecting the lake between the two years. There is no obvious explanation for these findings, other than the possibility of a difference in the benthic community due to variation in dissolved oxygen (DO) and aquatic macrophyte cover between the two sampling periods.

Total abundance was significantly lower in 2001 in the MacKay River, but there were only minor, non-significant differences in richness and PC1 scores between years. Since there was no change in development in the MacKay River basin between these years, the differences may reflect natural variation, possibly related to hydrological factors.

Results for the lower erosional reach of the Muskeg River were generally similar to those described for the MacKay River. Total abundance and PC2 scores were significantly lower in 2001. Only small differences were found in richness and PC1 scores, neither of which was statistically significant. Farther upstream, just above the change in dominant habitat type from erosional to depositional, differences in community structure between years consisted of a small, non-significant change in total abundance, a small increase in richness, a relatively large increase in PC1 scores, and declines in abundances of Oligochaeta and Sphaeriidae in 2001. Differences in richness, PC1 scores, and abundances of Oligochaeta and Sphaeriidae were significant.

Benthic communities in the Steepbank River were similar in 2000 and 2001. None of the variables compared between years differed significantly.

Although the current sampling designs of 15 samples collected from a reach and 10 samples collected from a lake have adequate power when analyzed using ANOVA, the benthic program could be adjusted to be more cost-efficient without loss of statistical power. Additionally, adjustments to the current design may be warranted to ensure that representative data are collected at each site within a reach.

The recommended approach for adjusting the sampling designs is based on study designs used in pulp mill EEM and consists of collecting a larger number of smaller samples at each site (analyzed in the laboratory as composites) and reducing the number of sites based on power analysis results. Additionally, establishing permanent monitoring site locations would standardize among site variation, potentially resulting in greater power to detect differences among years. Because the program is still in its initial phase, adjusting the sampling design would not entail loss of an unacceptably large amount of information. Data analysis methods should also be revisited once data are available for a larger number of years.

6.5.2.3 Upstream-Downstream Comparisons and Trends

The analysis of upstream-downstream trends was done using the Clearwater River data collected in 2001, to statistically test for existing differences before the start-up of in situ oil sands developments in the Christina River basin. Upstream and downstream reaches in similar habitats were not sampled by RAMP in other rivers until the 2002 program. However, a number of historical studies sampled several sites along the length of the MacKay, Muskeg and Steepbank rivers. Results of these studies were presented graphically, if at least three relatively widely-spaced sites were sampled along the length of a river.

Existing differences were found in benthic community structure between the reaches sampled in the Clearwater River upstream and downstream of the Christina River. In the Mackay River, total abundance increased with distance from the mouth in 1977, but there was no consistent trend in 1984. Similarly, there were no trends in richness (both years), and abundances of Oligochaeta and Chironomidae in 1977. In 1984, abundances of Oligochaeta, EPT and Chironomidae reflected the pattern in total abundance. In depositional habitat in the Muskeg River, trends were also inconsistent among years and variables. The only consistent trend was found in abundances of Sphaeriidae, which were higher in the upper reach in both years with data. In the Steepbank River, total abundance, richness and abundances of nearly all major invertebrate groups increased with distance from the mouth in 1995.

Based on visual qualitative examination, increasing abundances with distance upstream appear common in major tributaries in the Oil Sands Region. Total abundance showed this trend in at least one year in all three rivers and abundances of major taxa frequently did as well. The same trend was not apparent in richness in the MacKay and Muskeg rivers, but was seen in the Steepbank River. Changes in benthic community structure along rivers have been widely observed and are expected. This trend will need to be considered during data analysis, once RAMP data are available from both upstream and downstream reaches of the major tributaries.

Recommended changes to the study design to improve cost-efficiency of monitoring and representativeness of data are the same as those outlined in the previous section.

6.5.3 Monitoring Data to Verify EIA Predictions

The scope under this objective consisted of investigating whether the data collected by RAMP are appropriate for use in verifying EIA predictions. The evaluation included an examination of RAMP sampling locations (past and future) relative to waterbodies that have been assessed in EIAs.

North of Fort McMurray, all regionally significant waterbodies that will persist through development are monitored, or will be monitored by RAMP. Although EIA predictions encompass a greater number of waterbodies than are monitored by RAMP, practical constraints require that monitoring be limited to waterbodies of regional significance.

RAMP monitors some rivers and streams that will be lost to development (Calumet and Tar rivers and Fort Creek). Monitoring these watercourses beyond the baseline period is unlikely to be of value and monitoring reaches upstream of planned developments will also be of little value because there will be no future upstream-downstream comparisons.

Planned monitoring south of Fort McMurray is of much lower intensity relative to the area to the north, which is partly justified by the lower density of planned developments and lower magnitudes of predicted impacts. The monitoring reaches planned in the Hangingstone and Christina rivers are generally appropriate. The location of the upstream monitoring reach in the Christina River should be reconsidered because it is downstream of the EnCana Christina Lake Thermal Project. In addition, to achieve consistency in monitoring effort among southern in-situ oil sands developments, monitoring locations would be required in the immediate vicinity of all planned developments.

The reaches monitored in the Clearwater River appear superfluous, because they are too far downstream from the sources of potential effects to be useful and represent a duplication of effort. Therefore, the monitoring effort allocated to this river may be shifted closer to developments, where monitoring is currently not planned by RAMP.

7 FISH POPULATIONS

7.1 INTRODUCTION

7.1.1 Program Overview

The RAMP fisheries program consists of 13 components that include fish community inventories, radiotelemetry studies, fish tissue analysis, application of sentinel species concepts, fish assessment using a counting fence, an assessment of fish-habitat associations and a spawning survey. The component studies were not conducted annually; rather, each component occurred according to a specified schedule during 1997-2001. Table 7.1 identifies the components of the fisheries program, the basic work associated with each component's study design and the years in which each component was conducted. If the study design for a component varied between years, the differences are indicated.

Sampling locations for the fisheries program are presented in Figures 7.1 and 7.2, along with the sampling history (year and season) for each location.

Table 7.1 Overview of the RAMP Fisheries Program, 1997 to 2001

Component	Methods and Approach	Years Conducted	Differences Between Years
Fisheries inventory in the Athabasca River	Boat electrofishing survey of standard reaches in the Oil Sands Region. Data collected on number of fish per species, length, weight, age and external pathology. Floy tagging of target species.	1997, 1998, 1999	Spring, and fall sampling conducted each year; summer sampling conducted in 1997 and 1998, but not 1999. Additional reaches surveyed in the vicinity of Fort McMurray in 1997. Reference reach 200 km upstream of the Oil Sands Region surveyed in 1998. Additional inventory for small-bodied forage fish conducted at selected sites in association with the 1999 sentinel species component.
Fisheries inventory in the Muskeg River Basin	Summer electrofishing inventory of the lower Muskeg River. Data collected on number of fish per species, length, weight and external pathology. Floy tagging of target species.	1997, 2001	Additional inventory for small-bodied forage fish conducted at selected sites in association with the 1999 sentinel species component. Lower Jackpine Creek added to inventory area in 2001.
Fisheries inventory in the Steepbank River	Summer boat electrofishing inventory of the lower Steepbank River.	1997	One study year only for general inventory. Additional inventory for small-bodied forage fish conducted at selected sites in association with the 1999 sentinel species component.
Fisheries inventory in the MacKay River	Summer boat electrofishing inventory of the lower MacKay River.	1997	One year only.
Radiotelemetry in the Athabasca River	Radiotelemetry to monitor movements of selected species between Cascade Rapids and Lake Athabasca.	1997/1998, 2000/2001	Lake whitefish and walleye monitored from fall 1997 to fall 1998; longnose sucker monitored from spring 2000 to spring 2001.
Radiotelemetry in the Muskeg River	Radiotelemetry to monitor movements of longnose sucker and northern pike in the lower Muskeg River and in the Athabasca River.	2000/2001	One year only, from spring 2000 to spring 2001.
Fish tissue analysis in the Athabasca River	Collection of tissue (muscle) samples from selected species in the Oil Sands Region for analysis of organic and inorganic contaminants (PAHs and trace metals including mercury). Samples were composited for analysis by species and sex.	1998, 2001	Tissue samples collected in the spring and fall in 1998; samples collected in the fall in 2001. Tissue samples collected from goldeye, lake whitefish, longnose sucker and walleye in 1998; samples collected from lake whitefish and walleye in 2001. Tissue samples collected for longnose sucker and walleye from a reference area 200 km upstream of the Oil Sands Region in 1998 only.

Table 7.1 Overview of the RAMP Fisheries Program, 1997 to 2001 (continued)

Component	Methods and Approach	Years Conducted	Differences Between Years
Fish tissue analysis in the Muskeg River	Fall collection of tissue samples from northern pike in the lower river for analysis of organic and inorganic contaminants (PAHs and trace metals including mercury). Samples were composited for analysis by sex.	2001	One year only.
Sentinel species in the Athabasca River	Evaluation of fish health and reproductive parameters for selected species. Data collected on length, weight, age, gonad size, liver size, fecundity, pathology, MFO and sex steroids.	1998, 1999	Longnose sucker were sampled in 1998 in the Oil Sands Region and at a reference area 200 km upstream; trout-perch were sampled in 1999 in the Oil Sands Region and at a reference site 12 km upstream.
Sentinel species in tributary watercourses	Evaluation of fish health and reproductive parameters for slimy sculpin populations in the Muskeg and Steepbank rivers. Data collected on length, weight, age, gonad size, liver size, fecundity and pathology.	1999, 2000, 2001	Sampling conducted at two sites on the Muskeg River and two sites on the Steepbank River in 1999; sampling conducted at one site each on the Muskeg, Horse and Dunkirk rivers, and two sites on the Steepbank River in 2001. 2000 survey was to identify potential reference sites, no fish health assessment conducted.
Fish counting fence in the Muskeg River	A two-way counting fence was installed in the Muskeg River in the spring to monitor the fish migration. Data collected on number of fish per species, length, weight, age and external pathology. Floy tagging of target species.	1998, 2001	The fence was successfully installed 16.5 km upstream of the river mouth in 1998; in 2001 the fence was installed at the river mouth but washed out due to high flows, providing only a limited number of days of service.
Fish-habitat associations in the Athabasca River	Enumeration of number and life stages of important fish species captured in the Oil Sands Region during inventory studies in relation to specific habitat types present.	1997, 1998	An additional study area located 200 km upstream of the Oil Sands Region was surveyed in 1998 only.
Spawning survey in the Muskeg River basin	A spring survey to locate spawning sites for Arctic grayling, northern pike, longnose sucker and white sucker in lower Jackpine Creek and the lower Muskeg River.	2000	One year only.

Note: PAHs = Polycyclic aromatic hydrocarbons.
MFO = Mixed Function oxygenase.

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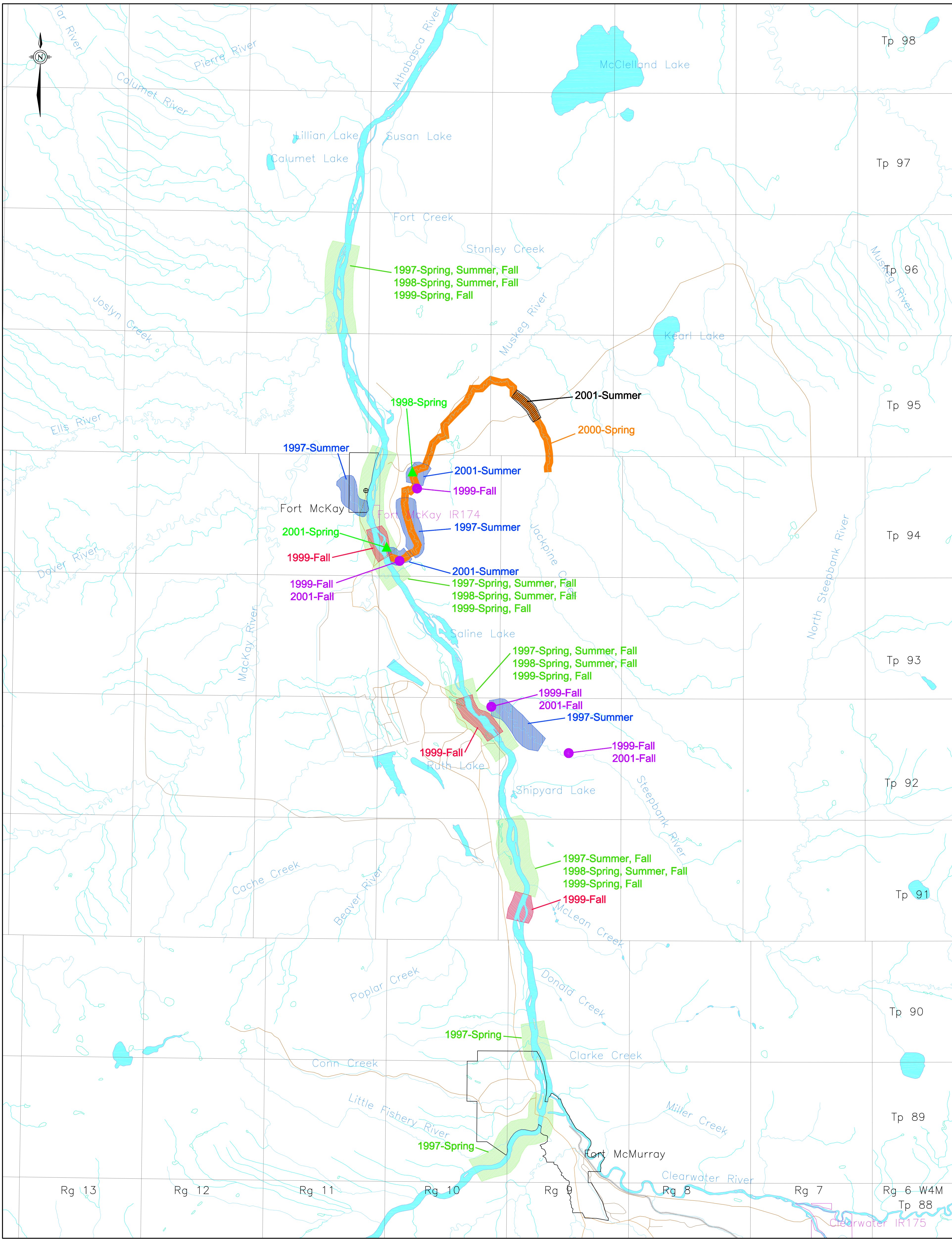

LEGEND

- BOAT ELECTROFISHING INVENTORY – ATHABASCA RIVER
- SMALL–BODIED SENTINEL SPECIES INVENTORY – ATHABASCA RIVER
- BOAT ELECTROFISHING INVENTORY – MUSKEG RIVER, MacKAY RIVER, STEEPBANK RIVER
- BACK PACK ELECTROFISHING INVENTORY – JACKPINE CREEK
- SMALL–BODIED SENTINEL SPECIES INVENTORY – MUSKEG RIVER, STEEPBANK RIVER
- FISH COUNTING FENCE – MUSKEG RIVER
- SPAWNING SURVEY – MUSKEG RIVER, JACKPINE CREEK

5 0 5
SCALE KILOMETRES

NOTE

ATHABASCA RIVER TISSUE COLLECTIONS AND SENTINEL SPECIES COLLECTIONS (LONGNOSE SUCKER) CONDUCTED AT INVENTORY SITES.

REFERENCE

ALBERTA NTDB DATA SUPPLIED BY GEOMATICS CANADA, AUGUST 2001.
NAD 83 ZONE 12. SHEETS 74D, E AND 74L IN NAD 27 ZONE 12.
ALL DATA CONVERTED TO NAD 83 UTM ZONE 12.

PROJECT

RAMP FIVE YEAR REPORT

TITLE

SAMPLING LOCATIONS FOR THE RAMP FISHERIES PROGRAM, OIL SANDS REGION, 1997 TO 2001

Golder Associates
Calgary, Alberta

PROJECT No. 022-2301.6410		FILE No. Fish-Base-Map.dwg	
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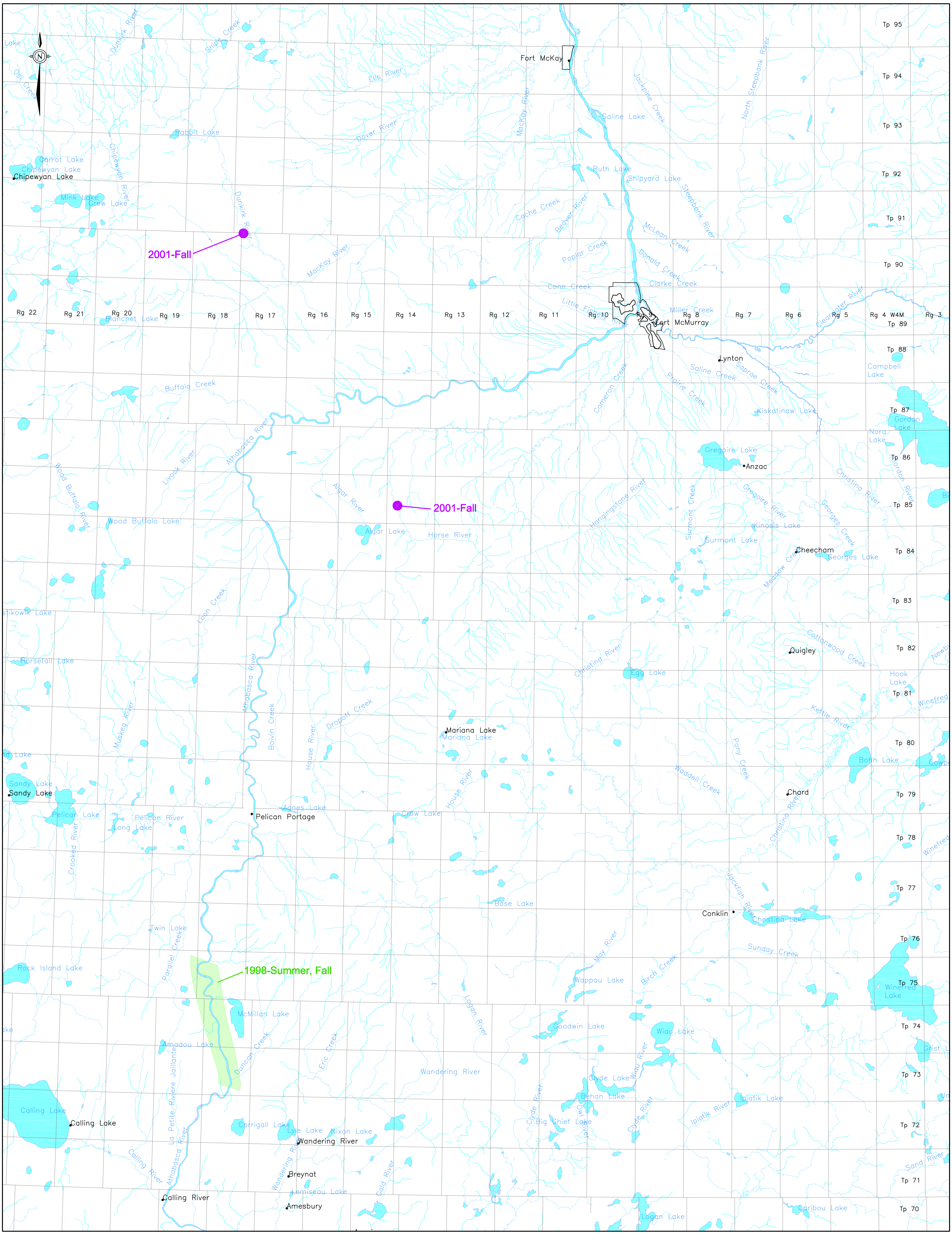
CADD	AS	06/03/03	
CHECK			
REVIEW			

FIGURE: 7.1

R:\CAD\2300\022-2301\6410\ Drawing file: Fish-Base-Map-South.dwg Mar 06, 2003 - 3:25pm



LEGEND

BOAT ELECTROFISHING INVENTORY – ATHABASCA RIVER

SMALL-BODIED SENTINEL SPECIES INVENTORY – DUNKIRK RIVER, HORSE RIVER

15 0 15
SCALE KILOMETRES

NOTE

ATHABASCA RIVER TISSUE COLLECTIONS AND SENTINEL SPECIES COLLECTIONS (LONGNOSE SUCKER) CONDUCTED AT INVENTORY SITES.

ALBERTA NTDB DATA SUPPLIED BY GEOMATICS CANADA, AUGUST 2001.
NAD 83 ZONE 12. SHEETS 74D, E AND 74L IN NAD 27 ZONE 12.
ALL DATA CONVERTED TO NAD 83 UTM ZONE 12.

PROJECT

RAMP FIVE YEAR REPORT

TITLE

SAMPLING LOCATIONS FOR THE RAMP FISHERIES PROGRAM, REFERENCE AREAS, 1997 TO 2001

Golder Associates
Calgary, Alberta

PROJECT No. 022-2301.6410			FILE No. Fish-Base Map-South	
DESIGN	CB	22/11/02	SCALE AS SHOWN	REV. 0
CADD	AS	06/03/03	**FIGURE: 7.2**	
CHECK				
REVIEW				

7.1.2 Objectives

The RAMP Terms of Reference specify eight overall objectives for the program, as listed in Section 1.6.1. Three of these eight objectives are relevant for defining the scope of the Five Year Report for the fisheries program. The following three objectives, which apply to monitoring and the collection of data, are addressed in this section:

- collecting scientifically defensible baseline and historical data to characterize variability in the Oil Sands Region;
- monitoring aquatic environments in the Oil Sands Region to detect and assess cumulative effects and regional trends; and
- collecting data against which predictions contained in environmental impact assessments (EIAs) can be verified.

Within these three overall objectives of RAMP, the general objectives of the fisheries program are to evaluate the health and sustainability of fish resources within the Oil Sands Region, with monitoring focused on the Athabasca River and tributaries potentially influenced by current or future oil sands development. Fish populations are monitored to provide a bioindicator of ecosystem integrity, with emphasis on regional fish resources and sentinel species.

The following issues were identified within the objectives for the fisheries program:

- ensure that fish populations identified as important to subsistence, commercial and sport fisheries are not adversely affected by oil sands development, including their suitability for human consumption;
- maintain the ecological integrity of the aquatic ecosystem, which for fish includes ensuring there are no adverse effects on fish populations in terms of ecological attributes such as growth, reproduction and survival; and
- use early warning indicators in the monitoring program.

In addition to the above, the RAMP Fish Subgroup of the Technical Subcommittee identified the following for consideration in the fisheries section of the Five Year Report:

- provide indices and statistical comparisons when possible to indicate the significance of observed differences between years;

- due to the nature of the fisheries program and the lack of yearly data, use historical and recent data collected outside of RAMP, where appropriate, to identify regional variability and trends; and
- consider potential links between trends observed in fish populations and the results of the other RAMP programs (i.e., water and sediment quality, hydrology and benthic invertebrate communities).

To address both the broad objectives of RAMP and the specific issues associated with the fisheries program, the specific objectives of the Five Year Report are as follows:

- using suitable historical information, recent information collected outside RAMP, and information generated by RAMP, characterize variability in the fish population data relative to species composition, relative abundance, population structure, growth, health, reproduction and suitability for human consumption;
- evaluate whether the present study design is suitable for characterizing variability;
- identify any cumulative effects or regional trends indicated by the data relative to the health and sustainability of regional fish resources;
- evaluate the ability of the present study design to detect cumulative effects or regional trends;
- evaluate whether the information being collected by RAMP could be used to verify EIA predictions regarding fish populations; and
- evaluate if and how the RAMP fisheries program may be improved.

The first five fisheries objectives, above, relate to the three broad program objectives as outlined in Table 7.2. The sixth objective regarding recommendations for program improvement applies to all three broad program objectives. As such, suggestions for improvement are given in several sections and in the overall summary (Chapter 8).

The objectives apply in different ways to each of the components of the fisheries program. For example, some components are designed to examine fish species composition and relative abundance (i.e., inventory components) while other components address fish health and do so for specific species (i.e., sentinel species component). The objectives for each component are presented in each component section.

Table 7.2 Relationship of the Specific Fisheries Objectives to RAMP's Overall Objectives

Program Objective	Relevant Fisheries Objective
characterize existing variability	examine available data to characterize variability in fish populations using appropriate indices
	evaluate the suitability of the data collected by RAMP to assess variability
detect and assess cumulative effects and regional trends	identify cumulative effects or regional trends in the fish population data
	evaluate the ability of the existing sampling program to detect changes and trends in fish populations
collect data that can be used to verify EIA predictions	determine if the information collected by RAMP could be used to verify EIA predictions

7.1.3 Scope

The scope of the Five Year Report for the fisheries program was limited to the six components that were conducted in more than one year (Table 7.1), and provide data suitable for assessing regional variability and trends. The scope was restricted to these components to focus the analysis on characterizing variability and evaluating regional trends and cumulative effects. Data associated with the other seven components was used, where appropriate, to provide additional information. Table 7.3 lists the 13 components of the fisheries program, identifies the six components included in the scope of the Five Year Report and presents the rationale for their inclusion or exclusion.

Because the components included in the Five Year Report have only two or three years of data under the fisheries monitoring schedule, data outside RAMP was included to assess regional variability and trends. This additional information included historical (e.g., Alberta Oil Sands Environmental Research Program [AOSERP] studies) and more recent data collected for oil sands EIAs or other initiatives (e.g., Northern River Basins Study [NRBS]). Information collected outside RAMP was only used after examining sampling technique, level of sampling effort, sampling location and methodology.

Table 7.3 Components of the RAMP Fisheries Program in Relation to the Scope of the Five Year Report

Component	Included or Excluded	Rationale	Years and Geographic Scope
fisheries inventory in the Athabasca River	included	Three years of RAMP data available. Historical data and recent EIA data also available.	RAMP inventory data from 1997, 1998 and 1999 were used in conjunction with comparable historical data and EIA data to describe variability and trends in species composition, fish abundance and general biology.
fisheries inventory in the Muskeg River Basin	included	Two years of RAMP data available. Historical data and recent EIA data also available.	RAMP inventory data from 1997 and 2001 were used in conjunction with comparable historical data and EIA data to describe variability and trends in species composition and abundance.
fish tissue analysis in the Athabasca River	included	Two years of RAMP data available. Historical data and recent NRBS data also available.	RAMP fish tissue data from 1998 and 2001 were used in conjunction with historical fish tissue data from the Oil Sands Region and beyond to assess variability and trends in concentrations of contaminants.
sentinel species in the Athabasca River	included	There is only one year of RAMP data each for longnose sucker and trout-perch so trend analysis is not possible. However, longnose sucker was dropped from this component pending analysis of its suitability as a sentinel species. The five-year report was used as the forum for this analysis.	Concerns for longnose sucker as a sentinel species relate to the level of variability in the health assessment data and the mobility of this species. RAMP health assessment data from 1998 and telemetry data from 2000/2001 were used in conjunction with health parameter data obtained from studies conducted for the Pulp and Paper Industry Environmental Effects Monitoring program to assess the suitability of longnose sucker as a RAMP sentinel species.
sentinel species in tributary watercourses	included	Two years of RAMP data available.	RAMP fish health assessment data from 1999 and 2001 were used to evaluate variability and trends in slimy sculpin populations in the Muskeg and Steepbank rivers over time and in relation to other regional populations.
fish counting fence in the Muskeg River	included	Two years of RAMP data available. Historical and recent EIA data also available.	RAMP data from 1998 and 2001 were used in conjunction with historical counting fence data to assess variability and trends in species composition, abundance and general biology of large bodied fish.
fisheries inventory in the Steepbank River	excluded	Only one year of RAMP data.	none
fisheries inventory in the MacKay River	excluded	Only one year of RAMP data.	none
Radiotelemetry in the Athabasca River	excluded	No more than one year of data for any species. Movement data not suitable for trend analysis. Telemetry data used as supporting data for some components included in the five-year report (e.g., longnose sucker movements in relation to suitability as a sentinel species).	none

Table 7.3 Components of the RAMP Fisheries Program in Relation to the Scope of the Five Year Report (continued)

Component	Included or Excluded	Rationale	Years and Geographic Scope
Radiotelemetry in the Muskeg River	excluded	No more than one year of data for any species. Movement data not suitable for trend analysis. Telemetry data used as supporting data for some components included in the five-year report (e.g., longnose sucker movements in relation to suitability as a sentinel species).	none
fish tissue analysis in the Muskeg River	excluded	Only one year of RAMP data. Muskeg River tissue data are suitable for use as supporting data in the analysis of Athabasca River tissue data, relative to defining regional conditions.	none
fish-habitat associations in the Athabasca River	excluded	Data do not provide specific indices for between year comparisons. This component has been dropped from the fisheries program.	none
spawning survey in the Muskeg River basin	excluded	Only one year of RAMP data. Habitat conditions documented during the spawning survey are useful as support data in the analysis of fish population trends in the Muskeg River, as determined in the inventory and counting fence components.	none

Note: NRBS = Northern River Basins Study.

Changes in study design in the components selected for the Five Year Report include changes in sampling location, sampling season and target species (Table 7.1). This further limits the power of between-year comparisons and the ability of the program to detect any change in the fish population. Within a component, the RAMP data that were used for characterizing variability and for trend analysis were limited to data of comparable origin.

7.2 CHARACTERIZING EXISTING VARIABILITY

7.2.1 Fisheries Inventory in the Athabasca River

The Athabasca River inventory component of the fisheries program provided information about the regional fish resource by collecting data regarding species composition and relative abundance for large-bodied fish species. In addition, biological data (i.e., size, age, size at age, health assessment) were examined for regionally important species. These important species included fish caught in the subsistence, commercial or sport fisheries, or designated as RAMP sentinel species.

The objective of the inventory was to enhance baseline information and provide data to assess year-to-year variability. The inventory program was not intended as a definitive tool for monitoring Athabasca River fish populations, but rather as a method to obtain general information on species abundance and biology. Catch-per-unit-effort data were used as an indication of relative abundance among species and among years.

7.2.1.1 Methods

RAMP inventory data for the Athabasca River in the Oil Sands Region from 1997, 1998 and 1999 (Golder 1998, 1999, 2000a) were used in the analysis. Suitability of additional data used for comparative purposes or to extend the period for trend analysis was assessed based on data collection (i.e., sampling location, method, effort and season) as well as the information made available (i.e., catch-per-unit-effort [CPUE] and population parameters).

Available data were analyzed for the following:

- percent composition (number per species as a percentage of total number for all species combined) using all fish captured and observed while sampling;

- CPUE (catch-per-unit-effort expressed as number of fish per 100 seconds of active boat electrofishing) using all fish captured and observed while sampling;
- length frequency distribution using fish captured and measured for fork length;
- age frequency distribution using fish captured and aged;
- length-at-age analysis using fish captured, measured and aged;
- length-weight regression analysis using fish captured and measured for both length and weight;
- mean condition factor for fish captured and measured for length and weight; and
- mean pathology index for fish captured and examined for external abnormalities.

All seasonal data from the 1997 and 1998 RAMP inventories were used in the analyses. For 1999, the spring data were used and compared to spring data collected in previous years. Fall sampling was not originally planned as part of the 1999 program but was conducted in collaboration with Environment Canada to collect adult longnose sucker (Golder 2000a). The total number of fish per species that were observed while electrofishing was recorded but the fish captured were limited and biased towards adult longnose sucker. Therefore, the fall 1999 data were used in analysis of percent composition and CPUE, but were not always suitable for comparisons of population parameter data for captured fish.

Historical data from 1974 and 1975 (McCart et al. 1977) provided comparable length frequency as well as length-at-age data for some species, but was not suitable for comparisons of percent species composition or CPUE due to the use of different sampling techniques. Data from 1976 and 1977 (Bond 1980) provided comparisons of species percent composition, but was not suitable for comparing CPUE and did not include size or age data. Data from 1995 (Golder 1996a) were collected and analyzed in a manner very similar to the RAMP study and were suitable for analyzing percent composition, CPUE and all population parameters. Data from 1996 (Golder 1996c) were used for comparison of percent composition but were not used for CPUE comparisons as it was not reported if the 1996 CPUE data were calculated using captured and observed fish or only captured fish. The 1996 data were also used for analyses that included length and/or weight data.

To assess variability and trends, analyses of population parameters were limited to large-bodied species captured in sufficient numbers in more than one year.

Length frequency distributions were developed by species and by season for each year. Length frequency distributions were transformed to percent frequency to standardize data and eliminate dependency on sample size. These data did not fit a 'normal distribution'; therefore, the non-parametric multiple comparisons for non-parametric repeated-measures analysis of variance test (α=0.05) (Zar 1999) were used to test for differences between annual length frequency distributions for each season.

The numbers of fish for which age was determined were fewer than those sampled for length and weight. Since age and growth data were insufficient to carry out analysis by season, the data were combined for all seasons. Age frequency distributions were transformed to percent frequency to eliminate dependency on sample size.

Weight-at-length for each species was estimated using a combination of length-weight regression analysis and condition factor. Length-weight regressions were constructed by transforming the data ($\log_e$) before deriving a geometric mean regression equation (Ricker 1975). An initial data screening was conducted prior to the analysis and any length-weight data pair was dropped from the analysis if the fish weight was more than 33.3% different from the predicted value for that length from the regression. Table 7.4 provides a list of the number of outlying data pairs identified by species and season. For each species and year, an analysis of covariance (ANCOVA) was conducted comparing the length-weight relationship between seasons (Snedecor and Cochran 1978) to determine if, in any year, there was a significant difference ($p>0.05$) between seasons.

The length and weight data were then used to calculate condition factor using a Fulton-type Condition Factor *k*, where *k* = body weight (g) x 10^5 / length (mm)^3 [Note: Fulton's Condition Factor was multiplied by 10^5 to scale k close to 1.0, as per MacKay et al. 1990]. To standardize the size range used for seasonal between-year comparisons, condition factor was calculated for adult fish with lengths greater than the female mean size-at-maturity (mean female age-at-length was estimated using information from Scott and Crossman [1973] and Nelson and Paetz [1992]). Comparisons of the seasonal condition factor between years were conducted using a parametric one-way analysis of variance test (ANOVA) (Zar 1999) to determine if mean condition factor differed significantly.

Table 7.4 Number of Outlier Data Points Removed for Each Species During Analysis of Length-Weight Relationships

Species	Season	Year				
		1995	1996	1997	1998	1999
lake whitefish	spring	0	0	0	0	0
	summer	0	0	1	0	-
	fall	0	2	1	1	1
walleye	spring	1	1	1	1	2
	summer	1	0	0	0	-
	fall	0	0	2	0	0
goldeye	spring	1	0	1	1	0
	summer	2	0	1	0	-
	fall	0	5	3	1	0
northern pike	spring	0	1	1	0	0
	summer	0	0	0	1	-
	fall	1	0	0	0	0
longnose sucker	spring	0	0	3	1	0
	summer	0	1	0	0	-
	fall	3	0	0	1	1
white sucker	spring	0	-	4	2	1
	summer	0	-	0	0	-
	fall	0	-	0	1	2

Note: "-" = no data.

Growth was determined by calculating length-at-age. This analysis resulted in a plot of mean length for ages of the species where sufficient age determination data were available (walleye, goldeye and longnose sucker). An ANCOVA analysis was used to determine if differences in the length-at-age data between years were significant. In addition, general growth curves were developed for each of the six main large-bodied species (lake whitefish, walleye, goldeye, northern pike, longnose sucker and white sucker). For each species, ages for all years were combined, since some species lacked sufficient data for annual estimates. The von Bertalanffy growth equation (Beverton and Holt 1957) calculated by computer program (VONB) (Abramson 1971) was used to describe a mean growth curve and estimate the theoretical $L\infty$ (maximum fork length) for these species in the Oil Sands Region.

Fish health was assessed during the fish inventory by conducting an external examination of captured fish for signs of abnormalities, disease and parasites. Eyes, gills, skin, fins, opercles, thymus, pseudobranchs, body form and parasites were examined. All abnormalities were recorded by type and severity and were assigned an index value. An external pathology index was calculated for each fish as the sum of the index values for all abnormalities. A mean index value was then calculated for each species and year to allow for between-year comparisons.

7.2.1.2 Results and Discussion

A total of 30 fish species has been documented to occur in the mainstem of the Athabasca River in the Oil Sands Region based on historical reports, recent fisheries programs outside of RAMP and RAMP data (Table 7.5). Nineteen of these species were found during the RAMP inventories, including 18 previously reported species and one new species (i.e., river shiner). There are 11 species known to occur in the Athabasca River that have not been recorded during the RAMP inventories, including three rare large-bodied species (bull trout, lake cisco and lake trout) and eight small-bodied species (Note: lake cisco were recorded during sampling associated with the 2001 RAMP tissue program). The differences in sampling techniques between years and biases associated with the RAMP inventory sampling technique (boat electrofishing) resulted in the capture of fewer small-bodied species compared to historical reports. This difference between current and historic studies is considered an artifact of the sampling program rather than a change in species diversity in the region. Due to this constraint, the remainder of the analysis is restricted to the large-bodied species.

Table 7.5 Fish Species in the Athabasca River in the Oil Sands Region

Species		Reported from Historical Inventories[a]	Reported from the 1997 to 1999 RAMP Inventories[b]
Common Name	Scientific Name		
Arctic grayling	*Thymallus arcticus*	●	●
brassy minnow	*Hybognathus hankinsoni*	●	
brook stickleback	*Culaea inconstans*	●	●
bull trout	*Salvelinus confluentus*	●	
burbot	*Lota lota*	●	●
emerald shiner	*Notropis atherinoides*	●	●
fathead minnow	*Pimephales promelas*	●	●
finescale dace	*Phoxinus neogaeus*	●	
flathead chub	*Platygobio gracilis*	●	●
goldeye	*Hiodon alosoides*	●	●
Iowa darter	*Etheostoma exile*	●	
lake chub	*Couesius plumbeus*	●	●
lake cisco	*Coregonus artedii*	●	[c]
lake trout	*Salvelinus namaucush*	●[d]	
lake whitefish	*Coregonus clupeaformis*	●	●
longnose dace	*Rhinichthys cataractae*	●	
longnose sucker	*Catostomus catostomus*	●	●
mountain whitefish	*Prosopium williamsoni*	●	●
ninespine stickleback	*Pungitius pungitius*	●	
northern pike	*Esox lucius*	●	●
northern redbelly dace	*Chrosomus eos*	●	
pearl dace	*Semotilus margarita*	●	
river shiner	*Notropis blennius*		●
slimy sculpin	*Cottus cognatus*	●	
spoonhead sculpin	*Cottus ricei*	●	●
spottail shiner	*Notropis hudsonius*	●	●
trout-perch	*Percopsis omiscomaycus*	●	●
walleye	*Stizostedion vitreum*	●	●
white sucker	*Catostomus commersoni*	●	●
yellow perch	*Perca flavescens*	●	●

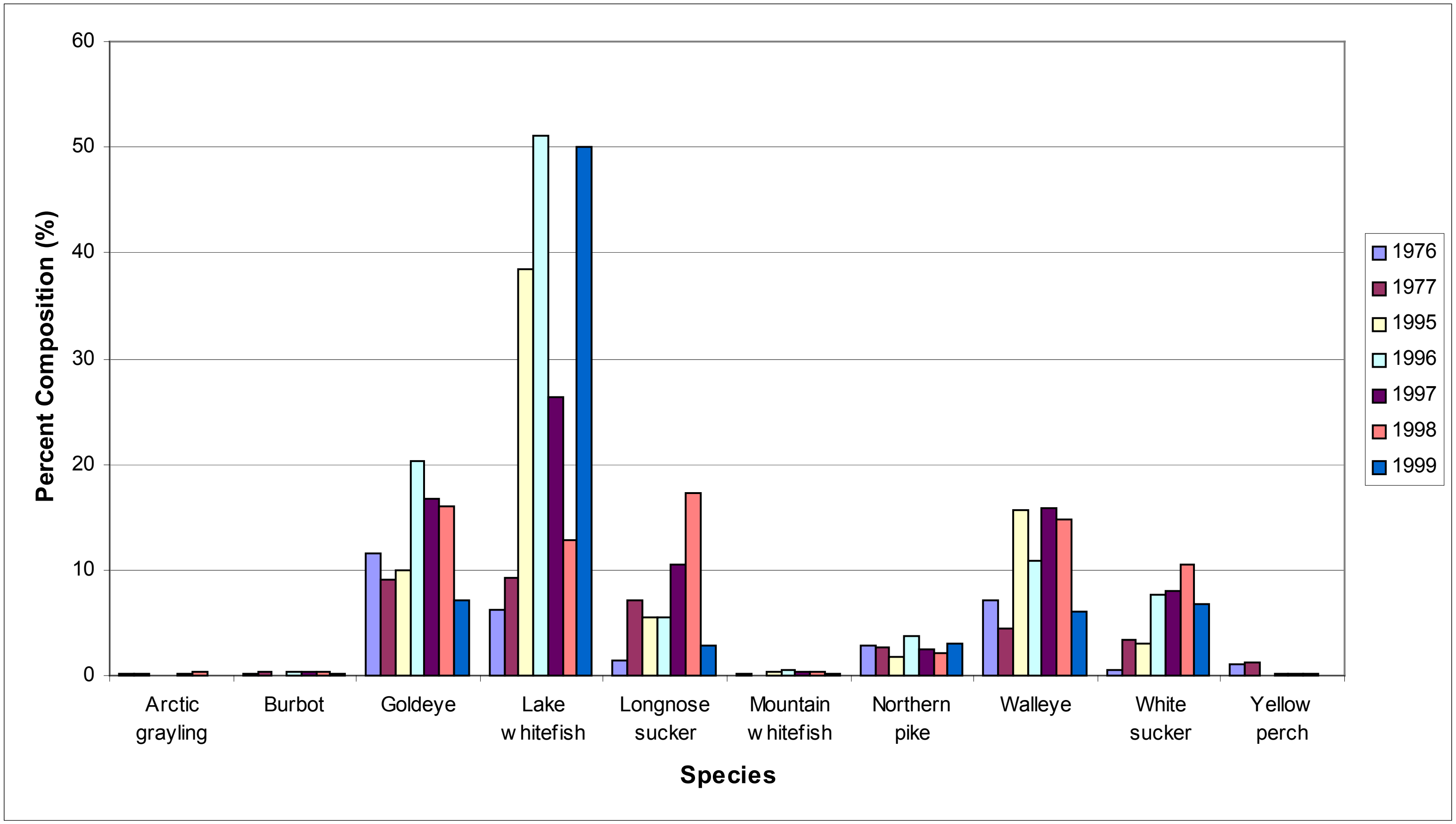
(a) Data compiled from: McCart et al. 1977; Tripp and McCart 1979; Bond 1980; Tripp and Tsui 1980; Wallace and McCart 1984; RL&L 1994; Syncrude's unpublished fish inventories 1989-91; Nelson and Paetz 1992; Golder 1996a, 1996c.
(b) Golder 1998, 1999, 2000a.
(c) Reported during sampling for tissue collection.
(d) Angler reports to ASRD (L. Rhude, pers. comm. 2003).

Figure 7.3 presents percent composition for the 10 large-bodied species recorded in the RAMP inventory and in the historical studies. Percent composition refers to the number of fish recorded per species as a percentage of the total number of fish recorded for all species. As mentioned, three large species that occur in the Athabasca River were not captured in the RAMP inventories: bull trout, lake cisco and lake trout. These three species were reported infrequently and it is not considered significant that they were not captured during the recent inventories.

Figure 7.3 shows the most common large-bodied species to be (roughly in order of relative abundance) lake whitefish, goldeye, walleye, longnose sucker, white sucker and northern pike. The remaining four species have not at any time comprised a significant proportion of the fish community in the Athabasca River. These results are comparable to all reported data that show lake whitefish, goldeye, walleye and longnose sucker to be the most abundant large fish species in the region (Golder 1996a).

Some variability between years in percent composition is apparent in Figure 7.3. The percent composition is somewhat higher for most species in the more recent inventories, starting in about 1995. This may be due to differences in sampling techniques, as studies from 1995 to 1999 were boat electrofishing inventories while studies prior to 1995 utilized gill nets, seine nets, angling and backpack electrofishing. Some variability is also apparent in the boat electrofishing inventories (i.e., 1995 to 1999 data), indicating that year-to-year variability in relative abundance may occur. Some of this year-to-year variability may be an artifact of differences in sampling. For example, the lower percent composition in 1998 (Figure 7.3) for lake whitefish is believed to be due to differences in the sampling periods. Lake whitefish abundance is low in the Oil Sands Region in the spring and summer but increases dramatically in the fall with the onset of the spawning migration from Lake Athabasca to the rapids located upstream of the Oil Sands Region. The inventories that show higher proportions of lake whitefish were those conducting the fall sampling from early to mid October, likely coinciding with the spawning run. However, in 1998, the fall survey was conducted in late September, which may have been too early to sample the period of highest abundance for this species.

Figure 7.3 Percent Composition for Large-Bodied Species, Athabasca River Inventories, 1976 to 1999



CPUE for all species combined is presented by season in Figure 7.4 for boat electrofishing inventories for which catch and effort were reported. Total CPUE for all seasons combined was similar among years (i.e., 8.2 fish/100 s in 1995, 8.0 fish/100 s in 1998 and 1999, and 10.2 fish/100 s in 1997). In contrast, CPUE among years was variable in each season, but most of this variability is likely due to differences in sampling. The main difference between years is the relatively low CPUE recorded in the fall of 1998 and 1999 compared to the fall of 1995 and 1996. This difference may be due to differences in sampling time rather than differences in fish abundance. High fall CPUE in the Athabasca River occurs mainly because large numbers of lake whitefish are involved in their spawning migration. Sampling in 1995 and 1996 was from early to mid October, when it would be expected that lake whitefish would be abundant. Sampling in 1998 and 1999 occurred prior to October 5, which may have been prior to the peak migration for spawning. Therefore, it is possible that the comparatively low fall CPUEs in 1998 and 1999 were due to time of sampling rather than lower fish abundance.

A comparatively high CPUE in summer 1998 is apparent in Figure 7.4. Since sampling methods and timing were similar between years, this may be a difference in relative fish abundance.

Total CPUE by year is presented for the six main large-bodied species in Figure 7.5. These results are similar to the percent composition results. The CPUE results indicate the order of species relative abundance in the Athabasca River to be lake whitefish, walleye, goldeye, longnose sucker, white sucker and northern pike. In most years, the relative abundance of walleye and goldeye was very similar.

Figure 7.4 Catch-Per-Unit-Effort for all Species Combined, Athabasca River Inventories, 1995 to 1999

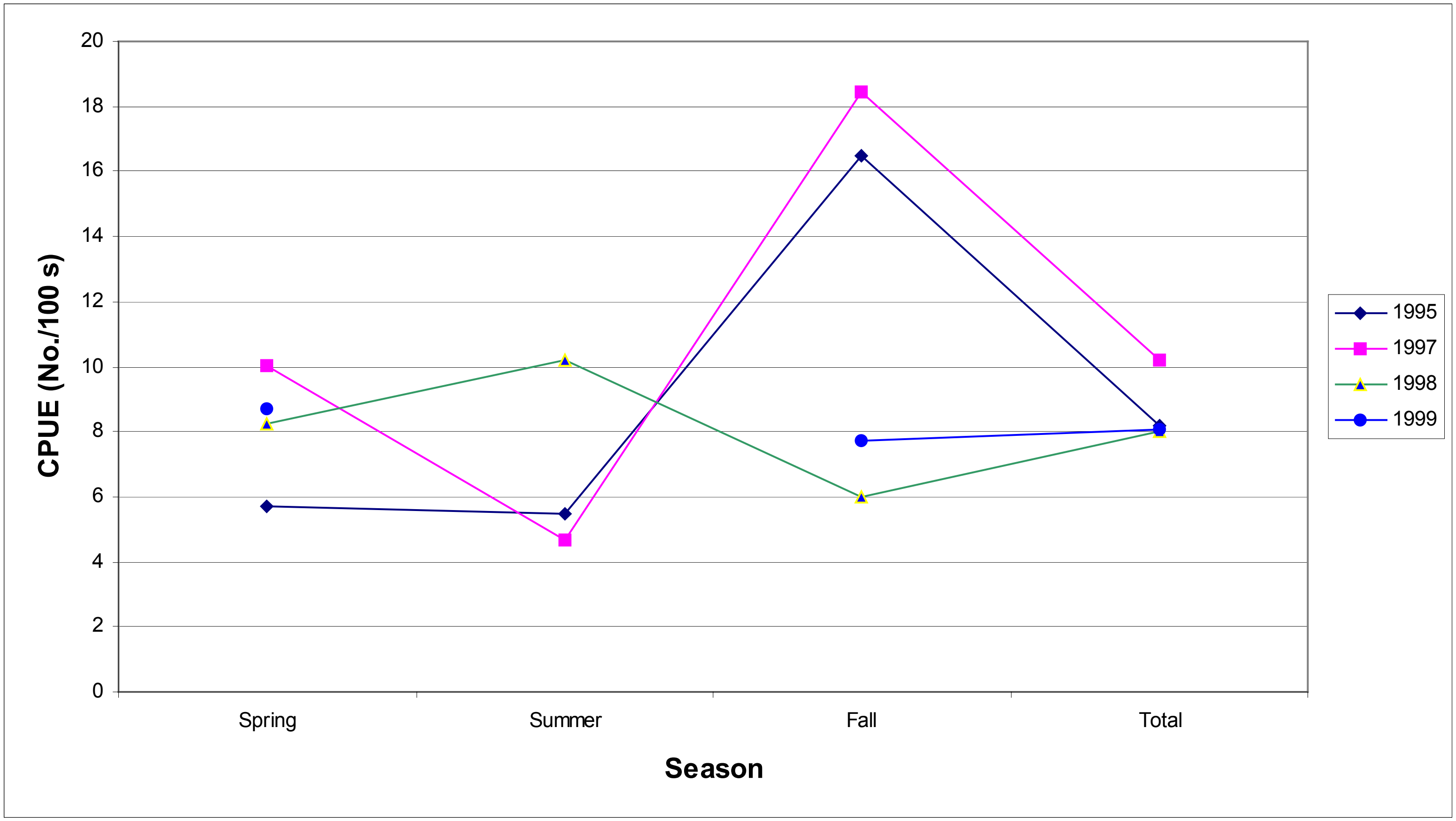
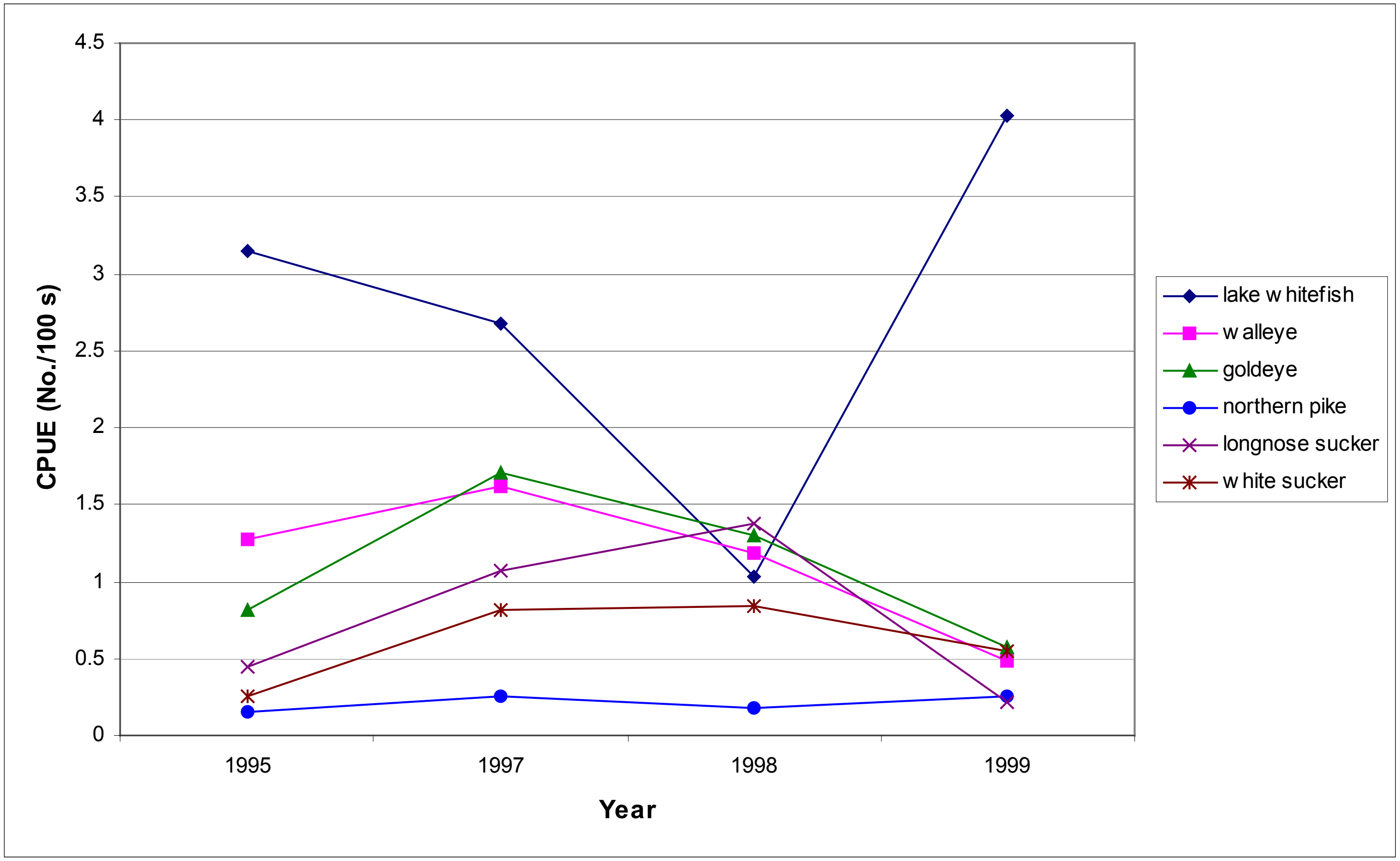


Figure 7.5 Catch-Per-Unit-Effort for the Main Large-Bodied Species in the Athabasca River, 1995 to 1999



Variability in annual CPUE (seasons combined) is apparent for some species (Figure 7.5), although some of the variability may be due to sampling differences. Annual CPUE results for lake whitefish show the highest amount of variability, low in 1998 and higher in 1999. The low 1998 CPUE may be the result of sampling activities being conducted earlier in the fall than in preceding years. Sampling in 1997 also was conducted in the early fall, but the CPUE for combined seasons is high. The high CPUE for 1999 is due to the lack of a summer sampling program in that year, which typically would provide additional samples with low capture success for this species. The lack of summer sampling creates an artificially high total CPUE for combined seasons in 1999 compared to the other years.

Walleye and goldeye show comparable trends in total CPUE over time, with increasing values from 1995 to 1997, followed by decreases through 1998 and 1999 (Figure 7.5). For goldeye, the 1999 CPUE is similar to the 1995 value, indicating that the recent decrease probably only reflects natural variability. On the other hand, the 1999 CPUE value for walleye is well below the 1995 value, suggesting a declining trend in abundance for this species. Additional years of data are required to determine if the low CPUE for walleye in 1999 is due to a change in abundance, is within the range of natural variability for this species, or is due to differences in the 1999 sampling program.

Longnose sucker CPUE increased from 1995 through 1998, declining in 1999 to below the 1995 level. The CPUE for white sucker increased from 1995 to 1997 and 1998, with a slight decrease in 1999, with 1999 remaining above 1995. Northern pike showed very little variability in total CPUE among years.

Additional analysis and comparisons of CPUE data and population parameters is presented in the following sections for the six common large-bodied species: lake whitefish, walleye, goldeye, northern pike, longnose sucker and white sucker. The first five of these species have been identified as Key Indicator Resource species (KIRs) for the Oil Sands Region. Table 7.6 presents a summary of the key findings that are presented in detail in the following species accounts.

Table 7.6 Summary of the Key Findings of Between-Year Comparisons for the Athabasca River Fish Inventory Component

Species	Population Parameter Analysis					
	Relative Abundance (CPUE)	Length Frequency	Age Frequency	Length-at-Age	Condition Factor	Pathology Index
lake whitefish	CPUE results for the period of high abundance (fall) indicate declining abundance in 1998 and 1999 compared to 1995 and 1997. This may be due to differences in sampling timing rather than a change in the magnitude of the fall run.	Minimal differences were evident between years during the fall sampling period (when sample sizes were sufficient).	Insufficient data.	Insufficient data.	Condition factors were found to fluctuate but showed no consistent trend over time. High condition factors were recorded in 1995 and 1997, with lower values in 1996 and 1998.	The incidence of abnormalities was high in 1995, but has been consistently low in all other years.
walleye	CPUE results indicate a declining trend in relative abundance, with the lowest level recorded in 1999. Additional years of data are required to determine if the low 1999 level represents a decline in abundance, is within the range of natural variability for this population or is due to sampling differences in 1999.	In all years, spring catches were dominated by larger fish. Summer and fall results showed a variable portion of the population consisted of smaller fish in different years, with no trends over time.	The age structure of the walleye population showed some variability between years, but no trends over time.	Variability was evident in walleye growth rates, with 1998 data showing the lowest length-at-age relationship. Although there were significant differences between years, there were no trends over time.	Indices of fish condition showed variability between years in all seasons, but there were no trends over time.	The incidence of abnormalities was low in all years, although the pathology index was slightly higher in 1999 than in previous years.
goldeye	CPUE results showed a high degree of variability in all seasons, but no trends over time.	There was a high degree of variability in the portion of the population consisting of smaller fish, but no trends over time.	Older fish dominated the population in 1997 and 1999, younger fish dominated in 1998 and an even age distribution occurred in 1995. There were no trends over time.	There was some variability in growth rates with smaller fish in the 5-7 year classes in 1975 and 1999, but no trends over time.	Indices of fish condition showed variability between years in all seasons, but there were no trends over time.	The incidence of abnormalities was low in all years.
northern pike	CPUE results showed a low degree of variability with no trends over time.	There was a high degree of variability in the portion of the population consisting of smaller fish, but no trends over time.	Insufficient data.	Insufficient data.	Indices of fish condition showed no trends over time.	The incidence of abnormalities was low in all years.

Table 7.6 Summary of the Key Findings of Between-Year Comparisons for the Athabasca River Fish Inventory Component (continued)

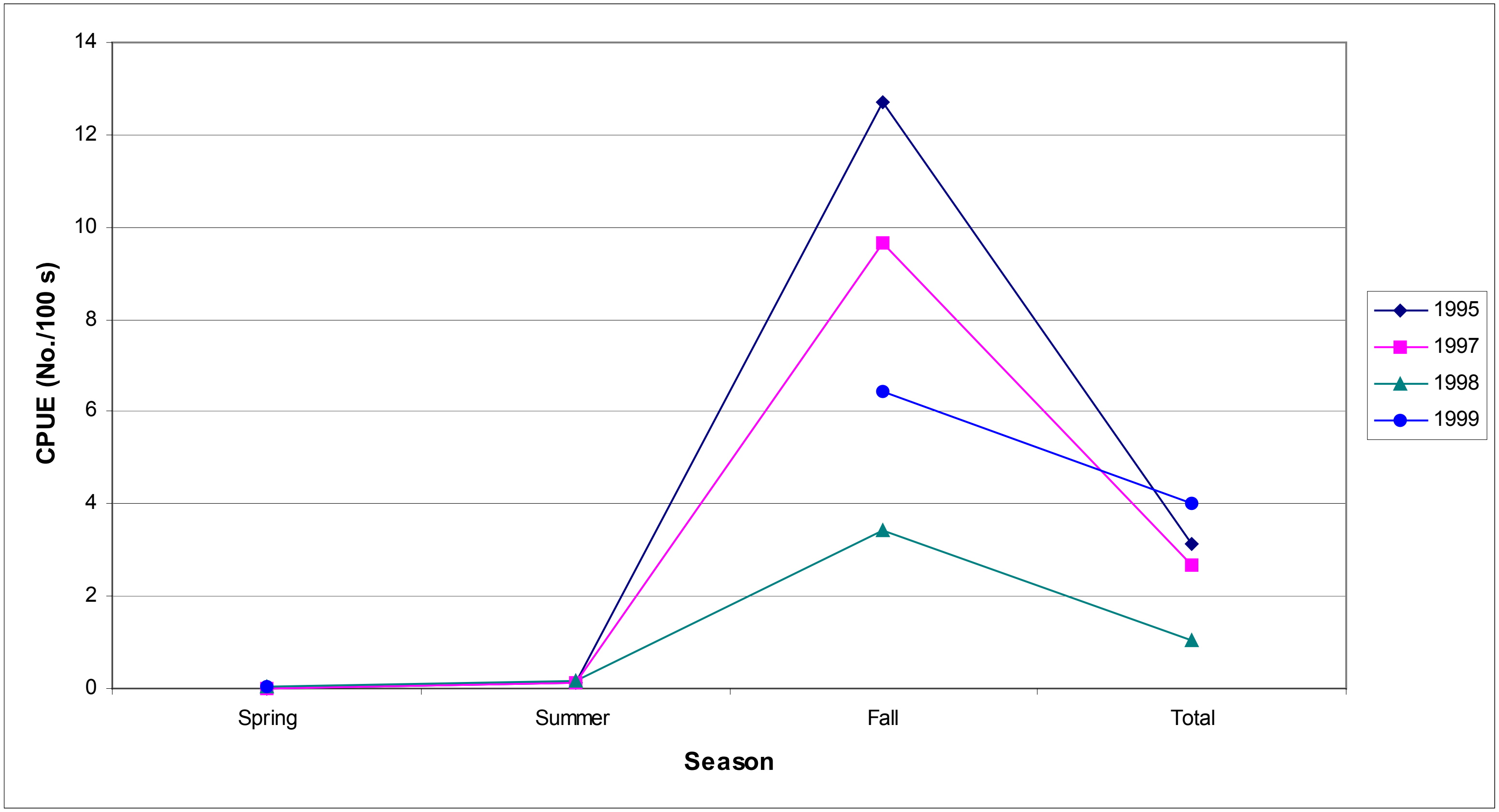
Species	Population Parameter Analysis					
	Relative Abundance (CPUE)	**Length Frequency**	**Age Frequency**	**Length-at-Age**	**Condition Factor**	**Pathology Index**
longnose sucker	CPUE results showed a high degree of variability in the spring but not in other seasons, with no trends over time.	There was a high degree of variability, but no trends over time.	There was a broad distribution of age classes in all years except 1999 when older fish were dominant. Differences were due to differences in sampling periods with no trends over time.	Growth rates were similar in all recent years and were generally higher than historical (1975) data.	Indices of fish condition showed variability between years in all seasons, but there were no consistent trends over time. There was a slight decline in condition over time in the summer, but this trend was not evident in other seasons.	The incidence of abnormalities was low in all years.
white sucker	CPUE results showed a high degree of variability in the spring but not in other seasons, with no trends over time.	Year to year variability was evident but there were no specific trends.	Insufficient data.	Insufficient data.	Indices of condition showed no changes between years for any season.	The incidence of abnormalities was low in all years, although it was slightly greater in 1995 than in subsequent years.

Overall, the fish inventory data indicate variability in relative abundance and population parameters for all species. However, consistent differences over time that would indicate trends are not apparent, with the possible exceptions of relative abundance estimates for lake whitefish and walleye (Table 7.6). Lower CPUE of lake whitefish and walleye in the recent inventories may be due to differences in sampling timing or seasons (see the following species accounts). One factor that could affect fish populations is the hydrological regime experienced during the RAMP years. However, even though the recent hydrological regime would be considered to be dry (see Chapter 3), there has been no consistent response in all large-bodied fish populations to indicate that hydrological regime has been a factor. For the years with CPUE date (1995, 1997, 1998 and 1999), 1997 had the highest mean annual discharge (1,012 m^3/s). The 1997 level was much higher than the long term average of 638 m^3/s. The mean annual discharges for the remaining years were 549, 507 and 458 m^3/s for 1995, 1998 and 1999, respectively. The CPUE for all species combined was highest in 1997 (Figure 7.4). CPUE for goldeye and walleye, two of the most abundant species, were also highest in 1997, corresponding with the high mean annual discharge. However, CPUEs for the other common large-bodied species were similar or higher in low water years compared to 1997.

Lake Whitefish

CPUE for lake whitefish (Figure 7.6) shows a distinct seasonal pattern in all years: low in the spring and summer, and higher in the fall. Although small numbers of lake whitefish are residents in the Athabasca River during the open-water period, large numbers from Lake Athabasca spawn at the rapids located upstream of Fort McMurray in the fall (Golder 1996a). Comparisons of fall CPUE (Figure 7.6) indicates lower catches in the two most recent years (i.e., 1998 and 1999). However, this variability may be due to differences in sampling timing rather than variability in the magnitude of the fall run. Although the CPUE data suggest a recent decline in the numbers of lake whitefish using the Athabasca River, this may be a sampling artifact. The sampling schedule should be standardized to remove this artifact.

Figure 7.6 Catch-Per-Unit-Effort for Lake Whitefish, Athabasca River Inventories, 1995 to 1999



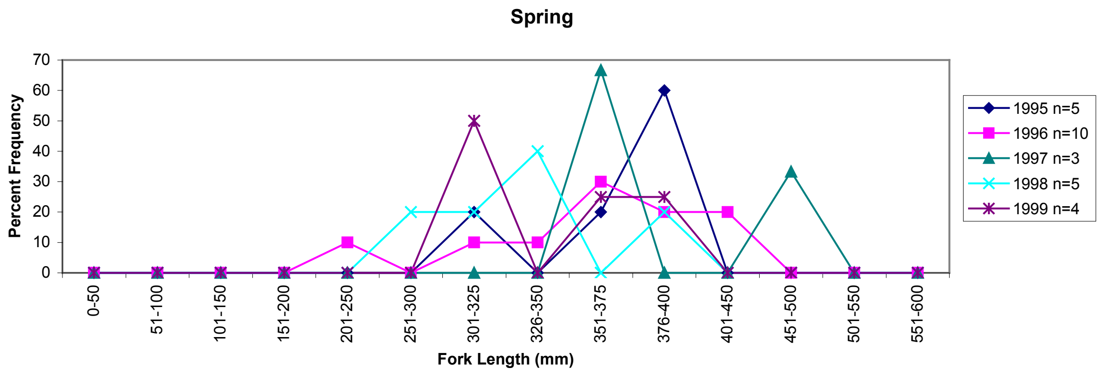
The length frequency distributions for lake whitefish (Figure 7.7) show the population using the Athabasca River to be mainly larger adult fish, particularly in summer and fall. The few fish present in the spring were smaller than those present in the summer and fall. In almost all years, the main size distribution of fish in the fall run was 376 to 500 mm, with the peak (i.e., modal class) at 401 to 450 mm. 1975 was an exception and consisted of more small fish, but included all seasons combined. For all years, size was more variable in the spring, but variability was low in the summer and fall when the difference between years was minimal. The statistical comparison of length frequency distributions indicated that the differences between years were not significant in any season (Appendix I).

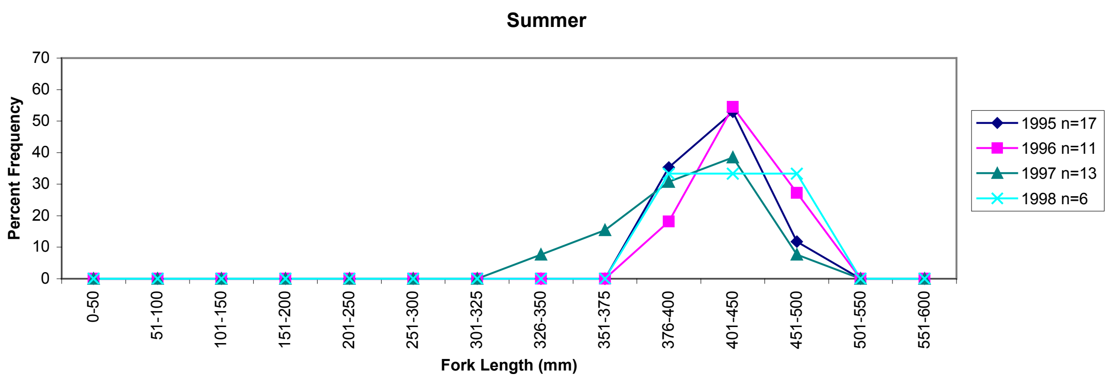
The length-weight regression analyses for lake whitefish are presented in Appendix I by year and season. The numbers of lake whitefish caught and measured for length and weight by season varied. In some years, too few fish were caught in spring and summer to calculate a valid regression equation (see Appendix I). The number of fish caught in fall 1995 was the highest and is used as a sample plot of the length-weight relationship for lake whitefish (Figure 7.8). This species has the greatest natural variability in length and weight of any of the large-bodied fish of the Athabasca River study area. This high natural variability and the resulting large overlap in samples reduces the discriminating power of the length-weight relation. This variability, coupled with the low sample sizes in the year/season pairs, precludes making definitive statements about seasonal differences in the length-weight relationship, although most of the comparisons had no significant difference ($p>0.05$).

Although the numbers of large lake whitefish (>350 mm in length) caught in spring were small, there appears to be a seasonal difference in condition factor, with lower condition factor in the spring compared to summer/fall (Figure 7.9). This difference may be due to gonadal development occurring over the summer, with fish being gravid in the fall. When numbers were greater in fall, there were significant differences in condition factor among years (Appendix I). Although condition factors were variable, there were no trends over time.

The sample sizes for aged fish in any given year were too small to conduct separate length-at-age analyses. The data were combined for all years to produce a general growth model (Appendix II).

Figure 7.7 Length Frequency Distributions for Lake Whitefish, Athabasca River Inventories, 1975 to 1999 (1975 data includes combined seasons)





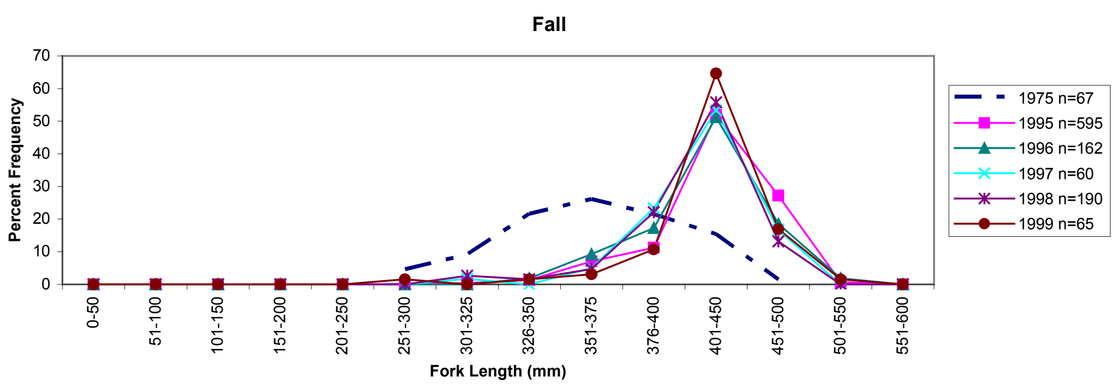


Figure 7.8 Example Plot of the Length-Weight Relationship for Lake Whitefish, Athabasca River Inventory, Fall 1995

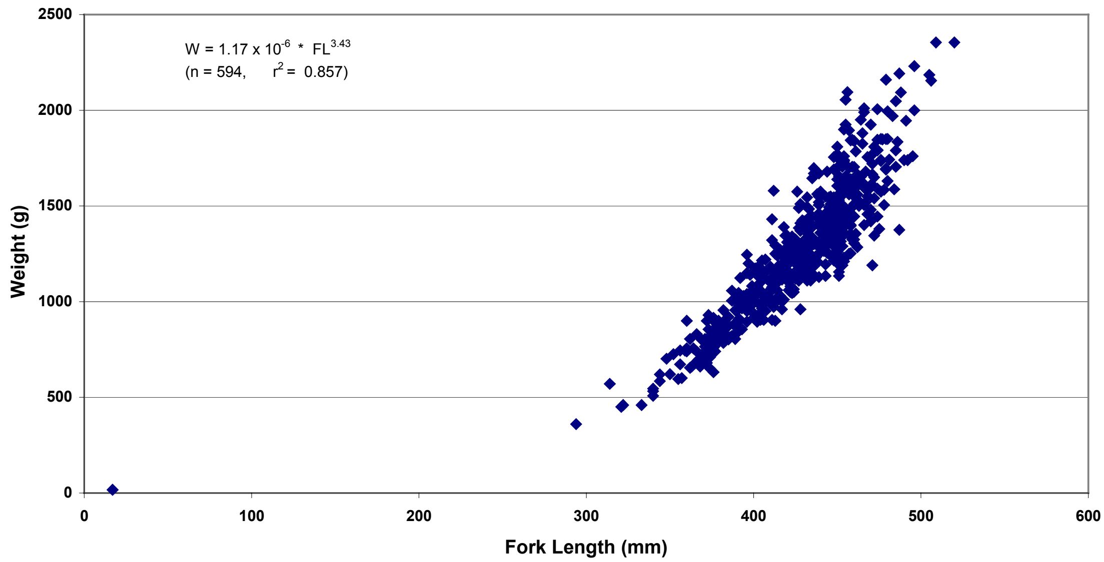
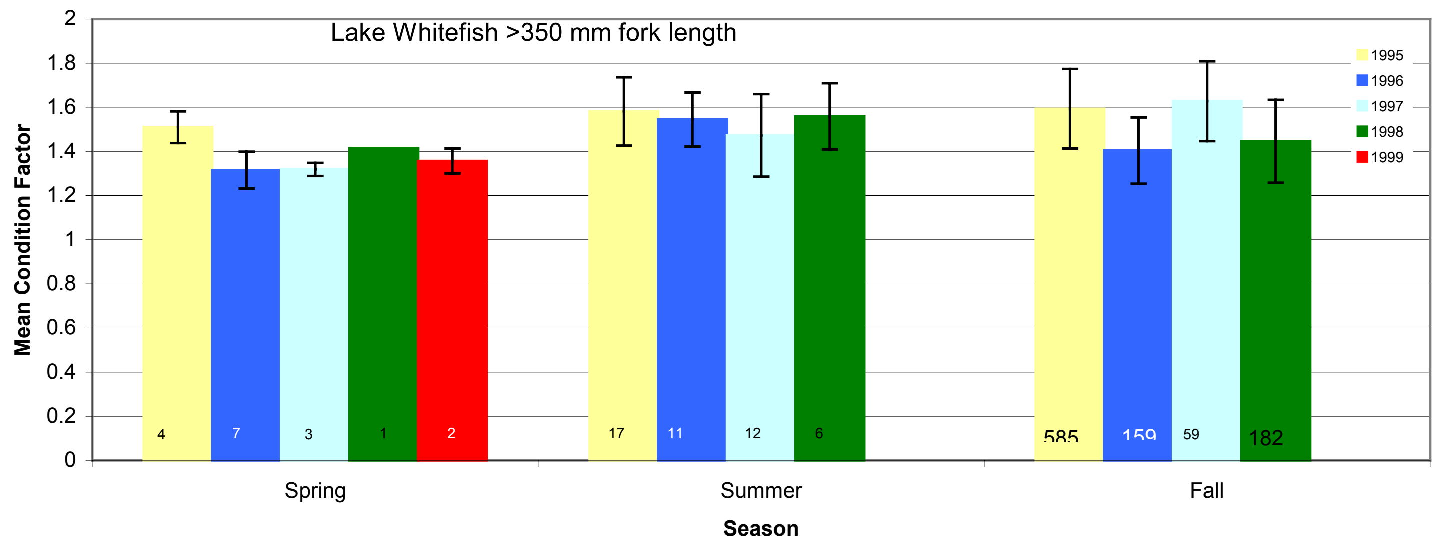


Figure 7.9 Condition Factors for Lake Whitefish, Athabasca River Inventories, 1995 to 1999 (with n value)



Walleye

CPUE for walleye was generally higher in the spring and lower in the summer and fall (Figure 7.10). The spring inventory sampling in 1995 was used to collect adult walleye for a fish health assessment study (Golder 1996a). Consequently, the 1995 sampling included repeated electrofishing runs in areas of known high walleye abundance to capture fish for the health study. The 1995 sampling was biased towards capture of walleye and the relatively high spring CPUE is likely an artifact of that.

The 1999 CPUE for walleye (spring and fall) was the lowest compared to previous years (Figure 7.10). It is not known if the low CPUE in 1999 was due to a change in walleye abundance, was within the range of natural variability for this species, or was the result of differences in the 1999 sampling program compared to previous years. Additional years of inventory data with a standardized sampling program would be required to determine if differences in walleye CPUE represent a trend.

The length frequency distributions for walleye are presented by season and year in Figure 7.11. For most years, the size distribution tends towards a greater proportion of larger fish in the spring and fall compared to the summer, with almost all years peaking in the 401 to 450 mm size class in the spring and fall. The main variability between years is in the proportion of smaller fish that occur in the summer and fall. During the spring spawning season in all years, the catch was dominated by larger fish. In the summer and fall, however, a variable proportion of the catch consisted of smaller fish. Although variability is apparent in the data, there are no specific trends with respect to an increase or decrease in the size classes that are dominant. The statistical comparison of length frequency distributions indicated that the differences between years were not significant in any season (Appendix I).

The age frequency distributions for walleye (Figure 7.12) show that, for all years combined, captured fish ranged from zero to 16 years old. The distributions of ages were similar in 1997 and 1999, with most fish distributed somewhat evenly among the three to nine year classes. In 1998, the distribution was spread across even a wider range of ages. In contrast, the four- and five-year age classes dominated in 1995.

A comparison of the length-at-age relationships for walleye from the Athabasca River (Figure 7.13) shows some variability in size at age. The length achieved at a given age was generally lowest for fish captured in 1998 compared to 1975, 1995, 1997 and 1999, although 1998 and 1999 data were similar. The ANCOVA analysis of the data indicated significant differences ($p>0.05$) among years, but no specific trend over time. The generalized von Bertalanffy growth curve for walleye for all aging data combined is presented in Appendix II.

Figure 7.10 Catch-Per-Unit-Effort for Walleye, Athabasca River Inventories, 1995 to 1999

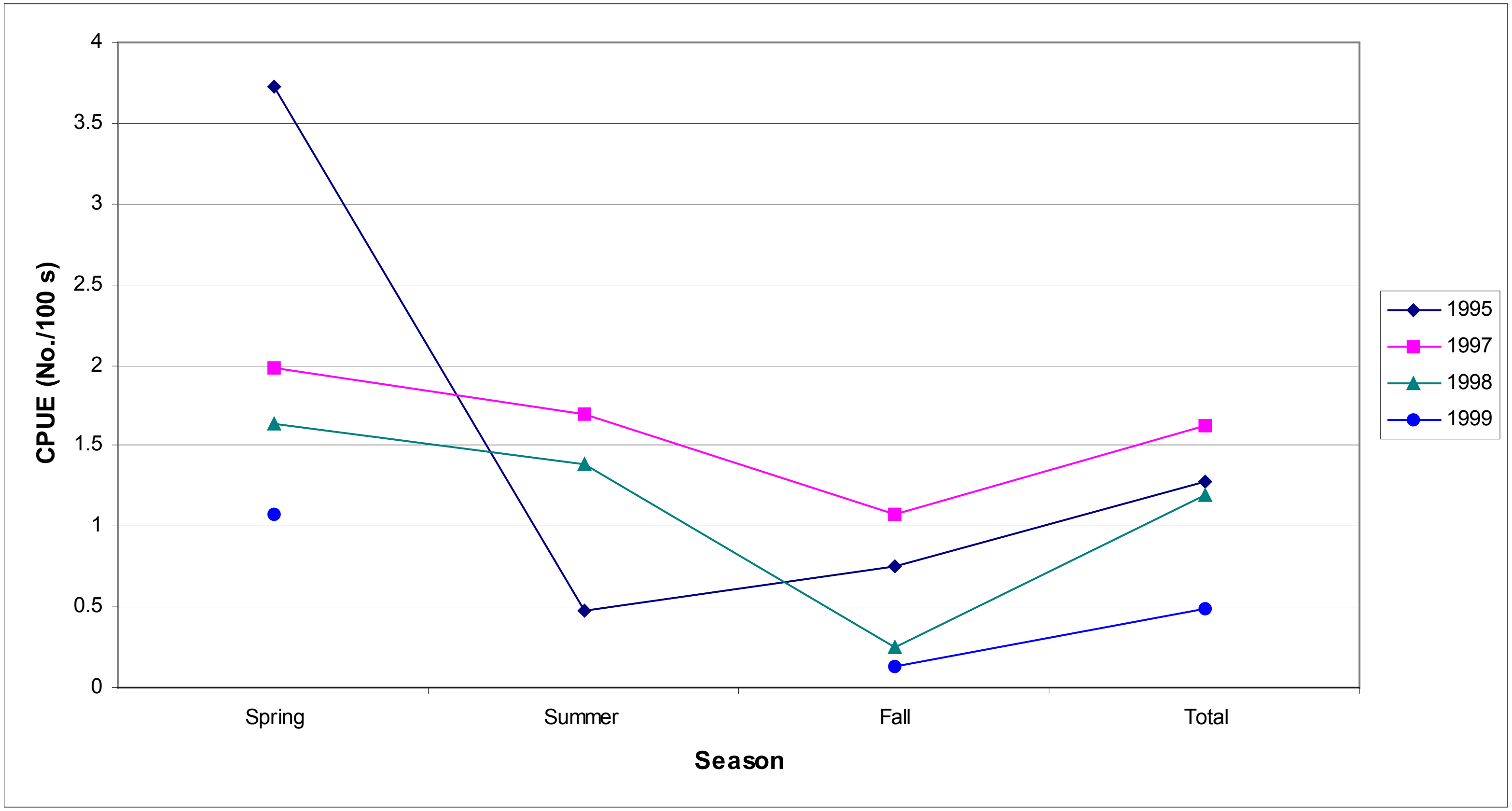
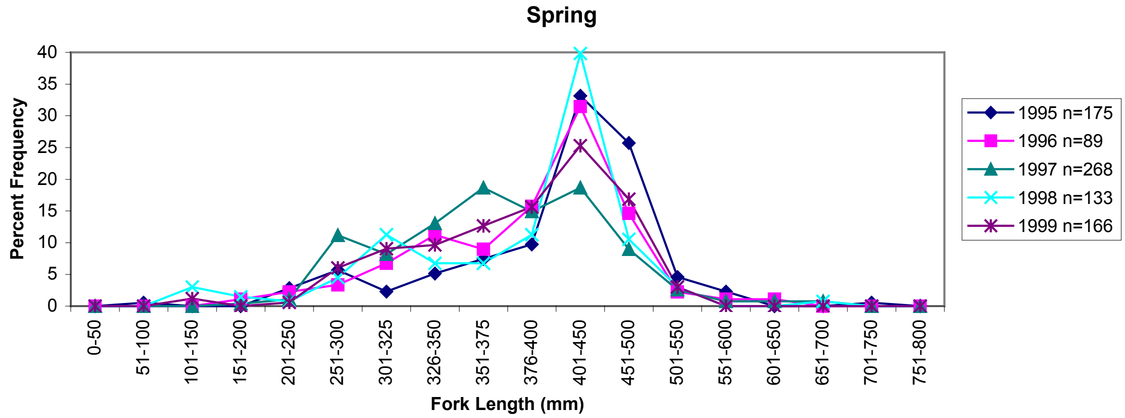
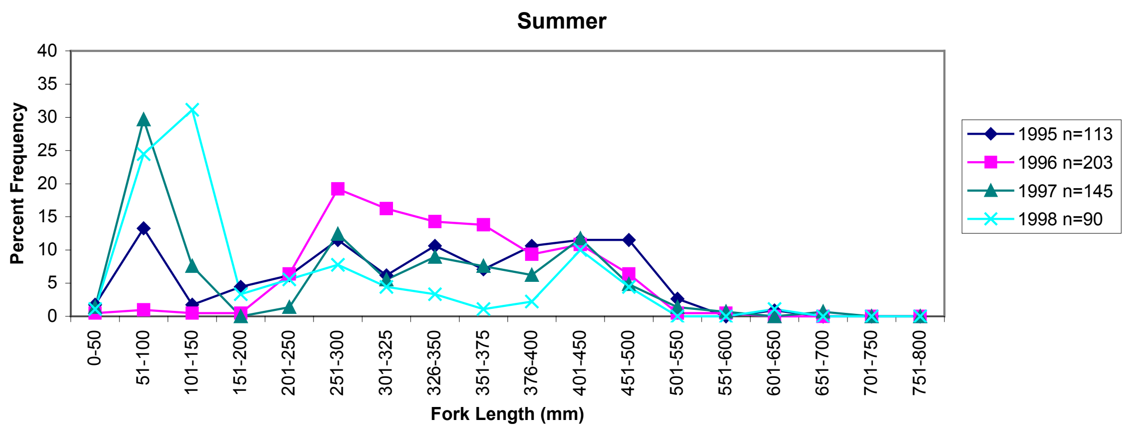


Figure 7.11 Length Frequency Distributions for Walleye, Athabasca River Inventories, 1975 to 1999 (1975 data includes combined seasons)





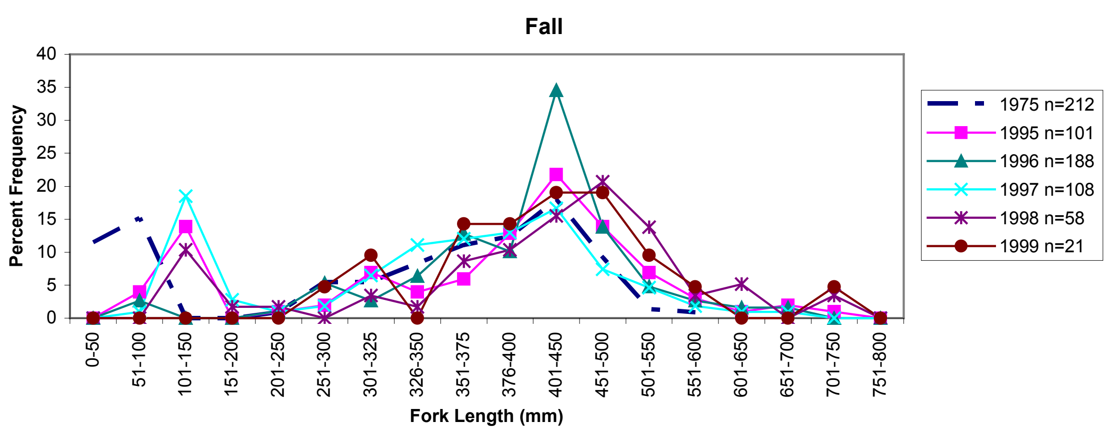


Figure 7.12 Age Frequency Distributions for Walleye, Athabasca River Inventories, 1995 to 1999

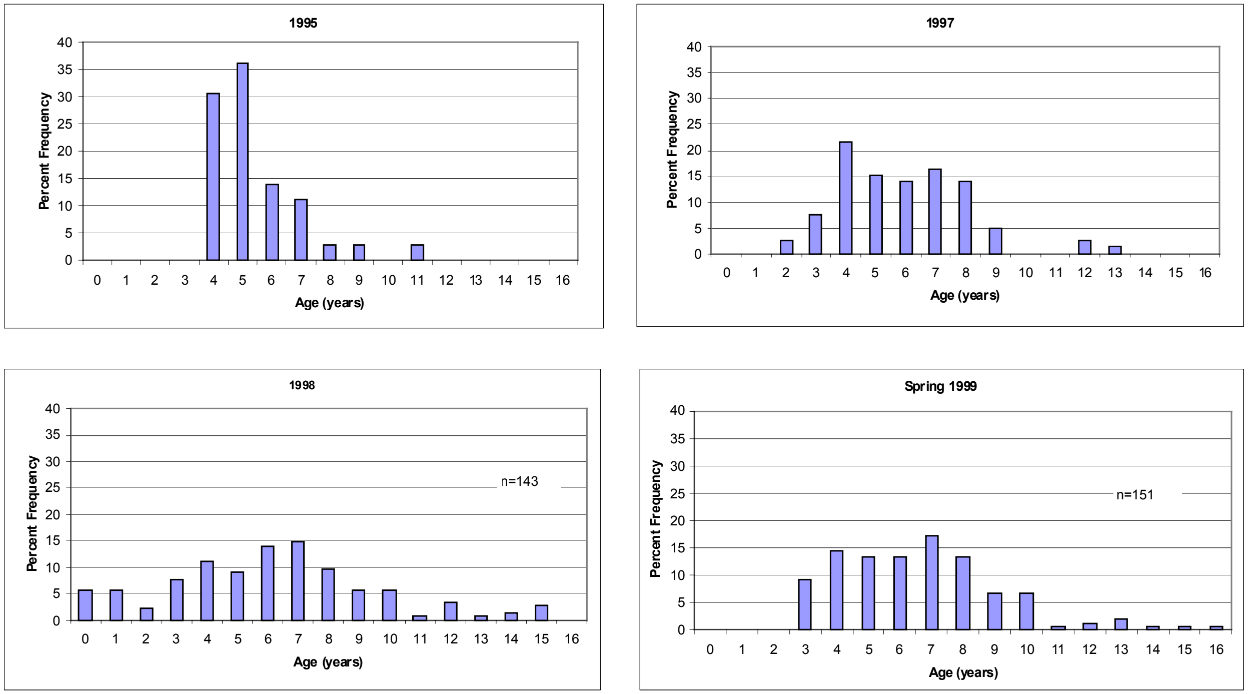
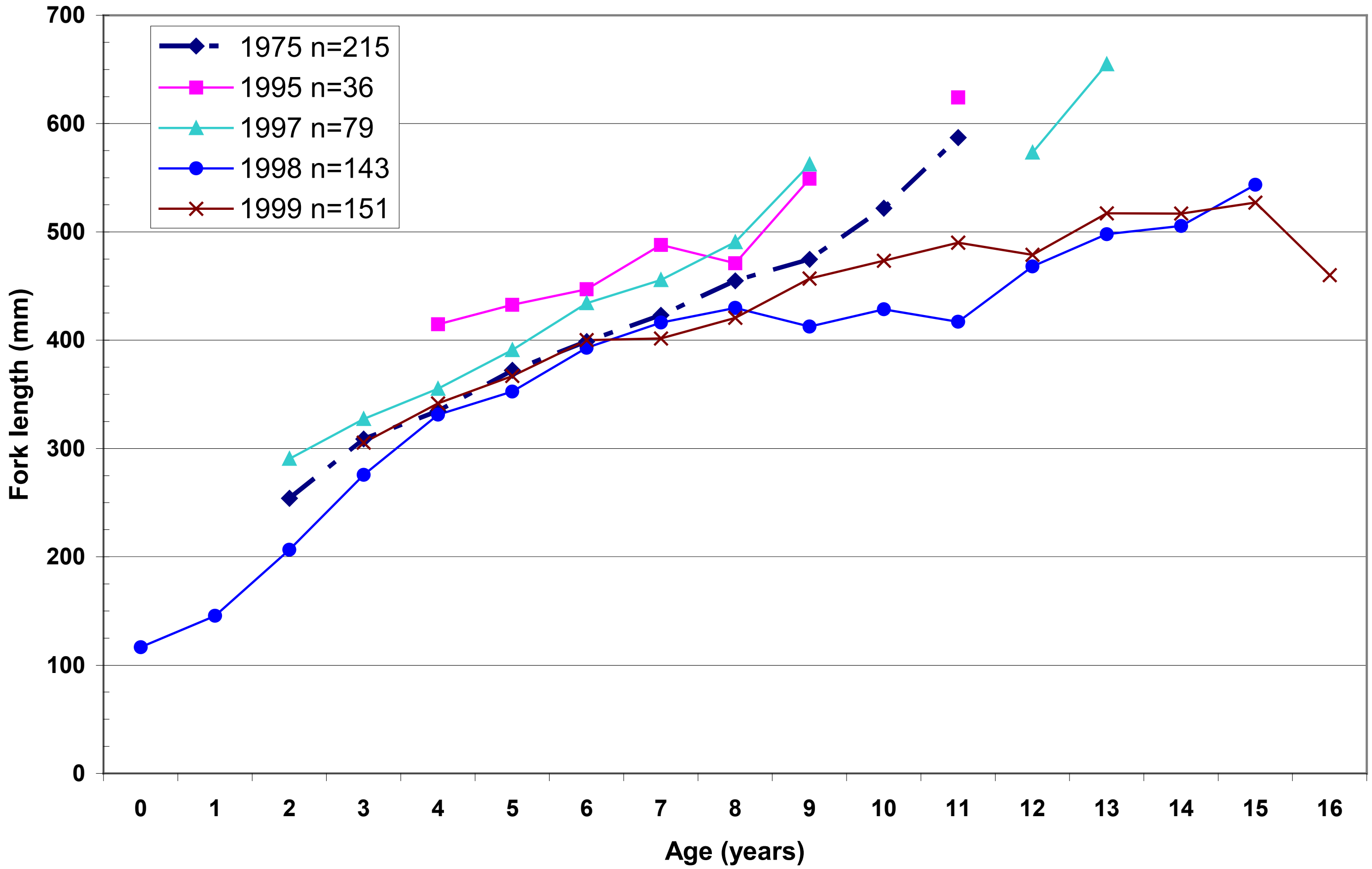
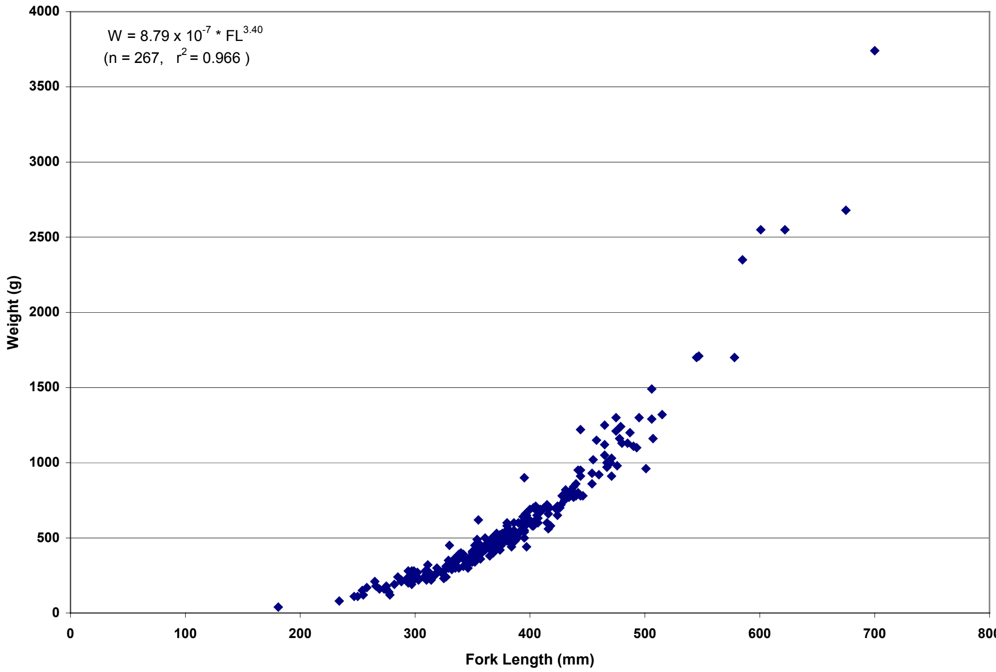


Figure 7.13 Length-at-Age Relationships for Walleye, Athabasca River Inventories, 1975 to 1999



Walleye have a tight length-weight relationship and relatively good sample sizes for the various years. The sample size in spring 1997 was the largest and was used as the example relationship for walleye (Figure 7.14). The statistical comparisons of length-weight relationships by season for the five years of available data are summarized in Appendix I. In most years there was a significant difference in the length-weight relationship between seasons (p>0.05).

Figure 7.14 Example Plot of the Length-Weight Relationship for Walleye, Athabasca River Inventory, Spring 1997



In all seasons, the numbers of large walleye (>400 mm in length) caught were adequate to provide a good evaluation of condition factors among years. The data indicate there does not appear to be any systematic change in the seasonal condition factor among years (Figure 7.15). Although there were significant differences among years in the spring and fall data (Appendix I), there is no trend over time in any season.

Goldeye

CPUE for all available years for goldeye indicates considerable variability in the relative abundance of this species (Figure 7.16). The spring, summer and fall CPUE were variable between years, particularly for the fall due to a high CPUE in 1997. As a result, the total CPUE also varied between years; it was higher in 1997 and 1998 and lower in 1995 and 1999.

Figure 7.15 Comparison of Condition Factors for Walleye, Athabasca River Inventories, 1995 to 1999 (with n value)

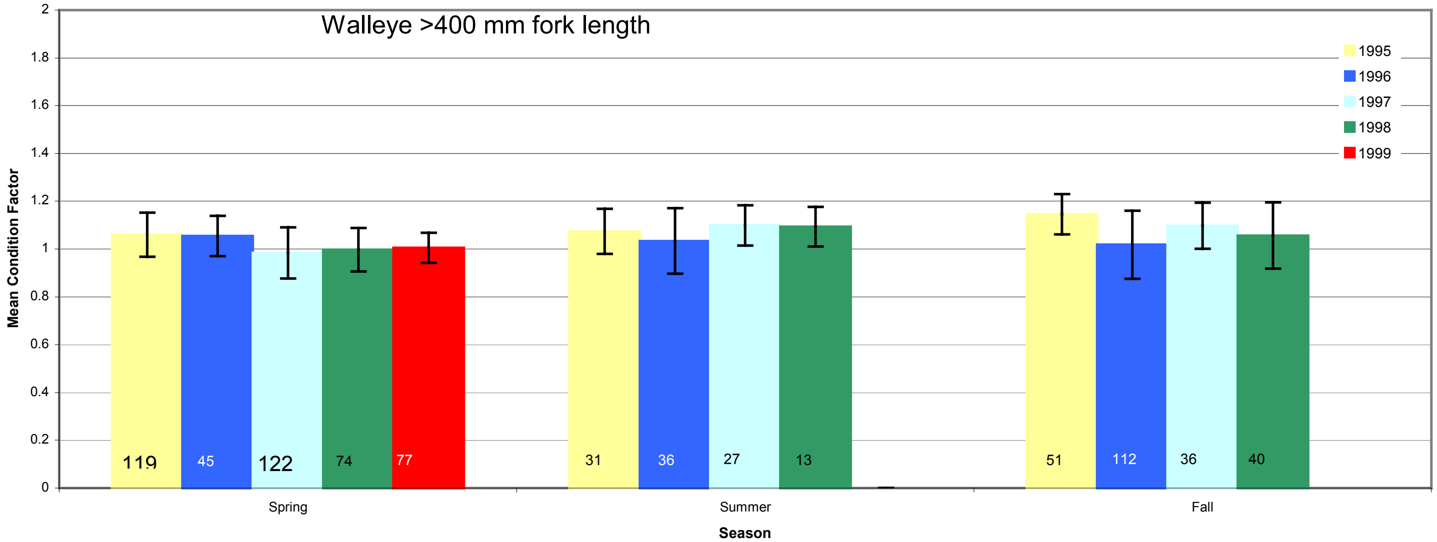
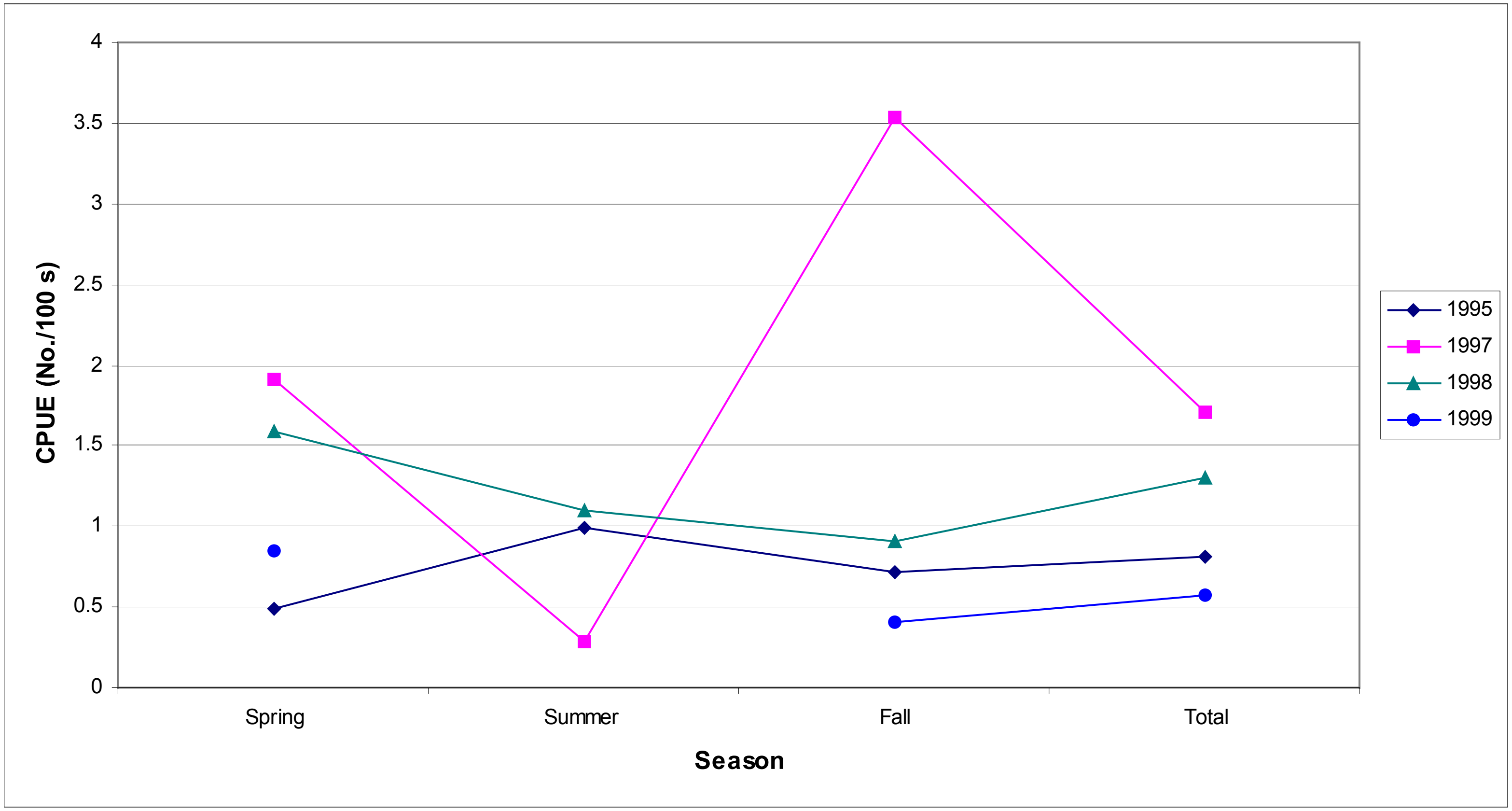


Figure 7.16 Catch-Per-Unit-Effort for Goldeye, Athabasca River Inventories, 1995 to 1999



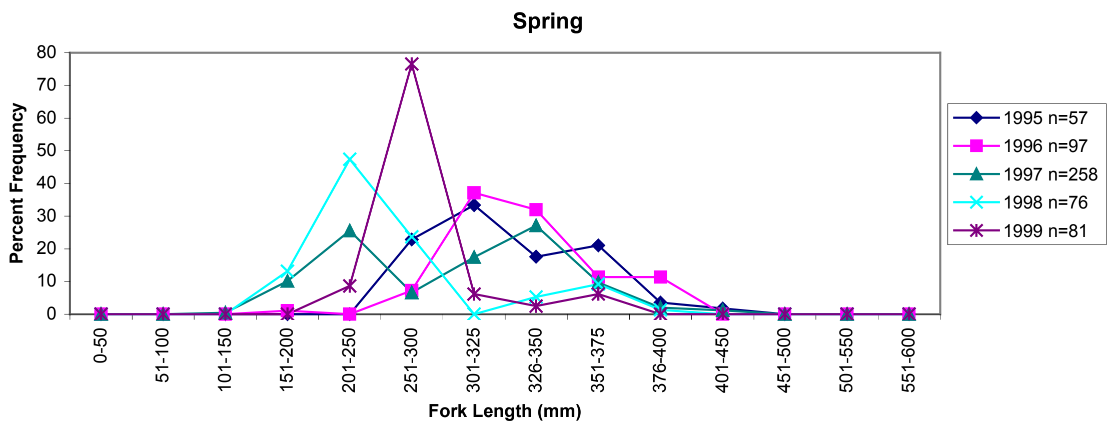
Length frequency distributions for goldeye are presented in Figure 7.17 by season and year. The proportion of the population in each size class varied in any given year, particularly in the spring and fall. The number of fish and size classes present each year varied, particularly for the smaller fish in the population. Although some variability is apparent in the data, there are no specific trends with respect to an increase or decrease over time in the size classes that are dominant. There is a slight tendency for smaller fish to make up a larger portion of the population in 1997 and 1998 compared to the other years, but this was not consistent between seasons and did not continue into 1999. The statistical comparison of length frequency distributions indicated that the differences between years were not significant in any season (Appendix I).

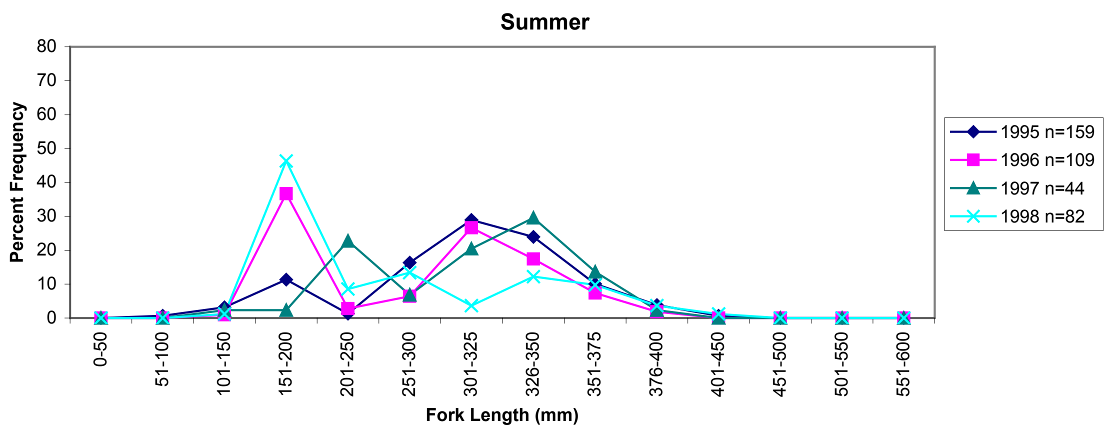
The age of goldeye in the Athabasca River was different among years (Figure 7.18). The data from 1997 and 1999 are somewhat similar, with older fish from five to seven years of age dominating the catch. In contrast, fish three years old or less were most abundant in 1998. In 1995, the age distribution was more evenly spread over the various age classes.

The length-at-age relationships for goldeye (Figure 7.19) show limited variability in growth. The relationships were very similar for 1995, 1997 and 1998. Some differences were seen comparing the 1975 and 1999 data to the other years. Size-at-age was smaller for fish from five to seven years old in 1975 and 1999, but the overall differences were not significant ($p>0.05$). The generalized von Bertalanffy growth curve for all age data combined is presented in Appendix II.

Goldeye have a relatively strong length-weight relationship and relatively good sample sizes (Appendix I). There appears to be a stronger relationship (coefficient of determination) in summer and particularly in fall compared to the spring data. This may be due to the extended spring spawning season resulting in higher weight-at-length variability at that time. The sample for spring 1997 was the largest and was used as the sample relationship for the goldeye (Figure 7.20). The statistical comparisons of length-weight relationships by season for the five years of available data are summarized in Appendix I.

Figure 7.17 Length Frequency Distributions for Goldeye, Athabasca River Inventories, 1975 to 1999 (1975 data includes combined seasons)





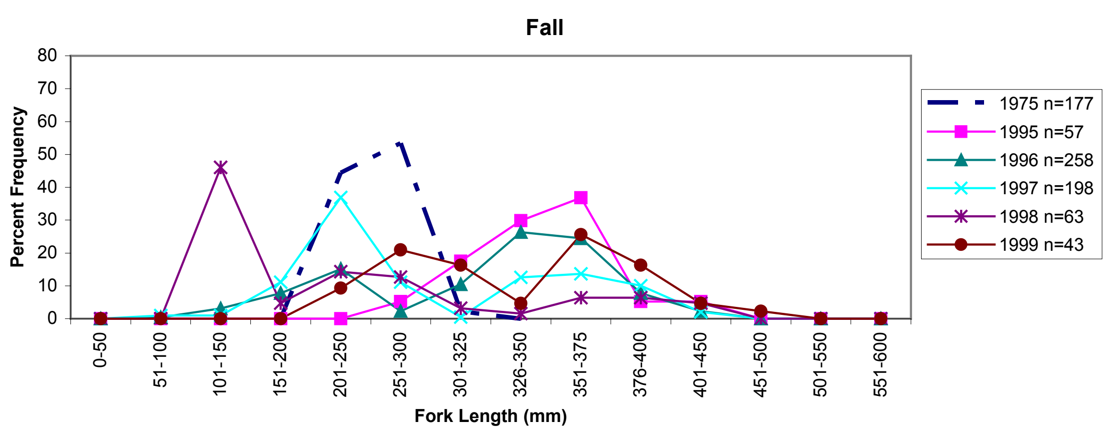


Figure 7.18 Age Frequency Distributions for Goldeye, Athabasca River Inventories, 1995 to 1999

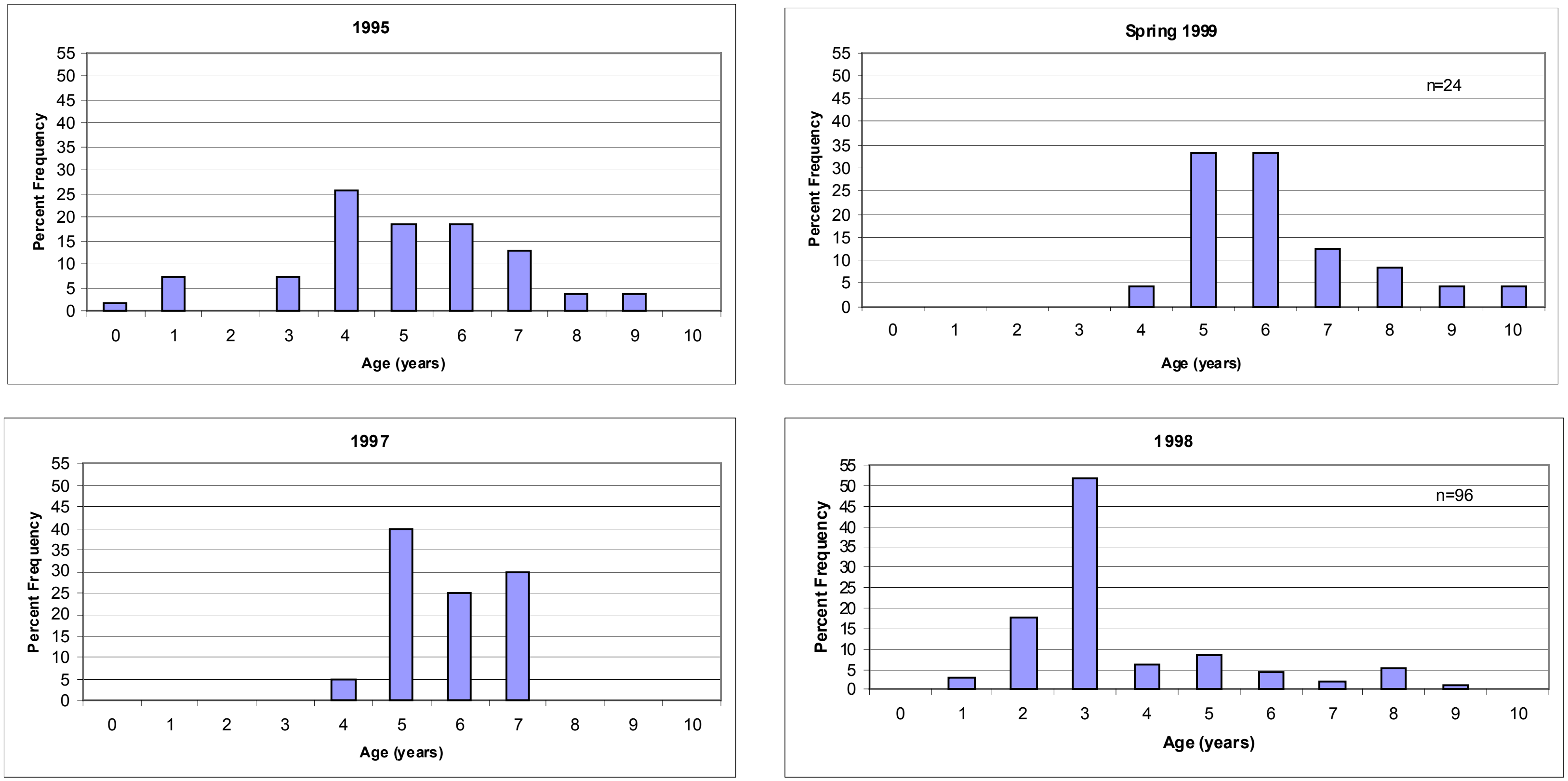


Figure 7.19 Length-at-Age Relationships for Goldeye, Athabasca River Inventories, 1975 to 1999

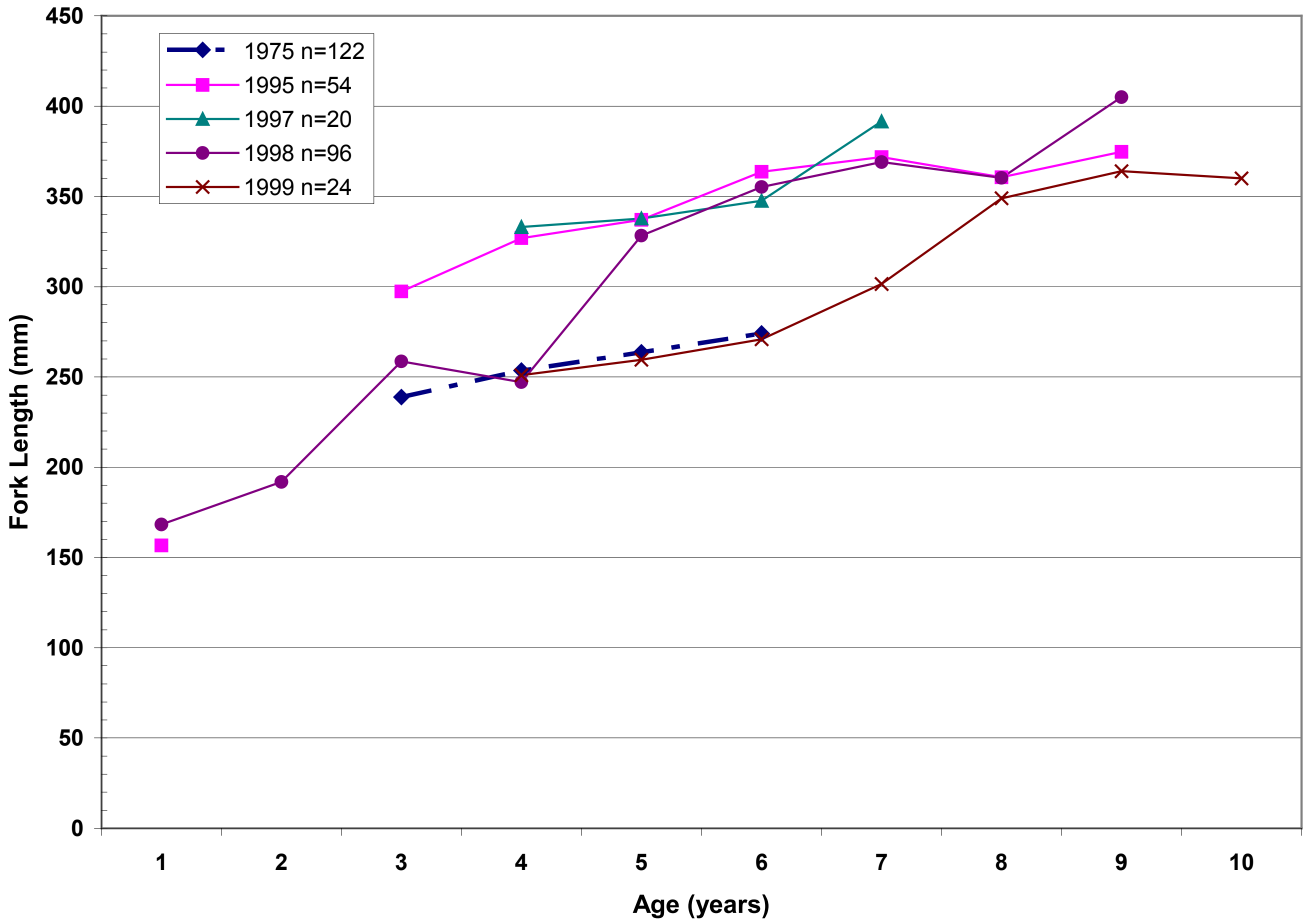
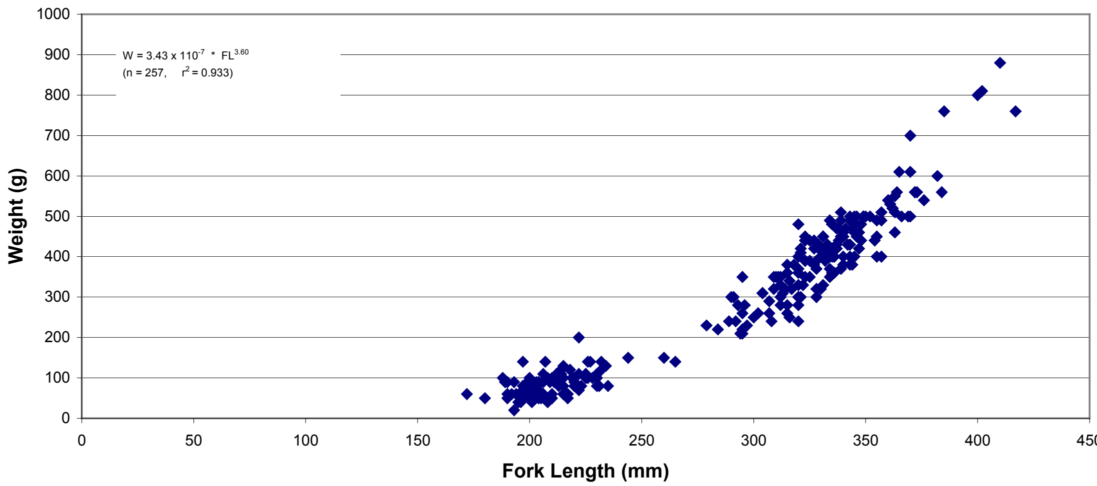


Figure 7.20 Example Plot of the Length-Weight Relationship for Goldeye, Athabasca River Inventory, Spring 1997



The numbers of large goldeye (>300 mm in length) caught in all seasons were adequate for condition factor analysis. There are significant differences among years in all seasons (Appendix I), indicating condition factor is variable for this species. However, there does not appear to be any systematic change in the condition factor over time (Figure 7.21) as there is no trend in any season.

Northern Pike

For northern pike, the CPUE (Figure 7.22) was variable among seasons and years. However, this variability is small as CPUE was low in all seasons and years (i.e., <0.36 fish/100 s). In 1995 and 1999, the CPUE was highest in spring while in 1997 and 1998 the CPUE was highest in summer. CPUE was lowest in the fall for this species. Between-year differences were fairly consistent, with CPUE in 1997 and 1999 generally higher than 1995 and 1998 for all seasons.

The length frequency distributions for northern pike indicate that a wide range of size classes were present for this species (Figure 7.23). Length was variable among seasons and years. In particular, the number of smaller fish present in the inventories varied, with these smaller length classes missing in some years. There is a small tendency for peaks in the distribution in the 400 to 550 mm size classes. Although variability is apparent in the data, there are no specific trends with respect to an increase or decrease over time in the size classes that are dominant. The statistical comparison of length frequency distributions indicate that the differences between years were not significant in any season (Appendix I).

Figure 7.21 Comparison of Condition Factors for Goldeye, Athabasca River Inventories, 1995 to 1999 (with n value)

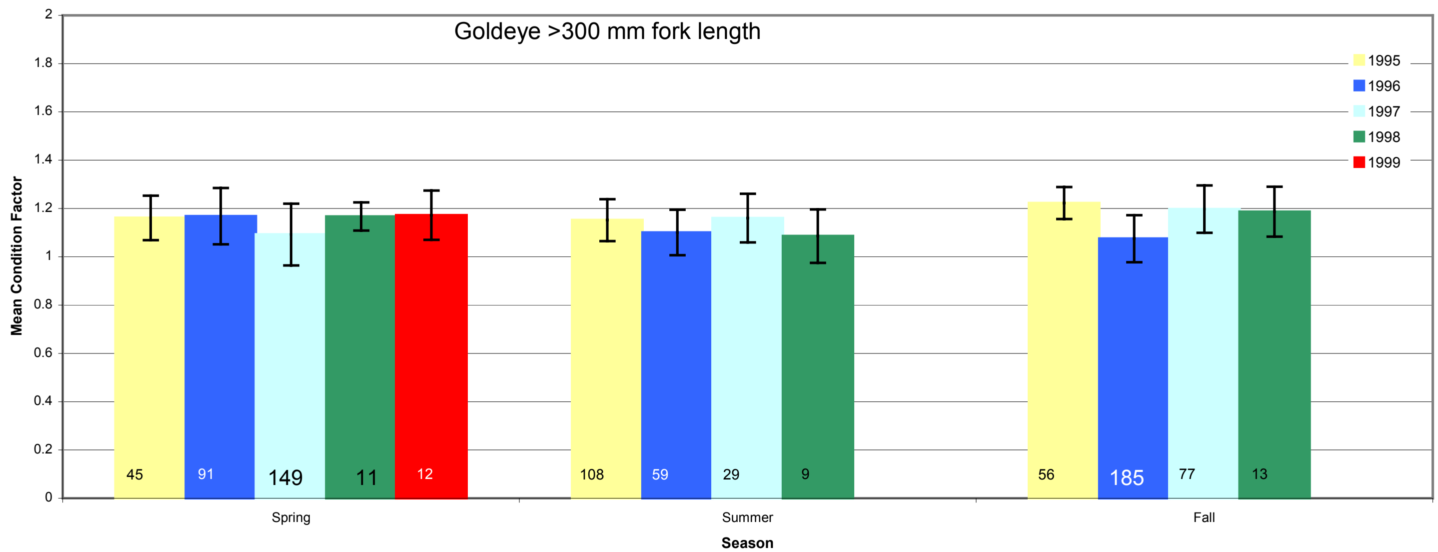


Figure 7.22 Catch-Per-Unit-Effort for Northern Pike, Athabasca River Inventories, 1995 to 1999

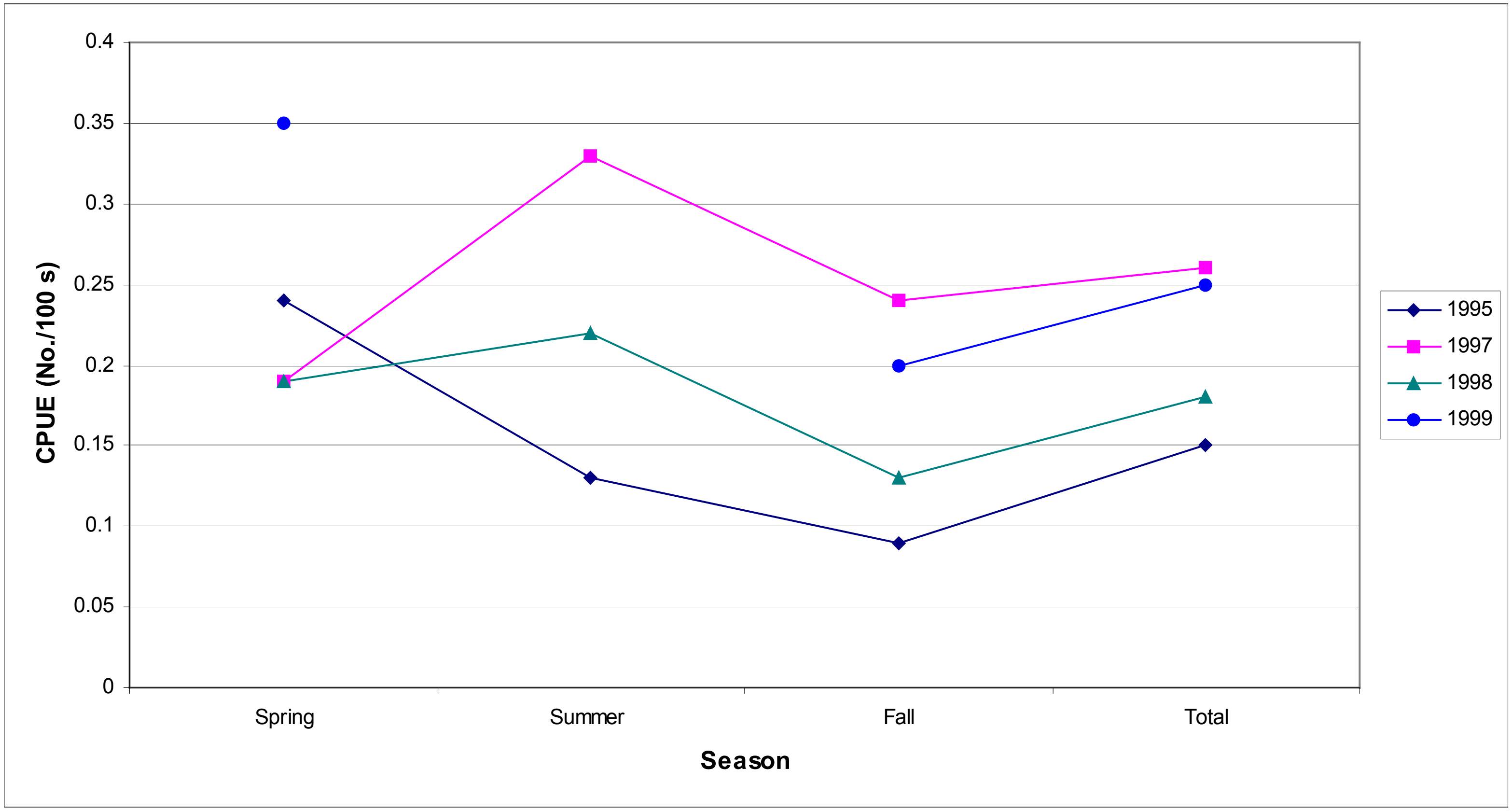
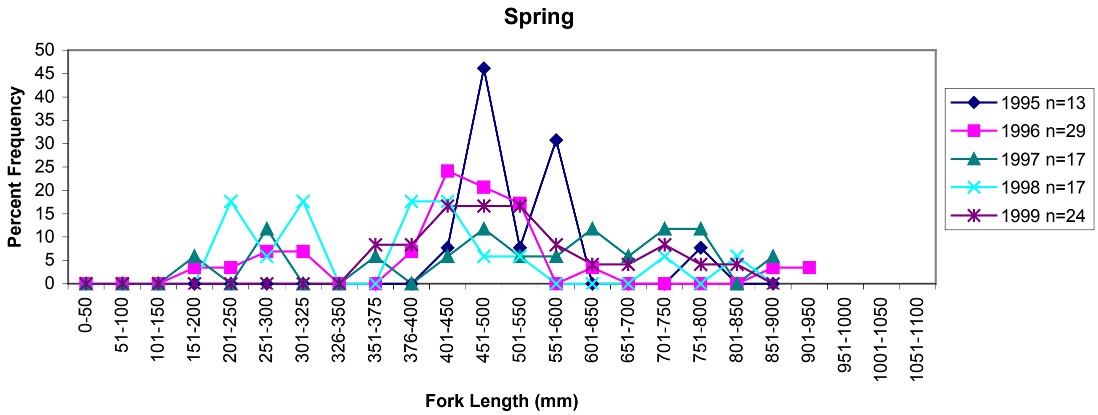
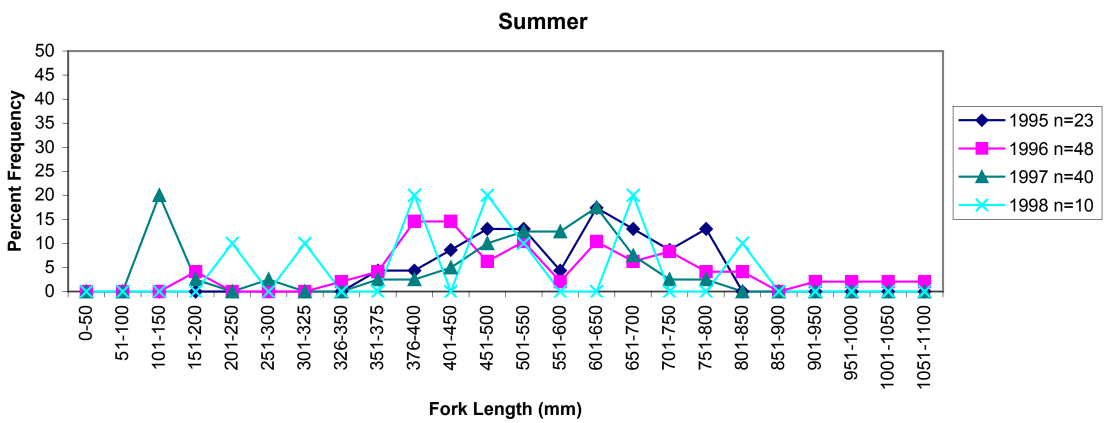
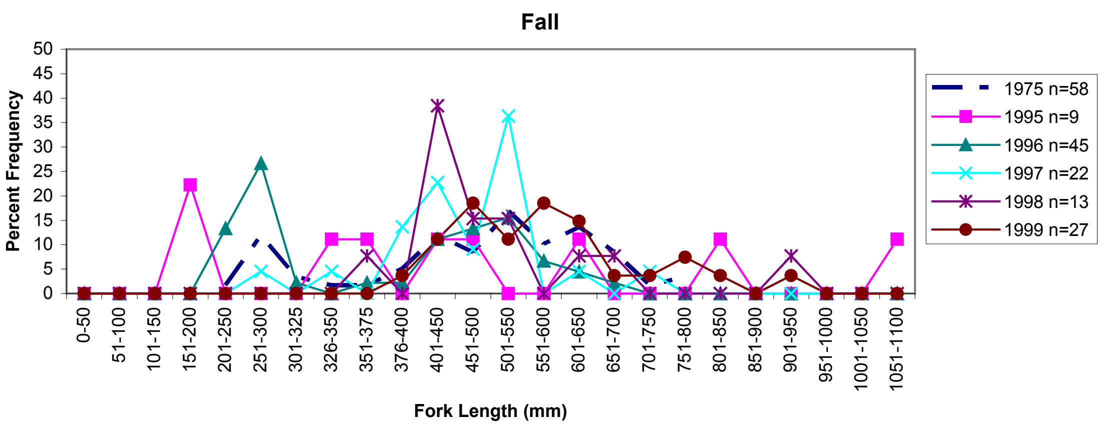


Figure 7.23 Length Frequency Distributions for Northern Pike, Athabasca River Inventories, 1975 to 1999 (1975 data includes combined seasons)







Although sample sizes were small, often in the order of a dozen or fewer fish, the length-weight regressions for northern pike are presented in Appendix 1. There was no significant difference ($p>0.05$) in length-weight relationships between seasons within years except spring/fall 1997 (Appendix I). The sample for summer 1996 was the largest and was used as a sample relationship for northern pike (Figure 7.24).

In all seasons, the numbers of larger northern pike (>400 mm in length) were low; however, there does not appear to be any systematic change in the seasonal condition factor between years (Figure 7.25). Although there are significant differences among years in the fall data (Appendix I), there is no trend over time in any season.

A small amount of ageing data has been collected for northern pike during inventory studies. The sample sizes in any given year were too small to conduct separate length-at-age analyses. The data were combined for all years to produce a general growth model for the region (Appendix II).

Figure 7.24 Example Plot of the Length-Weight Relationship for Northern pike, Athabasca River Inventory, Summer 1996

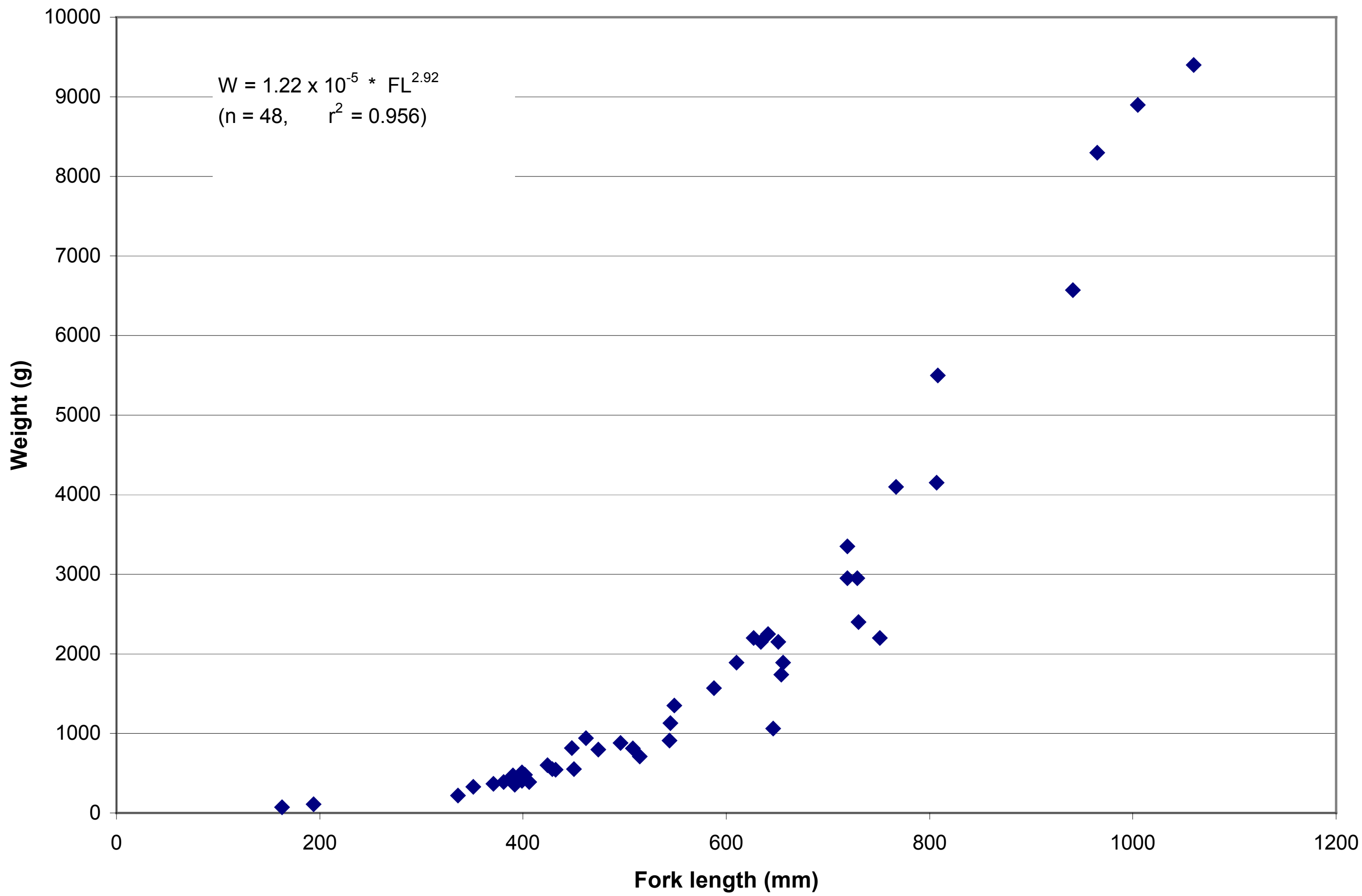
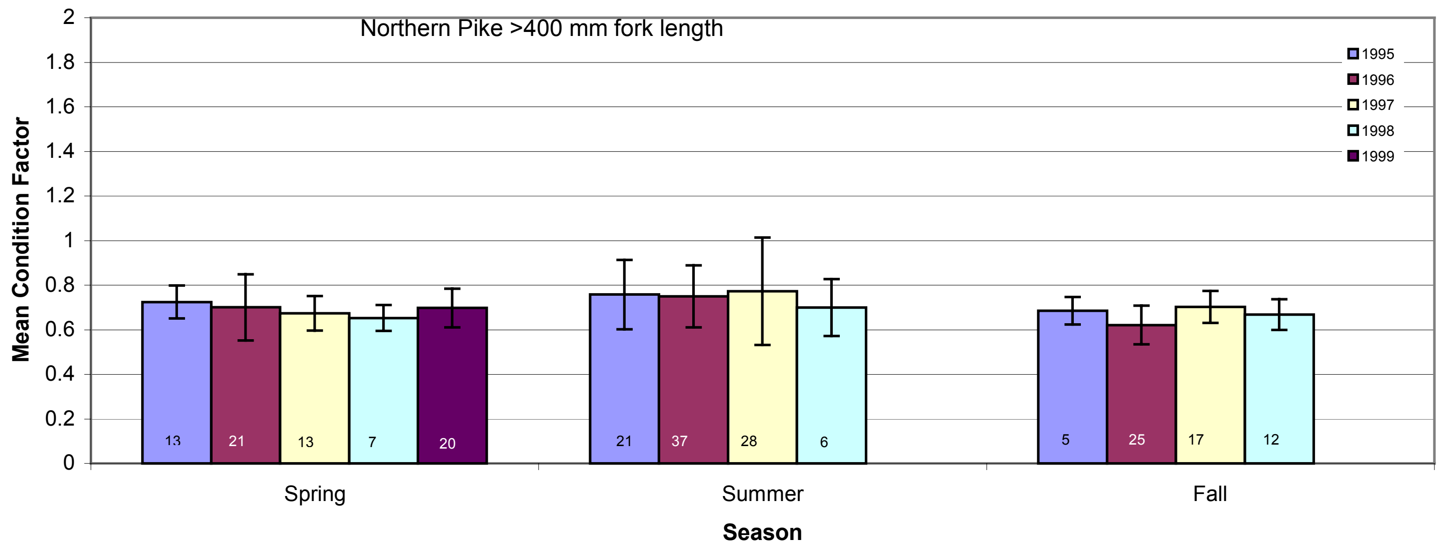


Figure 7.25 Comparison of Condition Factors for Northern Pike, Athabasca River Inventories, 1995 to 1999 (with n value)



Longnose Sucker

During the spring, CPUE for longnose sucker was high in 1997 and 1998 and low in 1995 and 1999 (Figure 7.26). This difference may be due to the time when sampling was conducted relative to the spawning period for this species. Longnose sucker in the region undergo a spring migration to spawning sites in the mainstem Athabasca River above the Oil Sands Region (i.e., at the rapids upstream of Fort McMurray) or in tributary watercourses (Tripp and McCart 1979). Sampling during the migration would capture more of this species than sampling prior to or after the run had moved through the Oil Sands Region. In contrast to the spring data, the summer CPUE is extremely similar among years. The fall CPUE is also similar in most years, with the exception of 1995.

The length frequency distributions for longnose sucker (Figure 7.27) are variable among seasons, with larger size classes dominating in the spring and fall. The proportion of the smaller size classes increases in the summer. The exception was spring 1998 when smaller size classes were dominant. The proportion of the population in each size class was highly variable between years but did not show any specific trends over time. The statistical comparison of length frequency distributions indicated that the differences between years were not significant in any season (Appendix I).

A wide range of age classes was present for longnose sucker in the study area (Figure 7.28). The sample size was limited for 1995, but the remaining years show fish ages from one to 18 years. The age distribution from 1999 was limited to older fish (i.e., five years or older), but this is likely due to sampling occurring only in the spring during spawning.

The length-at-age relationships for longnose sucker (Figure 7.29) show a small amount of variability between years, with fish captured in 1997 generally showing the highest growth rates and fish from 1975 and 1998 showing the lowest growth rates. Statistical analysis (ANCOVA) indicates that there were no significant differences between the years ($p>0.05$). The generalized von Bertalanffy growth curve for all age data combined is presented in Appendix II.

Figure 7.26 Catch-Per-Unit-Effort for Longnose Sucker, Athabasca River Inventories, 1995 to 1999

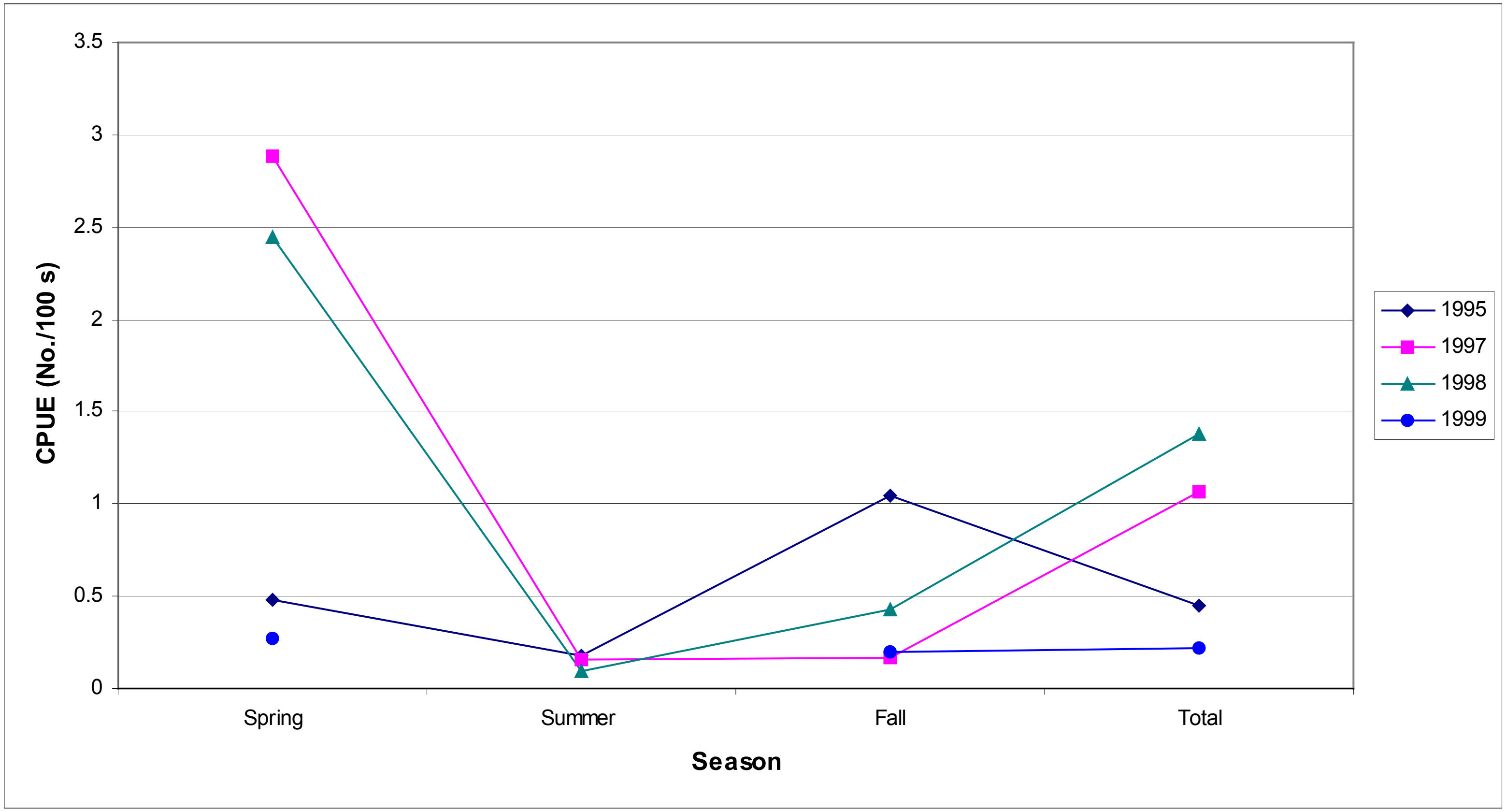


Figure 7.27 Length Frequency Distributions for Longnose Sucker, Athabasca River Inventories, 1975 to 1999 (1975 data includes combined seasons)

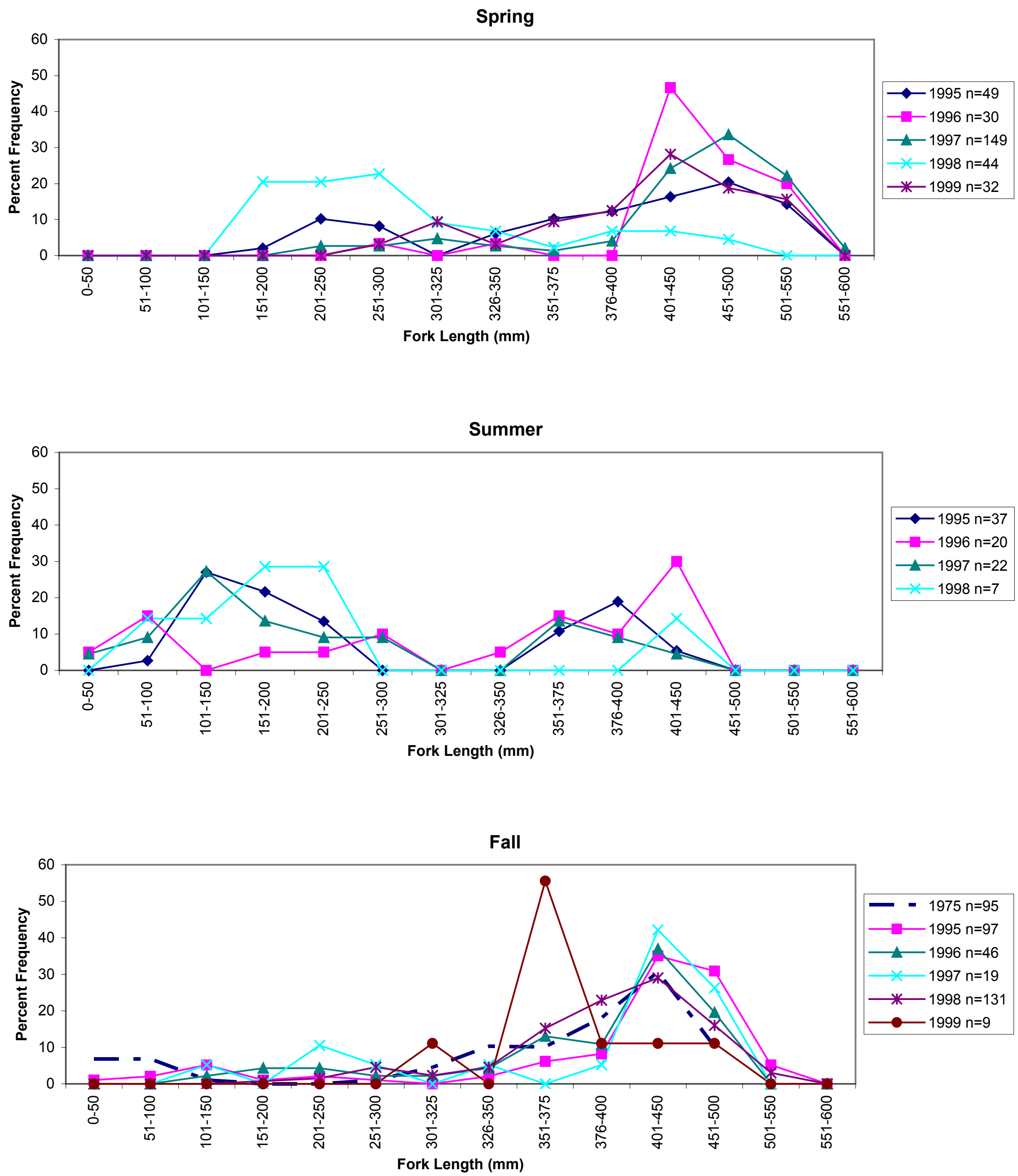


Figure 7.28 Age Frequency Distributions for Longnose Sucker, Athabasca River inventories, 1995 to 1999

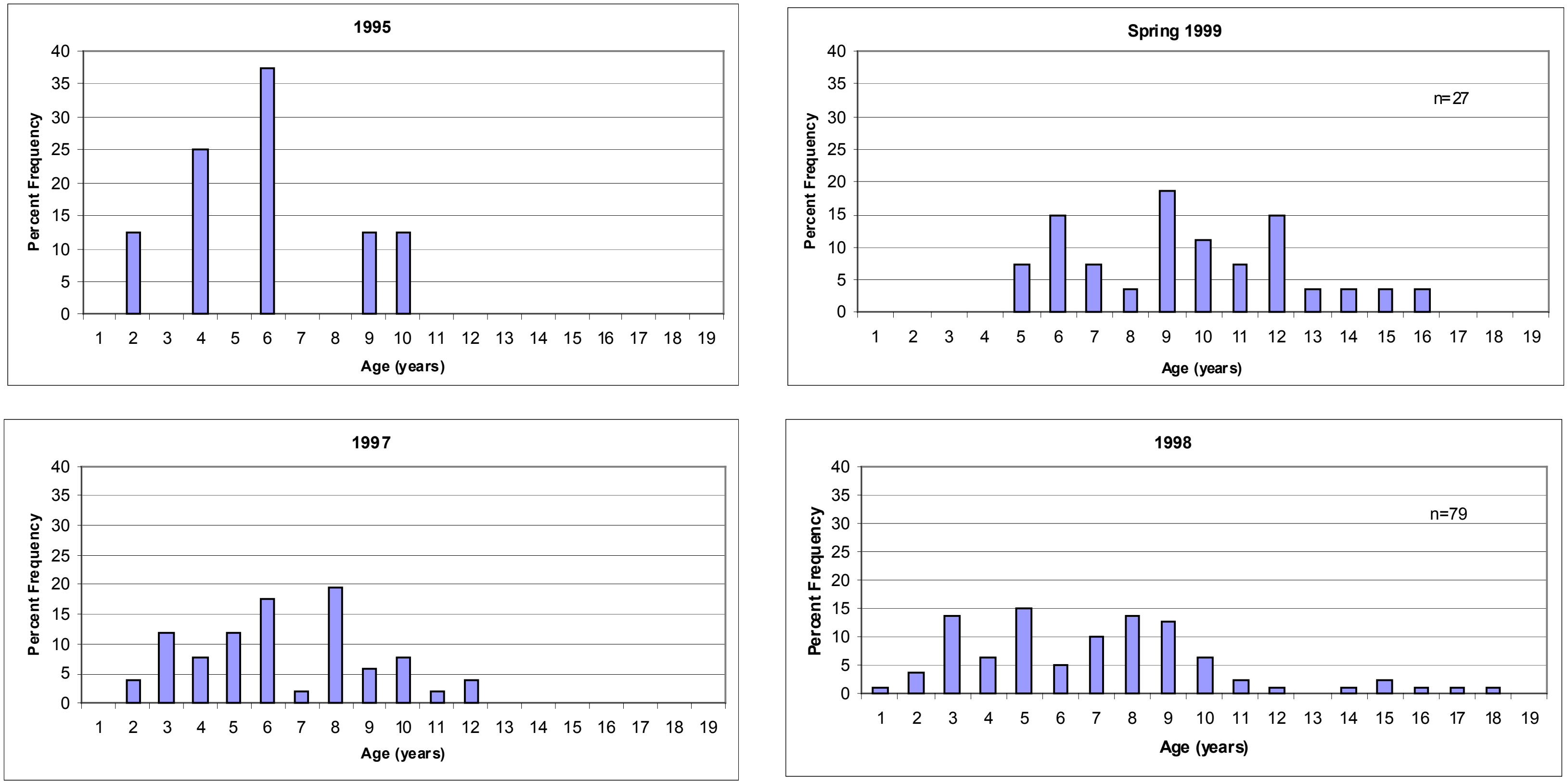
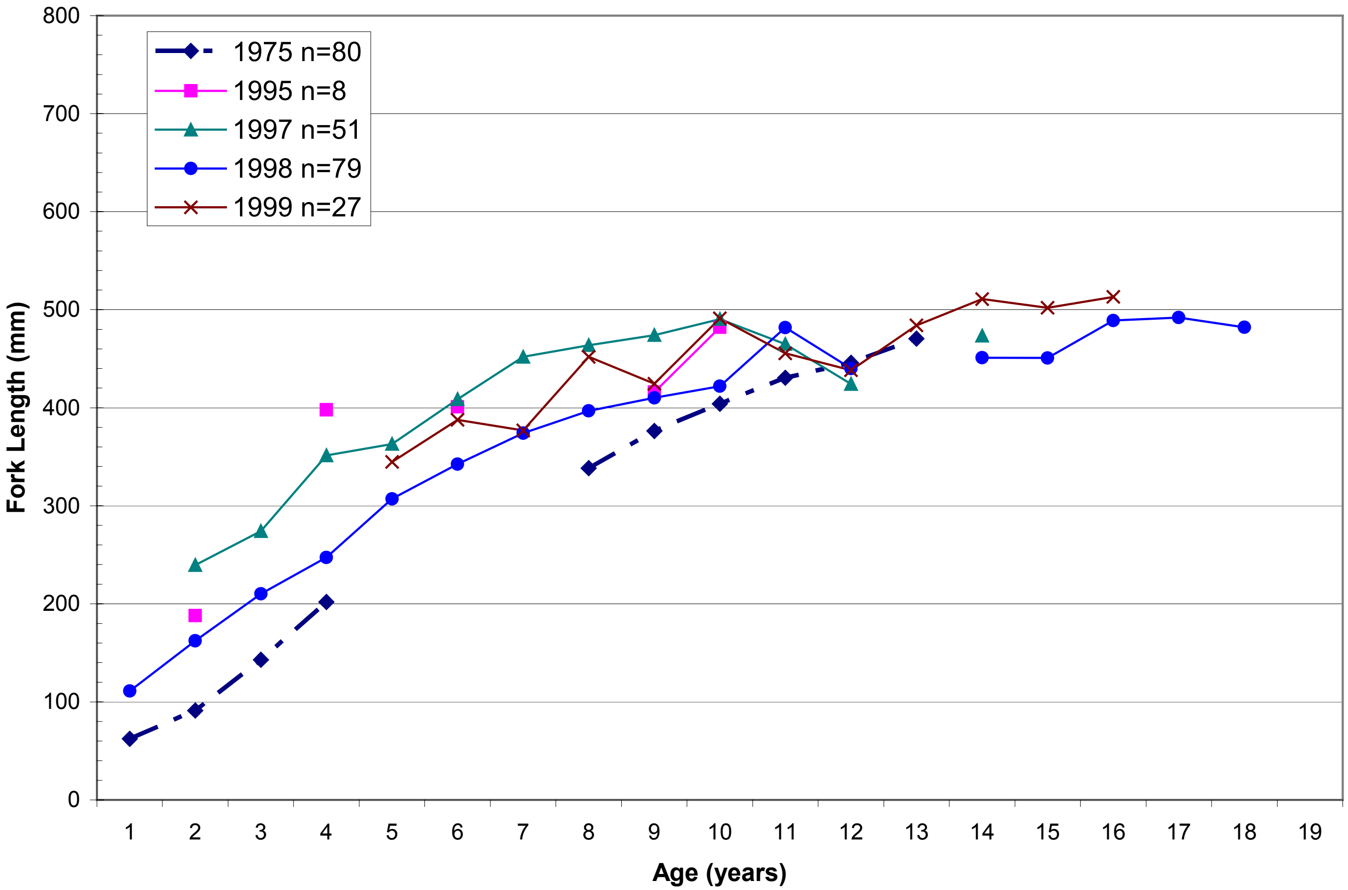


Figure 7.29 Length-at-Age Relationships for Longnose Sucker, Athabasca River Inventories, 1975 to 1999



The length-weight relationships for longnose sucker by season for the five years of available data are in Appendix I. There is no significant difference ($p>0.05$) in the length-weight regressions among most seasons within a year (Appendix I). The sample for spring 1997 was the largest and was used as a sample relationship for the longnose sucker (Figure 7.30).

In all seasons, the numbers of larger longnose sucker (>350 mm in length) caught were relatively low (except spring 1997 and fall 1998). Significant differences in condition factor occurred among years in the spring and fall (Appendix I), but there were no trends over time in either of these seasons. The summer data showed a decline in condition factor over time, but included small sample sizes and the trend was not apparent in other seasons (Figure 7.31).

Figure 7.30 Example Plot of the Length-Weight Relationship for Longnose Sucker, Athabasca River Inventory, Spring 1997

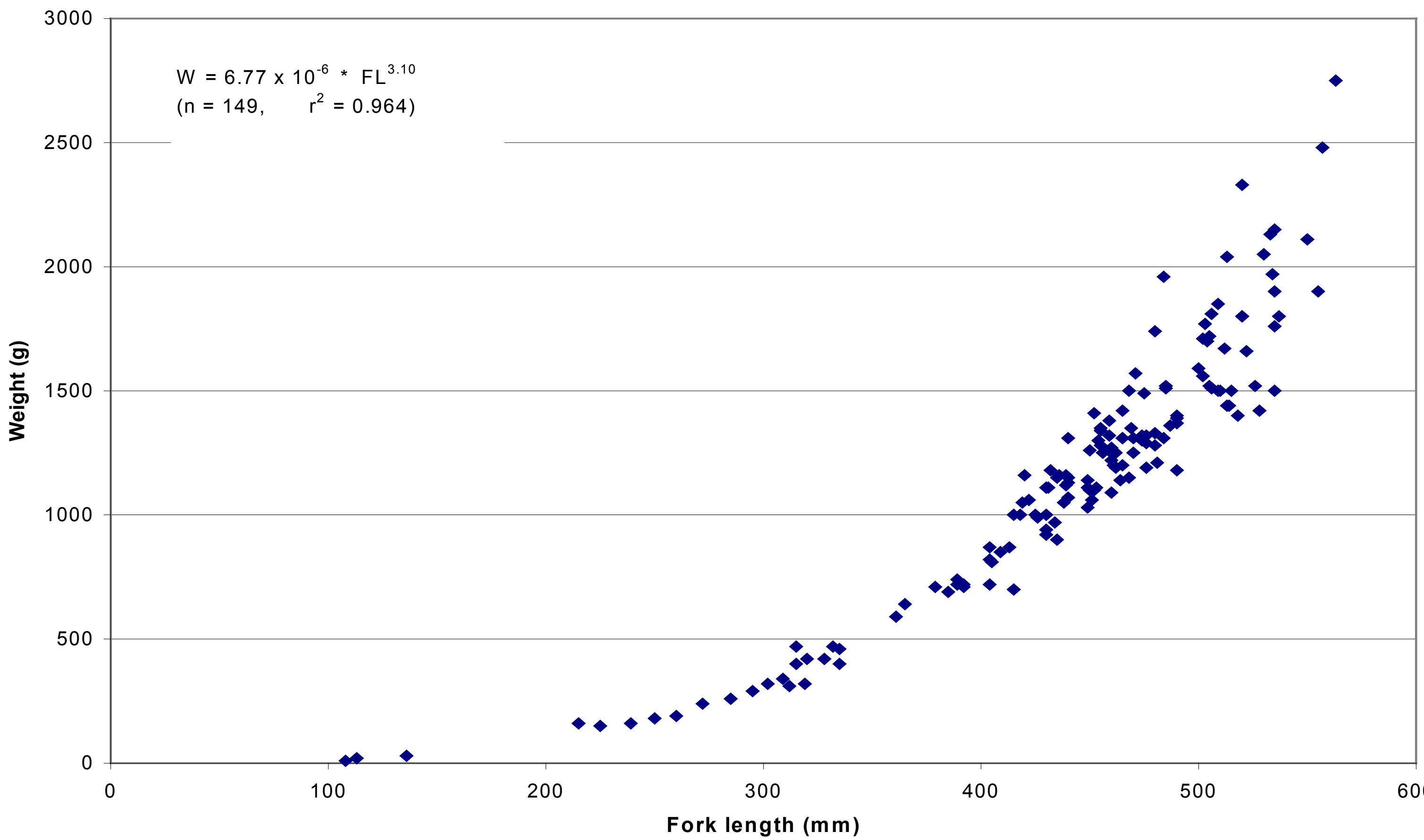
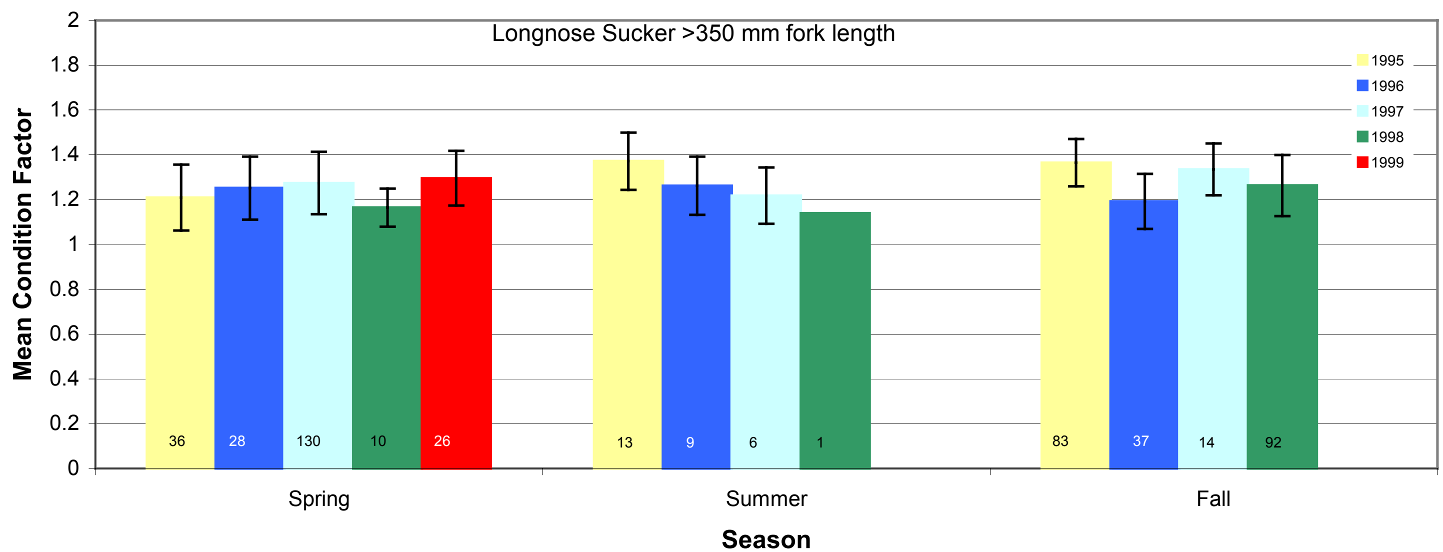


Figure 7.31 Comparison of Condition Factors for Longnose Sucker, Athabasca River Inventories, 1995 to 1999 (with n value)



White Sucker

CPUE for white sucker (Figure 7.32) show a very similar pattern to longnose sucker in that variability between years depends on the season examined. As with longnose sucker, the variability in CPUE for white sucker was high in the spring, low in the summer and moderate in the fall. Spring CPUE values were high in 1997, 1998 and 1999, but lower in 1995. As this species spawns in the spring, catches may reflect whether the sampling was conducted during the spawning migration. CPUE was low in summer in all years but increased in the fall, with this increase being more apparent in 1995 and 1997.

The length frequency distributions for white sucker (Figure 7.33) indicate that the fish in the Athabasca River are mainly larger adults, particularly in the spring and fall. Year-to-year variability is evident but is inconsistent and does not show any trends. There was some tendency for a larger proportion of the population to be bigger fish in the spring in 1997 and 1998 compared to the other years, but this tendency was not apparent in the fall data. The statistical comparison of length frequency distributions indicate that the differences between years are not significant in any season (Appendix I).

Appendix I presents a comparison of white sucker length-weight relationships by season for the five years of available data. There is a significant difference ($p>0.05$) between seasons in some years but not in others. The sample for spring 1997 was the largest and was used as a sample relationship for white sucker (Figure 7.34).

In all seasons, the number of larger white sucker (>300 mm in length) caught was low (except spring 1997); however, there does not appear to be any systematic change in the seasonal condition factor between years (Figure 7.35). When sample sizes are larger in the spring and fall, there are significant differences among years (Appendix I). However, there is no trend in any season.

Figure 7.32 Catch-Per-Unit-Effort for White Sucker, Athabasca River Inventories, 1995 to 1999

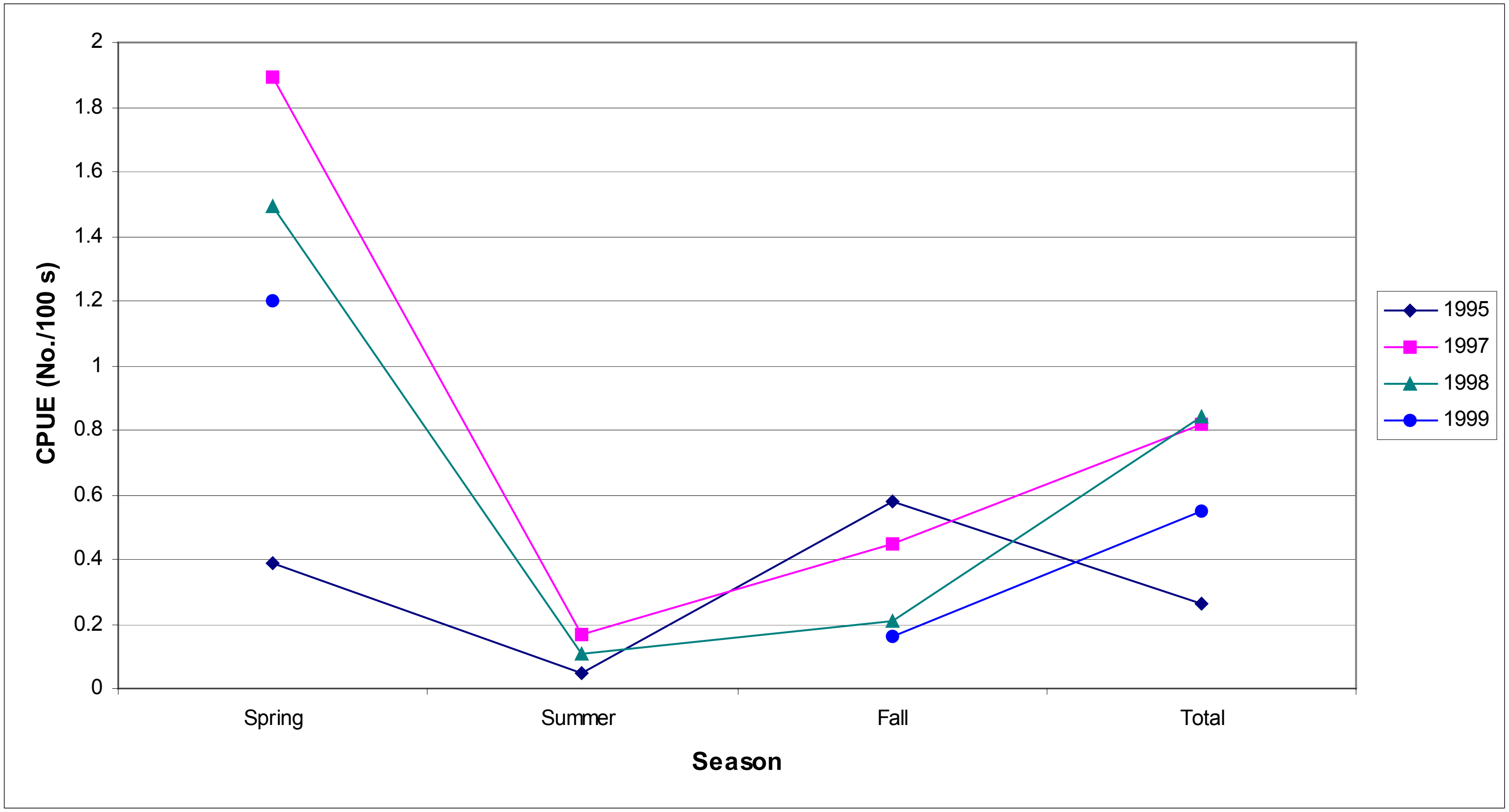
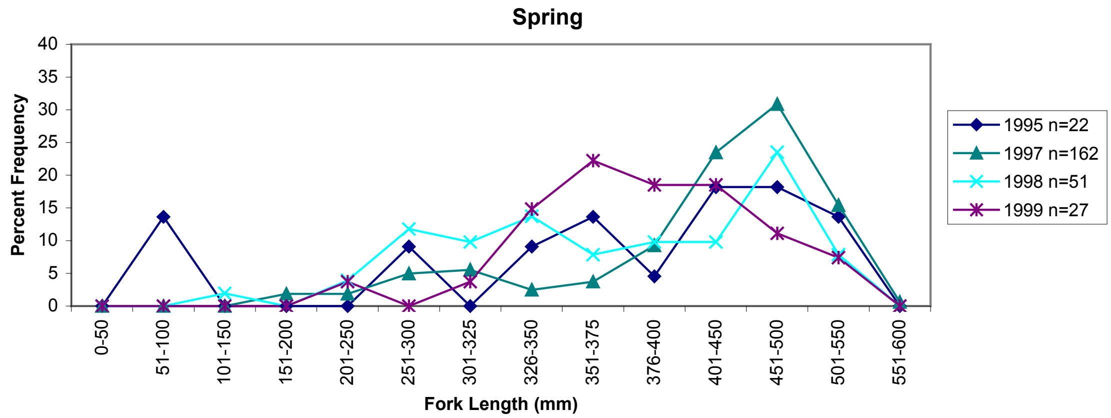
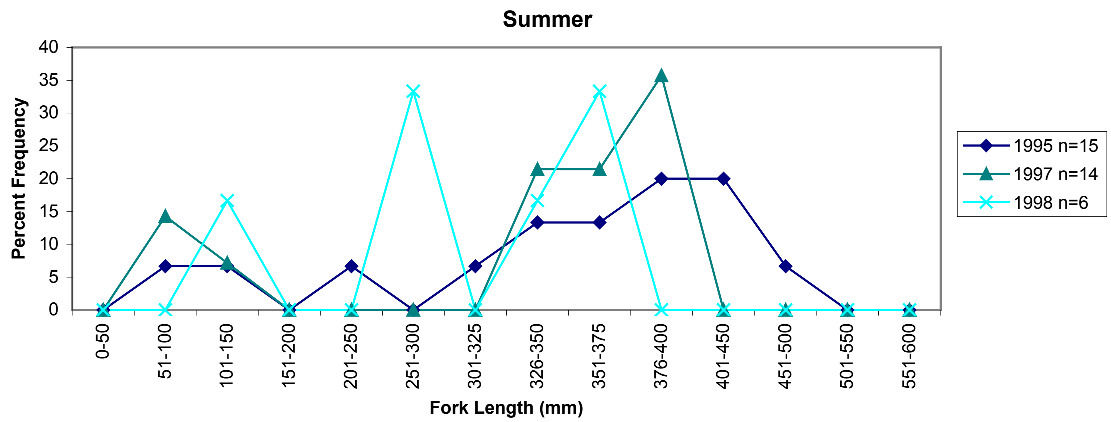


Figure 7.33 Length Frequency Distributions for White Sucker, Athabasca River Inventories, 1995 to 1999





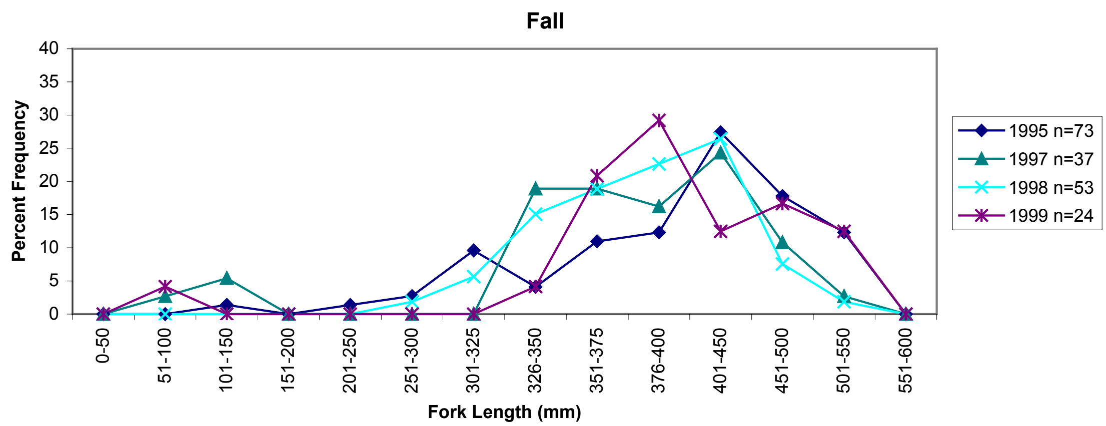


Figure 7.34 Example Plot of the Length-Weight Relationship for White Sucker, Athabasca River Inventory, Spring 1997

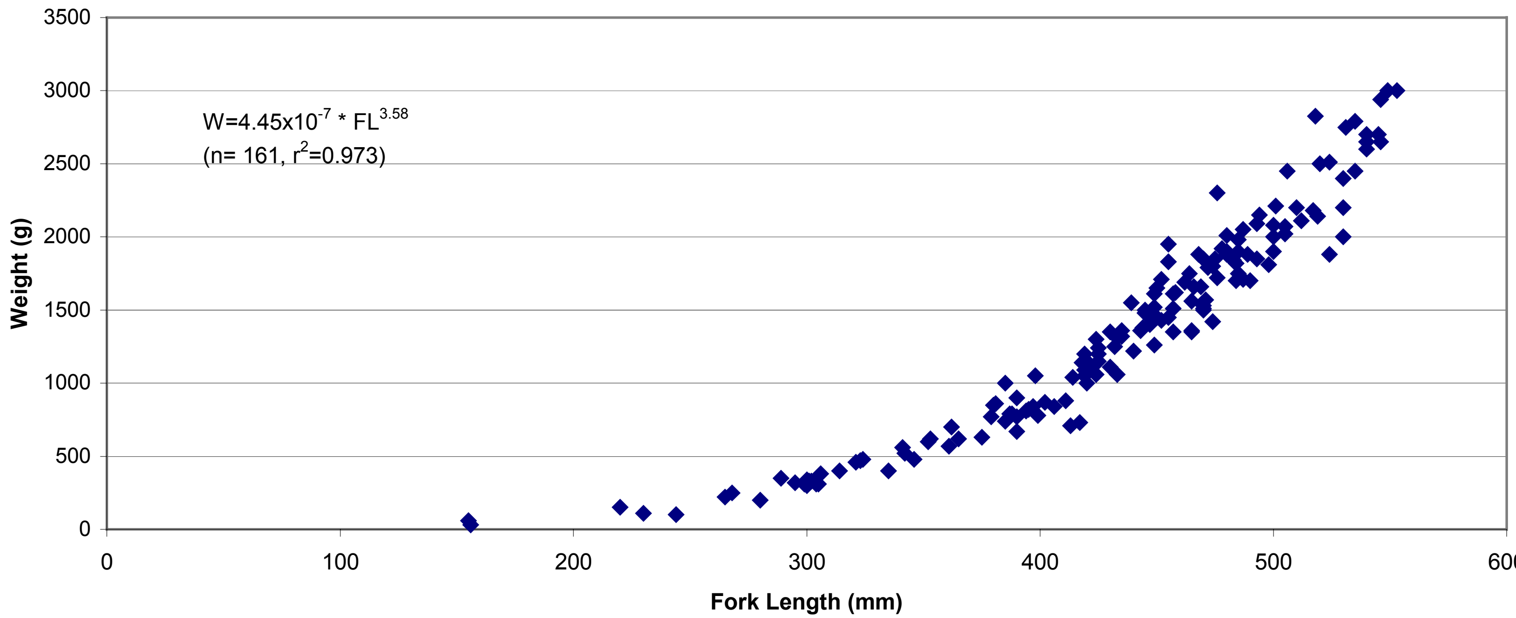
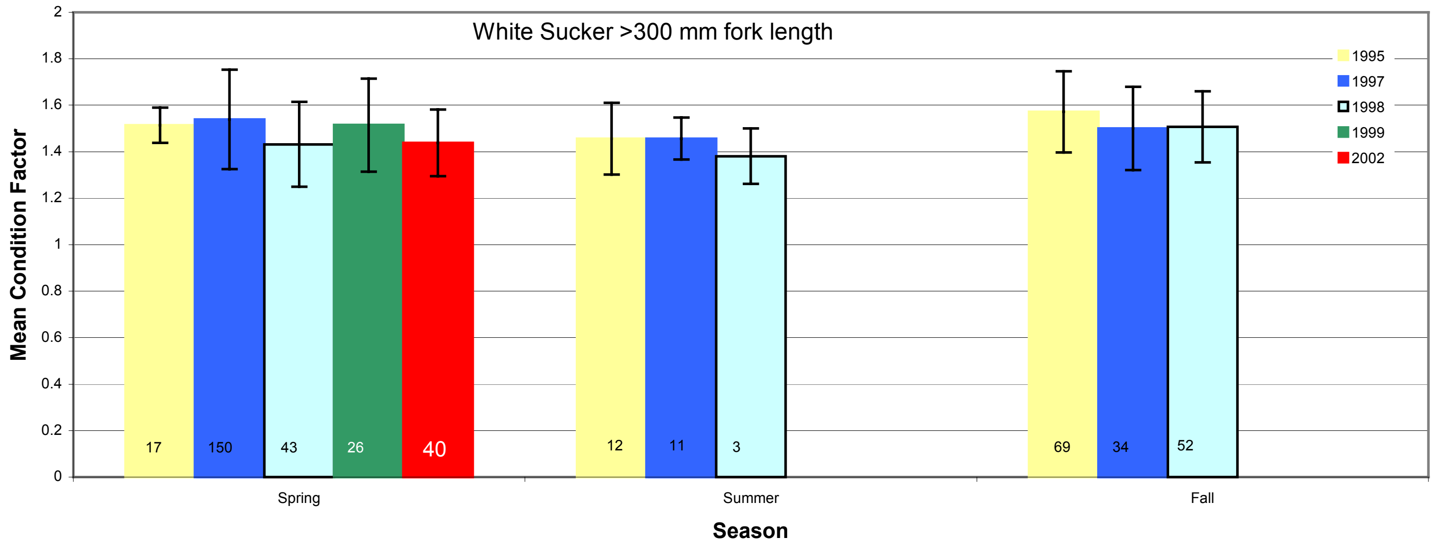


Figure 7.35 Comparison of Condition Factors for White Sucker, Athabasca River Inventories, 1995 to 1999 (with n value)



White sucker were not aged during the RAMP inventories, but a small amount of ageing data was collected during the 1998 inventory. These data were used to produce a general growth model for the region (Appendix II).

Fish Health

Mean external abnormality (pathology) index values were calculated for species for which a sufficient number of individuals were examined (Table 7.7). The maximum index value for an individual is 270, providing that the individual had an abnormal condition for all nine of the parameters examined.

Table 7.7 Summary of External Pathology Indices, Athabasca River Inventory, 1995 to 1999

Species	1995		1997		1998		1999	
	% With Abnormalities	Mean Pathology Index	% With Abnormalities	Mean Pathology Index	% With Abnormalities	Mean Pathology Index	% With Abnormalities	Mean Pathology Index
lake whitefish	84.9	36.9	15.9	4.8	17.0	5.4	14.1	4.6
longnose sucker	31.9	11.0	16.9	5.8	10.8	3.5	13.6	4.1
goldeye	30.4	9.6	13.7	4.3	1.2	0.5	12.5	3.7
northern pike	12.5	4.4	21.5	7.8	8.2	2.4	2.0	0.6
walleye	9.4	2.8	4.9	1.5	6.4	2.1	52.7	18.3
white sucker	42.3	18.6	6.5	3.2	27.8	9.6	17.2	5.7

Overall, the incidence of external abnormalities was low for fish captured in the Athabasca River. For most species, and in most years, the percentage of fish with one or more external abnormalities was <25%, as were the mean pathology index values (Table 7.7). Some exceptions exist. In 1995, the incidence of abnormalities for lake whitefish, longnose sucker, goldeye and white sucker was high, greater than 30%, although the average pathology index values were low. The main abnormalities for the latter three species were skin lesions, eroded fins and external parasites (lice). These abnormalities were not observed as frequently in subsequent years. Lake whitefish had a high incidence of abnormalities (84.9%) and the highest mean index value recorded for any species or year (36.9). The abnormalities were skin lesions, eroded fins or external parasites. The high incidence of abnormalities was not apparent in subsequent years. Walleye in 1999 showed a high incidence of abnormalities compared to previous years, due to fish with eroded fins and wounds on the body surface.

Although high indices of abnormalities occur, they do not occur consistently. Further, there is no indication that these relatively minor abnormalities have affected the well-being or abundance of any species.

7.2.2 Fisheries Inventory in the Muskeg River

This inventory component of the fisheries program provides information about regional fish resources by assessing species composition and relative abundance in the Muskeg River for large-bodied species. The inventory was to provide information for the summer period as a supplement to the assessment of fish abundance provided by the spring operation of the counting fence. In 2001, the inventory expanded to include the lower portion of Jackpine Creek, the main tributary to the Muskeg River. A secondary focus of this component was to check for the presence of the various life stages of Arctic grayling.

7.2.2.1 Methods

RAMP inventory data for the lower Muskeg River, from 1997 (Golder 1998) and 2001 (Golder 2002c) were used to assess variability in species composition and relative abundance. The comparison was based on species percent composition and CPUE, which were calculated using fish captured and observed while boat electrofishing. Catches were low for all species (i.e., <30) and there were too few fish to provide good size, size at age or length-weight information. However, longnose and white sucker were the most abundant large-bodied fish in the Muskeg River and the data were examined to determine if any population parameters could be provided for theses two species for future comparisons.

Length-weight analyses were conducted for longnose sucker and white sucker in 1997 and 2001 using the small sample sizes available. The data were tested for differences between the two years to see if the data could be pooled. Length-weight analysis was conducted using a geometric mean regression analysis (Ricker 1975) of the $\log_e$ transformed data. The regression results for 1997 and 2001 were compared using an analysis of covariance (Snedecor and Cochran 1978) and no significant difference was found between the two years ($p>0.05$). Therefore, the 1997 and 2001 data were combined to provide one length-weight regression for each species.

Most of the previous Muskeg River inventory data (Griffiths 1973; RRCS 1974; Bond and Machniak 1977, 1979; Sekerak and Walder 1980; Louma et al. 1986; RL&L 1989; Golder 1996a; Komex 1997b) were found to be unsuitable for analysis of population variability and trends relative to the RAMP data. Most of these data consisted of ‘small fish collections’ made by backpack electrofishing and seining and would not be comparable in terms of species composition and abundance. Although some boat electrofishing surveys were conducted, the locations sampled were very different from the habitats sampled in the RAMP inventories.

One survey (Golder 1997b) included a boat electrofishing inventory conducted during the summer in a large section of the Muskeg River and this study was considered suitable for comparison to the RAMP data. Unfortunately, Golder (1997b) did not estimate CPUE. Therefore, only percent occurrence data were used.

Fisheries sampling was conducted in the Muskeg River for other RAMP programs, including fish collections for tissue analysis, sentinel species analysis, radiotelemetry and the counting fence study. These data were included to identify variability and trends in fish species composition over time.

Fish health was assessed during the fish inventory by externally examining captured fish for abnormalities, disease and parasites. Eyes, gills, skin, fins, opercles, thymus, pseudobranchs, body form and parasites were assessed. All abnormalities were recorded by type and severity and were assigned an index value. A pathological index for these external characteristics was calculated for each fish as the sum of the index values for all abnormalities. A mean index value was then calculated for each species and year to allow between-year comparisons.

7.2.2.2 Results and Discussion

Based on existing studies (Golder 2003b), 23 fish species were found in the Muskeg River watershed prior to RAMP (Table 7.8). Of these species, 10 were rare and restricted to the lower-most portion of the Muskeg River near the Athabasca River (Table 7.8). The remaining 13 species had a wider distribution and/or were more common. Eleven species were captured during the 1997 and 2001 RAMP inventories, including all the common large-bodied species. One species (emerald shiner) captured during the 2001 RAMP inventory was a new species for the watershed, increasing the total species for the watershed to 24. Emerald shiner is common in the Athabasca River and would be expected to occur in the Muskeg River mouth on occasion.

Species historically reported as common that were not captured during the RAMP inventories included six small forage fish species (Table 7.8). Failure to capture these small fishes in the RAMP inventory does not indicate a decline in their abundance as the inventory sampling technique is size-selective and not suitable for assessing populations of small-bodied species. These species are known to still be present in the watershed based on the results of other sampling programs (Golder 1997b) or RAMP components (Golder 2002c).

Table 7.8 Fish Species Reported from the Muskeg River Watershed

Species		Historically Reported[a]	Present in RAMP Inventories
Common Name	Scientific Name		
Arctic grayling	*Thymallus arcticus*	C	X
brook stickleback	*Culaea inconstans*	C	
bull trout	*Salvelinus confluentus*	R	
burbot	*Lota lota*	R	
emerald shiner	*Notropis atherinoides*		X
fathead minnow	*Pimephales promelas*	C	
flathead chub	*Platygobio gracilis*	C	
lake chub	*Couesius plumbeus*	C	X
lake cisco	*Coregonus artedii*	R	
lake whitefish	*Coregonus clupeaformis*	R	
longnose dace	*Rhinichthys cataractae*	C	X
longnose sucker	*Catostomus catostomus*	C	X
mountain whitefish	*Prosopium williamsoni*	C	X
ninespine stickleback	*Pungitius pungitius*	R	
northern pike	*Esox lucius*	C	X
northern redbelly dace	*Chrosomus eos*	C	
pearl dace	*Semotilus margarita*	C	
slimy sculpin	*Cottus cognatus*	C	
spoonhead sculpin	*Cottus ricei*	R	X
spottail shiner	*Notropis hudsonius*	R	
trout-perch	*Percopsis omiscomaycus*	R	X
walleye	*Stizostedion vitreum*	R	X
white sucker	*Catostomus commersoni*	C	X
yellow perch	*Perca flavescens*	R	

[a] Data compiled in Golder 2003b.

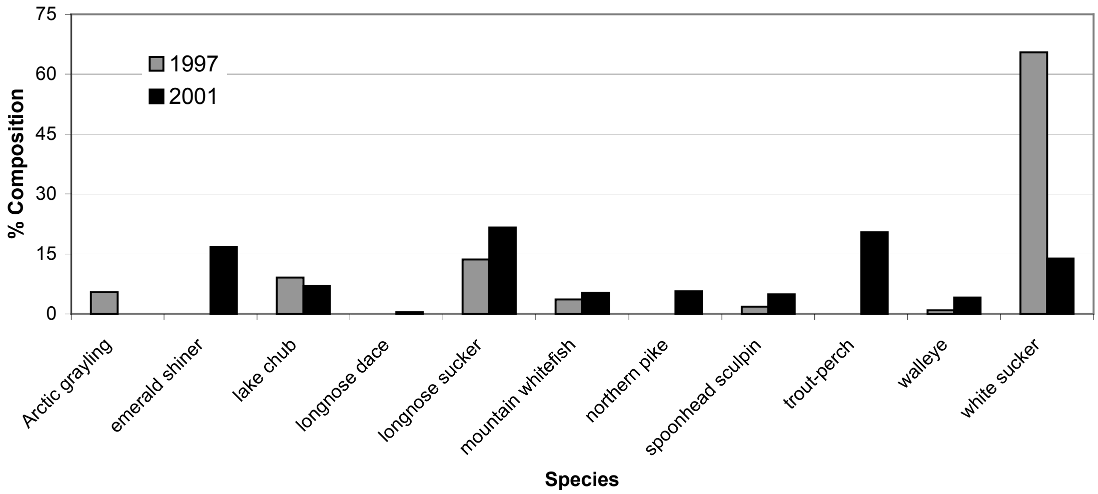
C = Common and/or widely distributed; R = rare or restricted to lower-most section of river.

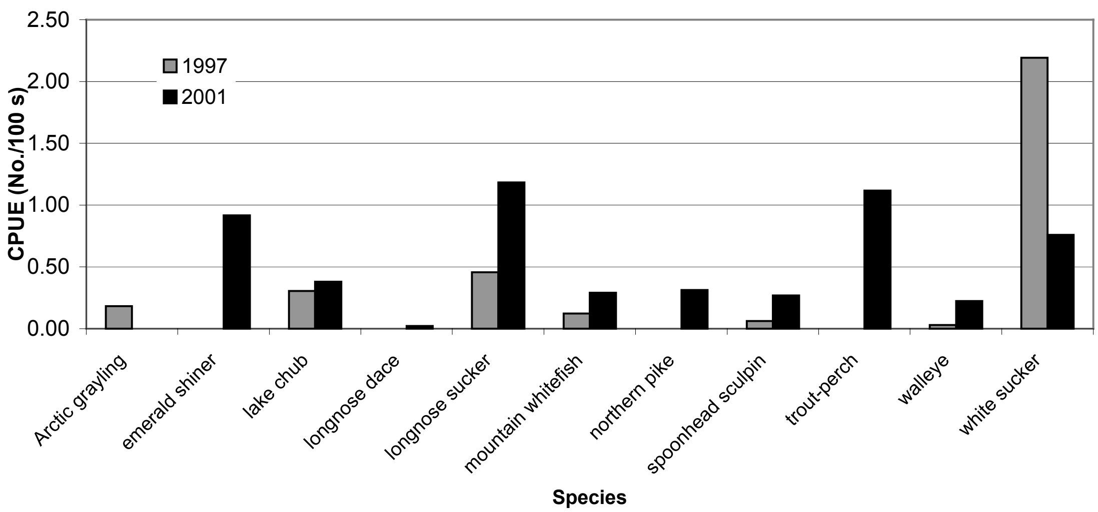
Total fish abundance (Table 7.9) was slightly higher in 2001 (5.47 fish/100 s) than 1997 (3.35 fish/100 s). The percent composition and CPUE were higher for all species in 2001, with the exception of Arctic grayling and white sucker (Figure 7.36). The only other comparable inventory was in 1997 (Golder 1997b). It showed percent composition to be similar to the RAMP 1997 data, with the exception that Golder (1997b) reported more pearl dace and fewer walleye and longnose sucker.

Table 7.9 Results of the RAMP Muskeg River Fisheries Inventories, 1997 and 2001

Species	1997 (Electrofishing Effort = 3284 s)						2001 (Electrofishing Effort = 4475 s)					
	Total Number		% Composition		CPUE (fish/100 s)		Total Number		% Composition		CPUE (fish/100 s)	
	Caught	Caught and Observed	Caught	Caught and Observed	Caught	Caught and Observed	Caught	Caught and Observed	Caught	Caught and Observed	Caught	Caught and Observed
Arctic grayling	6	6	6.7	5.5	0.18	0.18	0	0	0	0	0	0
emerald shiner	0	0	0	0	0	0	11	41	8.9	16.8	0.25	0.92
lake chub	8	10	8.9	9.1	0.24	0.30	17	17	13.7	6.9	0.38	0.36
longnose dace	0	0	0	0	0	0	1	1	0.8	0.4	0.02	0.02
longnose sucker	15	15	16.7	13.6	0.46	0.46	38	53	30.7	21.6	0.85	1.18
mountain whitefish	3	4	3.3	3.6	0.09	0.12	7	13	5.6	5.3	0.16	0.29
northern pike	0	0	0	0	0	0	4	14	3.2	5.7	0.09	0.31
spoonhead sculpin	2	2	2.2	1.8	0.06	0.06	5	12	4.0	4.9	0.11	0.27
trout-perch	0	0	0	0	0	0	6	50	4.8	20.4	0.13	1.12
walleye	0	1	0	0.9	0	0.03	10	10	8.1	4.1	0.22	0.22
white sucker	56	72	62.2	65.5	1.71	2.19	25	34	20.2	13.9	0.56	0.76
Total	**90**	**110**	**100**	**100**	**2.74**	**3.35**	**124**	**245**	**100**	**100**	**2.77**	**5.47**

Figure 7.36 Percent Species Composition and Catch-Per-Unit-Effort, Muskeg River Inventory, 1997 and 2001





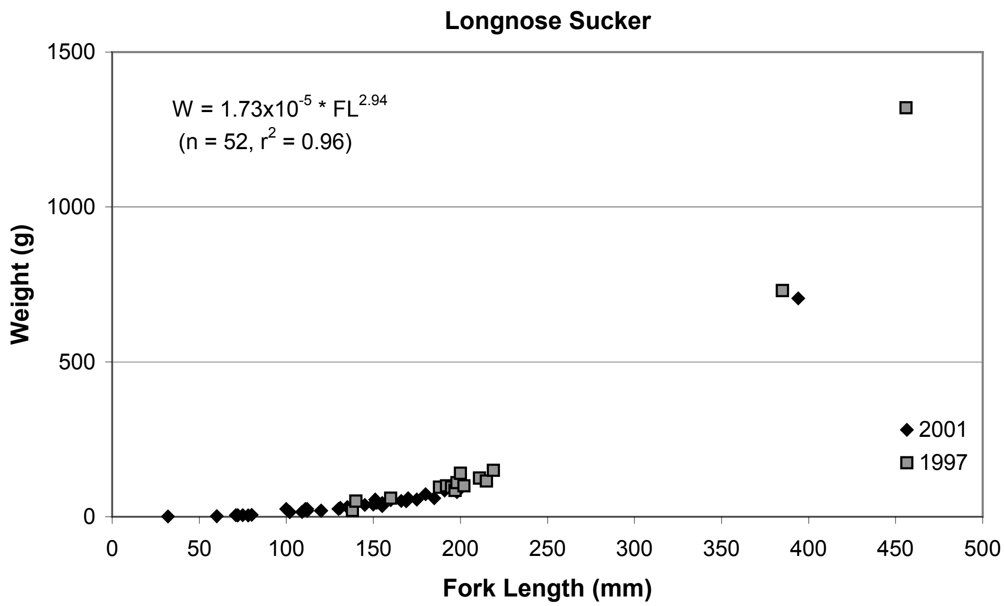
Although present in low numbers in the 1997 inventory, no Arctic grayling were captured in 2001. A small number of Artic grayling were captured by a local angler in the fall of 2001, indicating that the species was still present, but likely occurred in extremely low abundance.

Relative abundance for most fish species was variable, with generally higher abundances in 2001 relative to 1997. Assessing variability in fish composition and abundance using the existing inventory data was complicated by the different portions of the river that were sampled. As well, relative abundance and species presence were evaluated for large-bodied species only, because of the bias associated with electrofishing.

The length-weight regressions for longnose sucker and white sucker using combined 1997 and 2001 data are in Figure 7.37. The regression equations included in the figure were generated using log-transformed data, then converted back to standard length and weight units.

Mean external abnormality (pathology) index values were calculated for large-bodied species from the Muskeg River (Table 7.10). Abnormalities were few and, as a result, pathological index values were low. Indexes were zero for Arctic grayling, mountain whitefish and walleye in 1997 and 2001, and low for northern pike, longnose sucker and white sucker. External abnormalities consisted primarily of skin lesions, with one instance of skin lice. Differences in pathological index values between 1997 and 2001 were minor.

Figure 7.37 Length-Weight Regression Analyses for Longnose Sucker and White Sucker, Muskeg River Inventory, Combined 1997 and 2001 Data



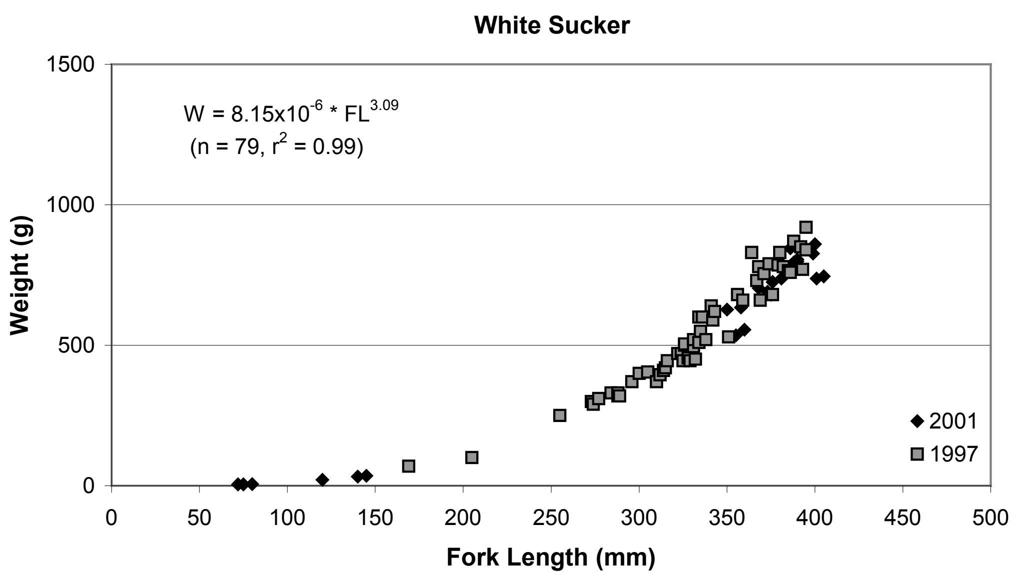


Table 7.10 External Pathological Index Values for fish from the Muskeg River Inventories, 1997 and 2001

Species	1997	2001
Arctic grayling	0	-
longnose sucker	0	0.8
mountain whitefish	0	0
northern pike	-	7.5
walleye	-	0
white sucker	2.5	2.7

Note: - = Not captured.

7.2.3 Athabasca River Fish Tissue Analysis

Contaminants in fish from the Athabasca River were measured for regionally important fish species during the 1998 and 2001 RAMP studies (Golder 1999, 2002c). The fish tissue component of the study provided information about ecosystem health and the sustainability of regional fish resources. Chemical concentrations in fish tissue were assessed in relation to fish health and the suitability of fish for human consumption. This component involved the collection and analysis of tissue samples from selected large-bodied species from the Athabasca River used in the subsistence, commercial and sport fisheries, or employed as RAMP sentinel species. Since this component is a general screening level assessment of tissue concentrations, sample sizes were relatively small and analysis was conducted on composite samples.

For the Five Year Report, tissue concentrations of contaminants above guidelines or toxic effect levels were compared to historical fish tissue data from the Athabasca River. Contaminants in fish tissue were also measured for one species from the Muskeg River during the 2001 RAMP study. These data were included in the Athabasca River analysis.

7.2.3.1 Methods

The following RAMP fish muscle tissue data (previously summarized in Golder 2002c) were available:

- 1998 Athabasca River: male and female walleye (fall and spring); male and female goldeye (spring only); male and female lake whitefish (fall only). For each species and sex, reported chemical concentrations were the result of a single composite muscle sample consisting of tissues from five to eight fish.

- 2001 Athabasca River: male and female walleye (fall); male and female lake whitefish (fall). All reported chemical concentrations were the result of single composite muscle samples from five fish.
- 2001 Muskeg River: male and female northern pike (fall). All reported chemical concentrations were the result of single composite muscle samples of five fish.

Each composite sample taken as part of RAMP in 1998 and 2001 was analyzed for a range of parameters, which included PAHs and inorganics. In 2001, fish muscle tissue was analyzed for 40 PAHs and 29 inorganic parameters. In 1998, most fish muscle tissue was analyzed for 14 PAHs and 28 inorganics. The exceptions were female walleye, which were analyzed for 38 PAHs and 28 inorganics, and male walleye, which were analyzed for 28 inorganics only.

The RAMP fish tissue data were screened to establish an appropriate list of parameters for the fish health assessment and to compare with consumption guidelines and risk-based concentrations (RBC) for protection of human health. The screening process involved separating the chemical parameters into one of the following categories:

- Parameters with concentrations below detection limits in 1998 and 2001. These chemicals were not considered further for the fish health assessment, or for comparison with consumption guidelines and RBC.
- Parameters with detectable concentrations in either or both of 1998 and 2001. These parameters were assessed for potential effects on fish health, and for comparison with consumption guidelines and RBC.

Fish Health Assessment

Data from all fish (i.e., eight composite tissue samples from 1998 and six composite samples in 2001) were assessed for potential linkages with effects on fish health. Where possible, the maximum reported fish muscle tissue concentrations were compared with muscle tissue data from a database (Jarvinen and Ankley 1998) linking chemical residues in various tissues of fish with effects on the health of the organism. Both acute and chronic effect-endpoints for a range of species and trophic levels are provided in the database. Data linking sublethal effects (e.g., growth and reproduction) with tissue residues were preferentially selected over those linking lethal effects with tissue residues. However, not all chemicals had sublethal effects reported from muscle tissue residues. Where data on muscle tissue were not present, tissue concentrations were compared to either whole body or carcass concentrations. Where several sublethal endpoints were listed for a particular chemical, the lowest, relevant, effect-endpoint in the Jarvinen and Ankley (1998) database was used.

Human Consumption Assessment

Maximum measured fish tissue concentrations from all of the fish data in 1998 and 2001 were compared with fish consumption guidelines and RBC (Health Canada 1999; U.S. EPA 2002). Where data for a particular chemical were found to exceed a guideline or RBC, additional data were reviewed to assess whether the exceedance was likely to be a natural or historical occurrence in the Athabasca River Oil Sands Region. Historical and background data used for comparison were the Northern River Basins Study (1996) and data from Environment Canada (Donald and Craig 1995).

7.2.3.2 Results and Discussion

Chemical Screening

The screening of the RAMP fish tissue data placed compounds into one of the following categories: non-detectable or not analysed in 1998 and 2001; detectable in 1998 but not 2001; detectable in 2001 but not 1998; and detectable in both 1998 and 2001. The latter three categories of detectable compounds made up the list of compounds carried forward for the fish health assessment and for comparison with consumption guidelines and RBC. The following summarizes the screening of the fish tissue data:

- *Compounds not detected or not analyzed in both 1998 and 2001*: arsenic, beryllium, cobalt, lithium, molybdenum and thallium were not detected in any fish muscle tissue in 1998 or 2001. Boron was analyzed in 1998 only, but was non-detectable. Therefore, these compounds were not carried forward.
- *Compounds detected in 1998 but not 2001:* with two exceptions, PAHs were not detectable (detection limits 0.01 – 0.02 mg/kg) in any fish muscle tissue in 1998. The exceptions were methylnaphthalene (at concentrations of 0.01 mg/kg – 0.03 mg/kg) and naphthalene (at a concentration of 0.02 mg/kg) in goldeye and walleye. Therefore, the PAHs methylnaphthalene and naphthalene from 1998 were carried forward. Polycyclic aromatic hydrocarbons were not detected in any fish muscle tissue in 2001. Silver was detected at a concentration of 0.1 mg/kg in male walleye in 1998 only, and was carried forward.
- *Compounds detected in 2001 but not 1998:* antimony was detected in a concentration of 0.05 mg/kg in female walleye in 2001 only. It was not detected in 1998. Titanium was analyzed and detected in 2001, but not 1998. Cadmium, chromium and vanadium were not detected in 1998 but were detected in most samples in 2001. All five parameters were carried forward.
- *Compounds detected in both 1998 and 2001:* the remaining parameters (aluminum, barium, calcium, copper, iron, lead, magnesium,

manganese, mercury, nickel, phosphorus, potassium, selenium, sodium, strontium, tin and zinc) were detected in both 1998 and 2001, and were carried forward.

Table 7.11 is a summary of the maximum concentrations of the 25 parameters detected in 1998 and/or 2001. These concentrations are the maximum reported for all fish species-gender combinations in that year.

Table 7.11 1998 and 2001 Maximum Tissue Concentrations Carried Forward to the Fish Health and Human Consumption Assessments

Parameter	1998		2001	
	Maximum Concentration (mg/kg)	Gender-Species	Maximum Concentration (mg/kg)	Gender-Species
aluminum (Al)	1.5	male LKWH	7	female LKWH
antimony (Sb)	<0.04	-	0.05	female WALL
barium (Ba)	0.09	male WALL	0.15	female WALL
cadmium (Cd)	<0.08	-	0.11	male WALL
calcium (Ca)	753	female GOLD	550	female NRPK
chromium (Cr)	<0.2	-	0.5	male WALL, male/female LKWH
copper (Cu)	0.92	female WALL	1.18	male NRPK
iron (Fe)	12	male LKWH	16	male LKWH
lead (Pb)	0.06	male LKWH	0.15	male WALL
magnesium (Ma)	279	male WALL	324	male NRPK
manganese (Mn)	0.24	male LKWH	0.42	female NRPK
mercury (Hg)	0.29	female WALL	0.46	female WALL
nickel (Ni)	0.75	female WALL	0.65	female LKWH
phosphorus (P)	2,030	male WALL	2,260	male WALL
potassium (K)	4,490	female WALL	4,020	male NRPK
selenium (Se)	0.6	female/male GOLD	0.6	male WALL
silver (Ag)	0.1	male WALL	<0.08	-
sodium (Na)	674	female GOLD	327	male LKWH
strontium (Sr)	1.08	female/male GOLD	0.37	male NRPK
tin (Sn)	3.73	male LKWH	0.12	female WALL
titanium (Ti)	-	-	0.83	female LKWH
vanadium (V)	<0.08	-	0.17	male LKWH
zinc (Zn)	4.8	female GOLD	7.4	female WALL
methylnaphthalene	0.03	male GOLD	-	-
naphthalene	0.02	female/male GOLD	-	-

Note: GOLD = goldeye; LKWH = lake whitefish; WALL = walleye; NRPK = northern pike.
"-" = no data

Data from Golder (2002c) - data are reported in mg/kg wet weight of tissue.

For comparison, and to assess whether the 1998 and 2001 RAMP fish tissue data are consistent with the ranges in tissue concentrations previously reported in the Athabasca River Oil Sands Region, fish tissue concentrations from 1995 are shown in Table 7.12 for walleye, goldeye and longnose sucker (Golder 1996a).

These data represent single composite muscle tissue samples for the species shown.

Table 7.12 Fish Tissue Concentrations Found in the Athabasca River in 1995

Parameter	Walleye (mg/kg)	Goldeye (mg/kg)	Longnose Sucker (mg/kg)
aluminum (Al)	3	<2	10
antimony (Sb)	-	-	-
barium (Ba)	<0.5	<0.5	<0.5
cadmium (Cd)	<0.5	<0.5	<0.5
calcium (Ca)	662	627	246
chromium (Cr)	<0.5	<0.5	<0.5
copper (Cu)	1	<1	<1
iron (Fe)	7	12	15
lead (Pb)	<2	<2	<2
magnesium (Ma)	307	315	328
manganese (Mn)	<0.5	<0.5	<0.5
mercury (Hg)	-	-	-
nickel (Ni)	<1	<1	<1
phosphorus (P)	2,880	2,590	2,760
potassium (K)	4,880	4,380	5,190
selenium (Se)	<0.5	<0.5	0.3
silver (Ag)	<0.2	<0.02	<0.02
sodium (Na)	228	360	352
strontium (Sr)	0.6	<0.5	<0.5
tin (Sn)	<2	<2	<2
titanium (Ti)	-	-	-
vanadium (V)	<1	<1	<1
zinc (Zn)	6	6	5

Data from Golder (1996a) - data are reported in mg/kg wet weight of tissue.
Note: "-" no data, parameter not analyzed.

Fish Health Assessment

The maximum measured fish tissue concentrations shown in Table 7.11 were compared with tissue residue levels shown to cause effects in fish. Table 7.13 summarizes the effect levels for relevant chemicals (Jarvinen and Ankley 1998). There were no data linking fish tissue residues of barium, calcium, iron, magnesium, manganese, phosphorus, potassium, sodium, strontium, tin, titanium, methylnaphthalene or naphthalene.

Table 7.13 Fish Tissue Effects Concentrations

Parameter	Effects Concentration (mg/kg)[a]	Endpoint	Tissue	Fish, Age/Size
aluminum (Al)	20	survival – reduced	whole body	Atlantic salmon (*Salmo salar*) Alevin
	1.15	survival – no effect	muscle	rainbow trout (*Salmo gairdneri*), 171g
antimony (Sb)	9.0	survival – reduced (50%)	whole body	fingerling
	5.0	survival – no effect	whole body	fingerling
barium (Ba)	-	-	-	-
cadmium (Cd)	2.8	survival, growth – no effect	muscle	rainbow trout – adult
	0.6	reproduction – reduced	muscle	rainbow trout – adult
	0.4	reproduction – no effect	muscle	rainbow trout – adult
calcium (Ca)	-	-	-	-
chromium (Cr)	0.58	survival – no effect	muscle	rainbow trout, 150-200g
copper (Cu)	0.5	survival – no effect	muscle	rainbow trout, 138 g
	3.4	survival, growth, reproduction – no effect	muscle	brook trout (*Salvelinus fontinalis*) – embryo, adult, juvenile
iron (Fe)	-	-	-	-
lead (Pb)	4.0	survival – no effect	carcass	rainbow trout – underyearlings
	2.5 – 5.1	growth – no effect	whole body	brook trout – embryo, juvenile
magnesium (Ma)	-	-	-	-
manganese (Mn)	-	-	-	-
mercury (Hg)[b]	4.9	survival, growth, reproduction – no effect	muscle	brook trout, embryo-larvae
	6.2	survival – reduced, death	muscle	rainbow trout, 100-150 g
	10.2	survival, growth, reproduction – reduced	muscle	brook trout, embryo-adult
nickel (Ni)	118.1	survival – reduced 50%	white muscle	carp (*Cyprinus carpio*), 15g
	0.82	survival – no effect	muscle	rainbow trout, 150-200g
phosphorus (P)	-	-	-	-
potassium (K)	-	-	-	-
selenium (Se)	0.8	growth – no effect	whole body	chinook salmon – fingerling
	0.8	survival – no effect; growth – reduced	carcass	rainbow trout – juvenile
	0.2	growth – no effect	carcass	rainbow trout – juvenile
silver (Ag)	0.06	survival, growth – no effect	whole body	young-of-the-year
	0.07	survival, growth – no effect	gill	young-of-the-year
	0.12	survival, growth – no effect	internal organs	young-of-the-year
sodium (Na)	-	-	-	-
strontium (Sr)	-	-	-	-
tin (Sn)	-	-	-	-
titanium (Ti)	-	-	-	-
vanadium (V)	5.33	survival – no effect	carcass	rainbow trout – juvenile
	5.74	survival, growth, reproduction – no effect	whole body	flagfish (*Jordanella floridae*) – adult
	0.41	growth – reduced	carcass	rainbow trout – juvenile
zinc (Z)	4.5	survival, growth – no effect	whole body	brook trout – embryo, larvae
	60	survival, growth – no effect	Whole body	Atlantic salmon – juvenile
methylnaphthalene	-	-	-	-
naphthalene	-	-	-	-

(a) Source: Data from Jarvinen and Ankley (1998).

(b) Data for methylmercury.

Note: "-" = no effects data.

Comparison of the maximum fish tissue concentrations from 1998 and 2001 with the effects concentrations indicates that all measured tissue concentrations are lower than the effects concentrations. Therefore, effects on fish health from the chemical concentrations measured in muscle tissue are unlikely. The only exceptions may be aluminum in female lake whitefish and silver in male walleye.

The measured fish tissue concentration of aluminum in 2001 was 7 mg/kg, which is below the concentration shown to reduce survival in Atlantic salmon (20 mg/kg), but above the no effect concentration (1.15 mg/kg; Jarvinen and Ankley 1998). However, the 1995 data show aluminum concentrations in longnose sucker from the Muskeg River ranged from <2 to 10 mg/kg. Since the RAMP 1998 and 2001 data fall within this range, effects on fish health are not predicted from aluminum tissue concentrations.

The measured fish tissue concentration of silver in 1998 (0.1 mg/kg) was below the no effect concentration for internal organs (0.12 mg/kg) but above the no effect concentrations for both gills (0.07 mg/kg) and whole body (0.06 mg/kg). However, the measured concentration in 1998 was below the chronic effects value (CEV) of 0.12 mg/kg provided by Suter and Tsao (1996). In addition, silver was detected in only one of the species-gender composites examined in 1998 and was not detected at all in 2001. Therefore, effects on fish health are not predicted from silver tissue concentrations.

Comparison with Consumption Guidelines and Risk-Based Concentrations (RBC)

The maximum measured fish tissue concentrations (Table 7.11) were compared with available criteria pertinent to the suitability of fish for human consumption.

Health Canada recommends a fish tissue mercury consumption guideline of 0.5 mg/kg, based on an assumed average consumption of fish (Health Canada 1999). This guideline is for an occasional fish consumer, which is assumed to be a person eating an average of 310 g of fish per week, or approximately three meals (Health and Welfare Canada 1984). For native peoples who consume greater quantities of fish, the maximum acceptable level of mercury has been recommended to be 0.2 mg/kg (Health Canada 1999). This guideline is for a subsistence level consumer, which is assumed to be a person eating an average of 780 g of fish per week, or about eight servings (Health and Welfare Canada 1984). Health Canada has not provided fish tissue consumption guidelines for other chemicals.

Risk-based concentrations (RBC) of inorganic and organic compounds for fish tissue consumed by people have been provided by the U.S. EPA (U.S. EPA 2002). Although these are not enforceable fish consumption guidelines, they do provide useful health risk-based benchmarks for evaluation of fish tissue concentrations. Table 7.14 presents the Health Canada mercury guideline and the summarised RBC for the chemicals listed in Table 7.11 for which RBC are available. The maximum concentrations for each chemical in fish tissue from the 1998 and 2001 RAMP data (also taken from Table 7.11) are included in Table 7.14 for comparison with the guidelines and RBC.

Table 7.14 Fish Tissue Consumption Guidelines and Maximum Measured Concentrations in Fish Muscle from 1998 and 2001

Parameter	Guideline or RBC[a] (mg/kg)	1998 Maximum Concentration (mg/kg)	2001 Maximum Concentration (mg/kg)
aluminum (Al)	1,400	1.5	7
antimony (Sb)	0.54	<0.04	0.05
barium (Ba)	95	0.09	0.15
cadmium (Cd)	1.4	<0.08	0.11
chromium (Cr)	2,000/4.1[b]	<0.2	0.5
copper (Cu)	54	0.92	1.18
Iron (Fe)	410	12	16
manganese (Mn)	190	0.24	0.42
mercury (Hg)	0.2/0.5	0.29	0.46
nickel (Ni)	27	0.75	0.65
selenium (Se)	6.8	0.6	0.6
silver (Ag)	6.8	0.1	<0.08
strontium (Sr)	810	1.08	0.37
tin (Sn)	810	3.73	0.12
titanium (Ti)	5,400	-	0.83
vanadium (V)	9.5	<0.08	0.17
zinc (Z)	410	4.8	7.4
methylnaphthalene	27	0.03	-
naphthalene	27	0.02	-

[a] RBC from U.S. EPA (2002); mercury guideline from Health and Welfare Canada (1984).

[b] Chromium III = 2000; chromium VI = 4.1.

Note: "-" = no data.

With the exception of mercury, all compounds in fish muscle tissue in 1998 and 2001 were found to be at concentrations below fish consumption guidelines or RBC.

None of the samples collected to date by RAMP have contained mercury concentrations above the "average fish consumption" guideline of 0.5 mg/kg. However, all of the walleye composite samples collected in the Oil Sands Region in 1998 and 2001 (six in total) contained mercury above the subsistence guideline of 0.2 mg/kg (Table 7.14). The mercury concentrations measured in walleye composite samples ranged from 0.20 to 0.29 mg/kg in 1998 and from 0.36 to

0.46 mg/kg in 2001. All other fish species analyzed as part of RAMP contained mercury at a concentration below the subsistence guideline.

Although mercury levels in walleye from the Oil Sands Region are above the subsistence guideline, they are consistent with levels recorded historically and in other portions of the Athabasca River basin. Historical data from the Athabasca River in the Oil Sands Region and beyond shows a wide range in fish tissue mercury concentrations. For example, in 1992; concentrations of mercury in walleye in the Athabasca River upstream of the Oil Sands Region ranged from 0.34 to 0.79 mg/kg (n=6; summarized in NRBS 1996). In 1984, mercury concentrations in walleye in the Athabasca River downstream of the Suncor operation ranged from 0.15 to 0.74 mg/kg (n=19; summarized in NRBS 1996). In 1977, mercury in walleye tissue from Lake Athabasca was found to range from 0.31 to 0.79 mg/kg (n=5; summarized in NRBS 1996). Earlier data from 1975 (AOSERP 1977) reported mean walleye whole body mercury concentrations of 0.38 mg/kg in the Muskeg River mouth and also in the Athabasca River near Embarras. Walleye composite samples collected for RAMP in 1998 at the Athabasca River reference site 200 km upstream of the Oil Sands Region had mercury concentrations ranging from 0.33 to 0.37 mg/kg (Golder 1999).

In conclusion, the mercury concentrations in fish tissue from the 1998 and 2001 RAMP collections appear to be representative of both regional and historical fish tissue mercury data, and indicative of the natural variability in mercury concentrations in fish of the Athabasca River region.

7.2.4 Sentinel Species in the Athabasca River

The Athabasca River sentinel species component of the fisheries program was designed to provide information about the sustainability of regional fish resources by examining the health of a chosen indicator species. The objective of this component was to measure population level and whole-organism parameters of the indicator species in the Athabasca River as a representation of regional conditions. Within this objective was the goal of determining the variability in the measured parameters in order to refine the study design of a long-term sentinel species monitoring program. In this context, this section of the report evaluates the suitability of using longnose sucker as an Athabasca River sentinel species.

Longnose sucker was removed from the sentinel species component by the Fish Subgroup of the Technical Subcommittee, based on concerns regarding the level of variability in the health assessment data for this species, as well as its mobility and suitability for indicating trends. Elimination or reinstatement of the longnose sucker in this component was to be determined pending analysis of its suitability as a sentinel species for the Athabasca River in the Oil Sands Region. Therefore, this component was included in the Five Year Report to allow for analysis of variability in longnose sucker health parameters and known movements of this species. The results provide the basis for a recommendation on its status as a sentinel species. Longnose sucker health parameter data was obtained from the 1998 RAMP study (Golder 1999) and from other fish health studies conducted in the Athabasca River for Environmental Effects Monitoring (EEM) associated with the Pulp and Paper Industry. Longnose sucker movement data was provided by the results of the RAMP radiotelemetry component (Golder 2002c).

Monitoring of fish populations is a key component of RAMP. The main reason for evaluating fish populations is that fish are known to integrate the effects of natural and anthropogenic factors and are, therefore, an important ecological indicator. The sentinel species component of the Athabasca River program focuses on monitoring whole-organism parameters for a sentinel fish species (i.e., longnose sucker) resident in the Oil Sands Region and in the reference area. The status of a sentinel species, as indicated by a variety of characteristics measured in individual fish, should reflect the overall condition of the aquatic environment in which the fish reside. The sentinel species program will, over the course of RAMP's iterative process, identify whether differences occur in the health parameters of fish exposed to oil sands activity. The main objective of the sentinel species program, therefore, is to monitor a fish population in order to detect early signs of change in the ecosystem. This is to be achieved by monitoring for changes in growth, reproduction and health of fish.

There are two important advantages to the sentinel species approach:

- it uses traditional, well-established fisheries measures (e.g., growth, condition factor); and
- it focuses on one fish species and does not depend on intensive (and costly) sampling of fish communities.

The determination of changes in the sentinel fish species can only be accomplished over several cycles of monitoring. The annual variability in the fish parameters being assessed must be understood in order to determine if changes detected in the fish population over time are beyond those that would be expected to occur due to natural cycles.

If the variability for a given population is so large that the ability to detect change is compromised, then the species chosen as a sentinel should be reconsidered. In this regard, the variability in the longnose sucker data collected to date under

RAMP was evaluated to assess whether this species could indeed be used to detect impacts to the Athabasca River. Other factors, such as exposure to the Oil Sands Region, movement in and out of the Oil Sands Region, and behavioural traits of longnose sucker, are also considered in the evaluation of this species as a suitable sentinel for this program.

7.2.4.1 Methods

Since there is only one year of longnose sucker data thus far for RAMP, the determination of variability among years is not possible. In order to determine whether the variability within the two populations examined would allow any effects to be detected, a comparison with the variability found in other longnose sucker populations in Alberta was conducted.

Power analysis can be employed to determine the sample size required to detect a given effect size. Power analysis should be conducted prior to the next cycle of monitoring to help establish the sample sizes required to detect a pre-determined percent change. However, power analysis was not conducted here for the purposes of determining suitability of the sentinel species since making any decisions strictly on the basis of parametric statistics generated from one year of data would be inappropriate.

Data from studies where effects had been detected were used for our comparisons with other longnose sucker populations. The variability of several fish parameters from each of these populations are presented graphically. Variability is expressed as the coefficient of variation (CV). The longnose sucker populations considered were from the following rivers:

- North Saskatchewan River (NSR), near Rocky Mountain House, sampled during spring 1994 (Golder 1996d);
- Little Smoky River, sampled during fall 1998 (Golder 2000c);
- Wapiti River, near Grande Prairie, sampled during spring 1994 (Golder 1996d);
- Wapiti River reference area, near Wapiti Gardens, approximately 65 km upstream from Grande Prairie, sampled during fall 1998 (Golder 2000c);
- Wapiti River, near Grande Prairie, sampled during fall 1998 (Golder 2000c);
- Lesser Slave River (LSR) reference area, upstream of Slave Lake Pulp, sampled during fall 1998 (Stantec and Golder 2000);
- Lesser Slave River, downstream of Slave Lake Pulp, sampled during fall 1998 (Stantec and Golder 2000);

- Athabasca (Ath) River, near Hinton, sampled during spring 1995 (Golder 1996e);
- Athabasca River reference area, upstream of Hinton, sampled during fall 1998 (Stantec and Golder 2000);
- Athabasca River, near Hinton, sampled during fall 1998 (Stantec and Golder 2000);
- Athabasca River reference area, upstream of Whitecourt, sampled during fall 1998 (Stantec and Golder 2000);
- Athabasca River, downstream of Whitecourt, sampled during fall 1998 (Stantec and Golder 2000);
- Athabasca River reference area, upstream of Athabasca, sampled during fall 1998 (Stantec and Golder 2000);
- Athabasca River, downstream of Athabasca, sampled during fall 1998 (Stantec and Golder 2000);
- Muskeg River, sampled during spring 1995 (Golder 1996a) ;
- Athabasca (Ath) River RAMP reference area, near Iron Point, sampled during fall 1998 (Golder 1999); and
- Athabasca (Ath) River RAMP exposure area, near Fort McMurray, sampled during fall 1998 (Golder 1999).

7.2.4.2 Results and Discussion

Variability

The evaluation of variability indicates that, based on the first year of monitoring, the variability observed in the RAMP longnose sucker population data is of a magnitude that would allow for effects to be detected if present. The CV of several key parameters assessed during the RAMP sentinel species survey for the Athabasca River was compared to that of other longnose sucker populations in Alberta (Figures 7.38 and 7.39). Parameters examined included condition (Fulton-type condition factor), age, liver somatic index (LSI) and gonad somatic index (GSI). The variability observed in both males and females of the two RAMP populations fall within the range observed in other Alberta populations. The majority of these data are from studies where statistically significant differences between populations (e.g., exposure population versus a reference population) have been found. Moreover, the statistically significant differences observed in some of these studies were of a magnitude considered to reflect an effect due to exposure.

The sentinel species program under RAMP was designed to be a sequential series of monitoring and interpretation cycles in a manner similar to federal monitoring programs established for the pulp and paper industry. The requirements of each cycle would be dependent on the findings of previous cycles (Environment Canada 1998). The focus of the first cycle conducted in 1998 was to conduct a preliminary survey that would allow the investigator to become familiar with the selected sentinel species (i.e., longnose sucker) and to provide data describing the variability in fish parameters. The estimate of variability for the various parameters should now be used in power calculations to refine the study designs of subsequent cycles of RAMP.

The results of the first cycle of the RAMP sentinel species program were also used to assess:

- the exposure of longnose sucker to the Oil Sands Region stressors;
- the capture success of longnose sucker;
- the adequacy of the reference area; and
- the suitability of longnose sucker as a sentinel.

These aspects of the program are discussed below.

Figure 7.38 Coefficient of Variations (CV) in Various Populations of Male Longnose Sucker [F = fall, S = spring, ref = reference area]

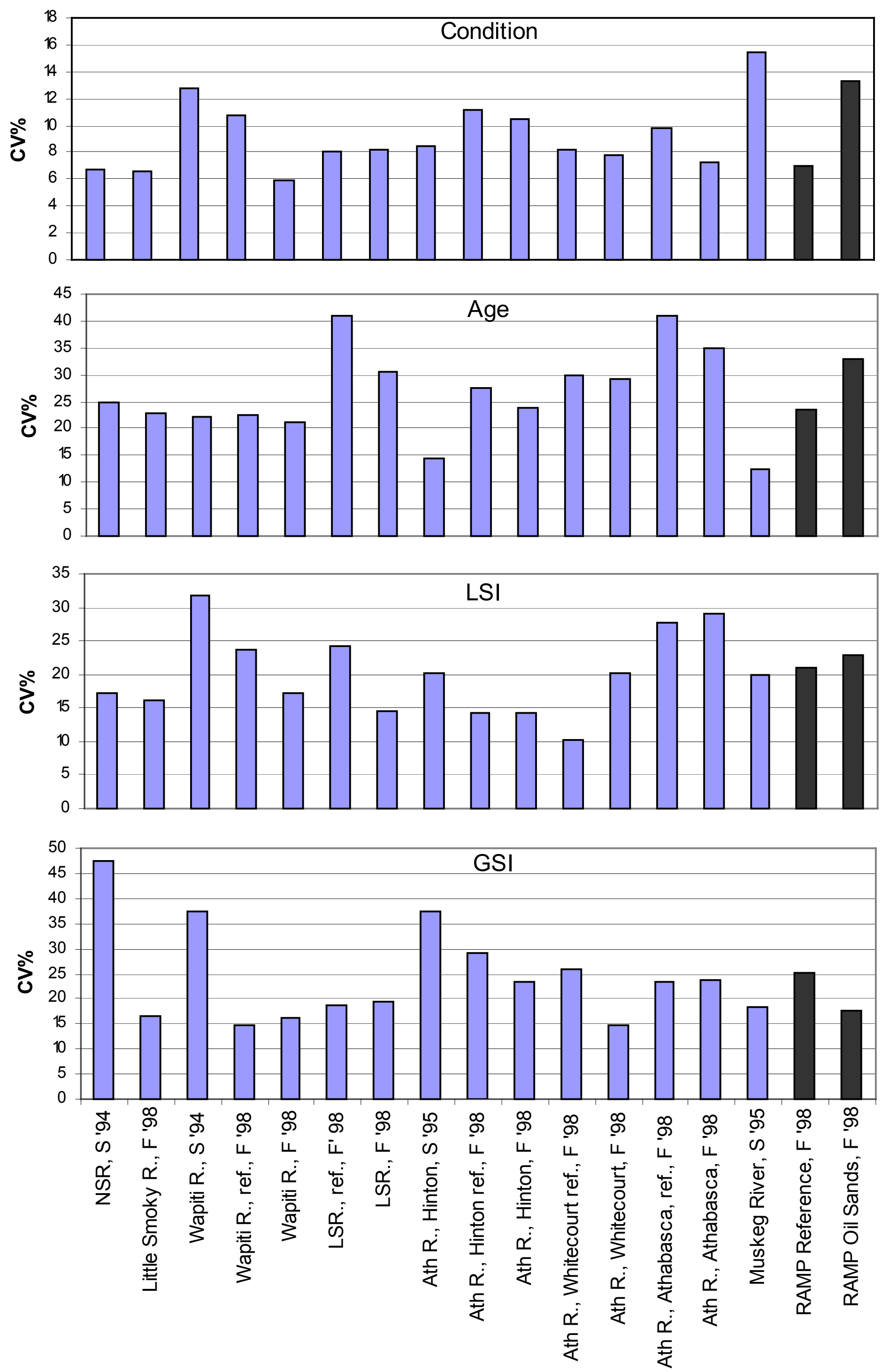
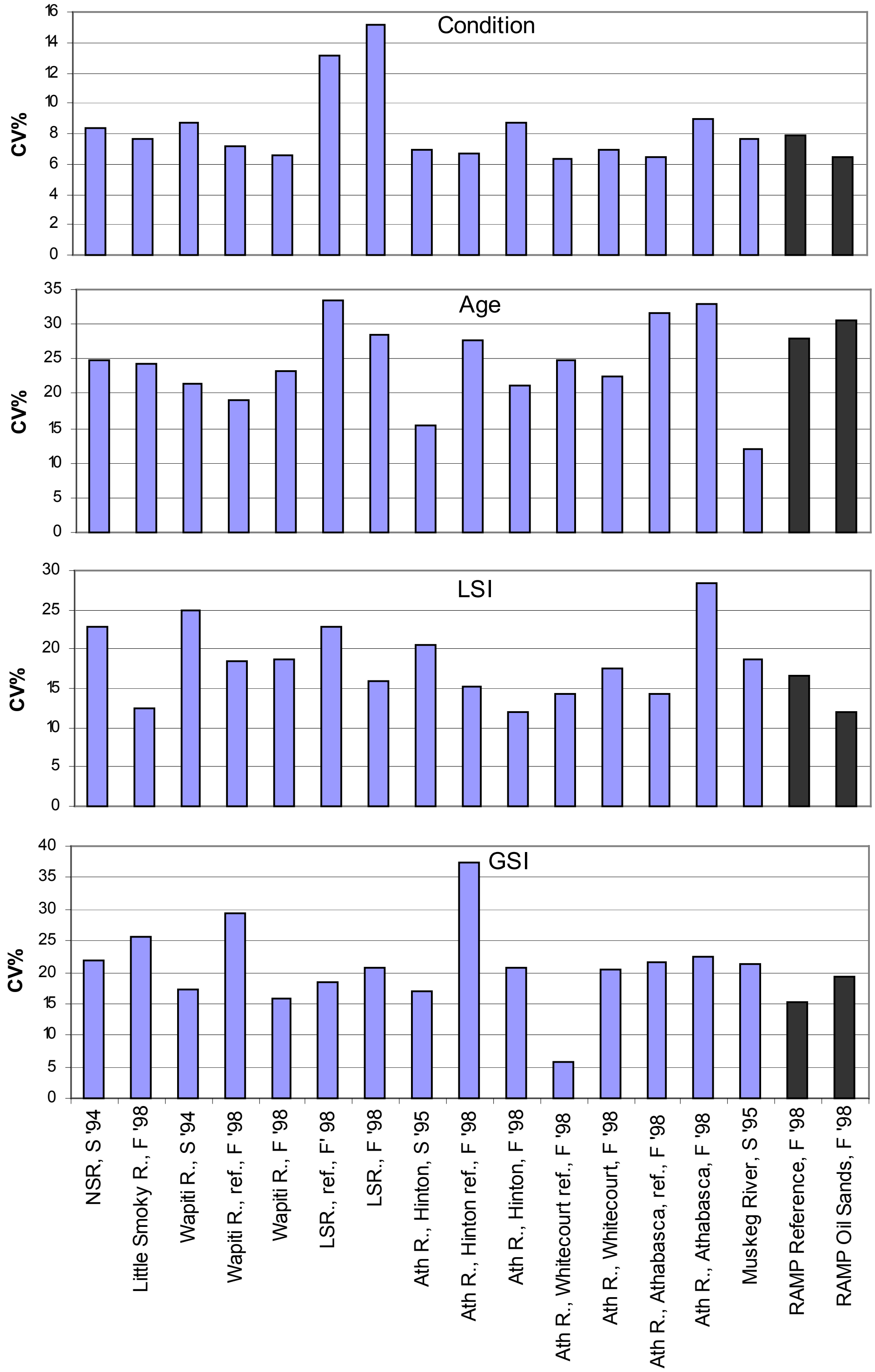


Figure 7.39 Coefficient of Variations (CV) in Various Populations of Female Longnose Sucker [F = fall, S = spring, ref = reference area]



Movement and Exposure

A concern with using longnose sucker as a sentinel species is its ability to migrate over substantial distances. Hence, there could be some movement of this species in and out of the Oil Sands Region and the duration of exposure of fish captured in the exposure area will be questionable. Conversely, questions will also arise as to whether fish captured in the reference area upstream of the Oil Sands Region had been previously exposed.

A radiotelemetry study on longnose sucker was initiated in 2000 to evaluate the mobility of longnose sucker in the Athabasca and Muskeg rivers and, thus, its suitability as a sentinel species for the Oil Sands Region (Golder 2002c). Of the 25 post-spawning fish radio-tagged near their spawning grounds in the Athabasca River, three did not survive. Based on the movements of those that did survive, the Athabasca River spawning subpopulation of longnose sucker appears to use the mainstem river in the Oil Sands Region primarily as a spring migration route to and from spawning sites at rapids located upstream of Fort McMurray.

The majority (16 out of 22) of radio-tagged fish were only found in the telemetry survey area during spring spawning, although two of these fish visited the Muskeg River before leaving the survey area. All 16 fish were radio tagged following spawning upstream of Fort McMurray in 2000, and five of these fish returned to the rapids area during the spawning season in 2001, after which they again left the survey area. Although a few fish moved downstream after spawning in 2000 and in 2001, the frequency of telemetry flights was not high enough to record whether the fish moved to Lake Athabasca. Although it is not known exactly where fish went outside the telemetry survey area, the results do show that the majority of radio-tagged longnose sucker were present in the survey area and utilized the mainstem Athabasca River in the Oil Sands Region only during the spawning period in the spring.

A smaller proportion (six out of 22) of the radio-tagged longnose sucker remained in the Athabasca River basin for a prolonged period of time, particularly in the fall and winter. These fish either utilized specific locations in the mainstem river from summer to winter, or are speculated to have used tributary streams other than the Muskeg River during the open water period, returning to the Athabasca River for the winter. Some fish remained in the mainstem river for the winter while others left the survey area later in the winter, possibly moving to Lake Athabasca.

Compared to longnose sucker that spawned in the mainstem Athabasca River, fish spawning in the Muskeg River exhibited greater use of the Athabasca River basin. In total, 11 of the 17 radio-tagged fish are known or believed to have utilized the Athabasca River and/or its tributaries during much of the year. A small number of the fish radio-tagged in the Muskeg River (two of 17 fish) may have used the Muskeg River for summer feeding in addition to spring spawning. Another nine fish were speculated to use the Athabasca River basin outside the telemetry survey area and were known to return to the mainstem river in the survey area in the fall or early winter. These fish spent all or part of the winter in the river, with some leaving the survey area in the late winter. The remaining six of the 17 radio-tagged longnose sucker left the telemetry survey area soon after spawning. Four fish left immediately, while two fish moved from the Muskeg River to the Athabasca River in the spring and then left the survey area for the remainder of the study. It is possible that these fish only utilized the river basin for spawning activity.

The population captured in the fall for the sentinel species program will have likely undergone sufficient exposure to the Oil Sands Region to be of use as a sentinel. The data indicate that fish captured in the Athabasca River during the fall have a high probability of having inhabited the river for a substantial portion of the year, likely moving out of the river to tributaries during the spawning period in the spring. It is the fish captured in the Athabasca River during the spring that appear to be transient because they enter the Athabasca River to access spawning grounds upstream of Fort McMurray, and then leave the river system immediately thereafter.

Results from the MFO analysis in longnose sucker in 1998 support the foregoing conclusion regarding exposure. Induction of MFO activity has been observed in fish exposed to some PAH compounds (e.g., benzo(a)pyrene), chlorinated aromatic hydrocarbons and complex mixtures such as petroleum oils (Hodson et al. 1991). Under the sentinel species study, MFO activity was measured as an indicator of exposure to MFO-inducing compounds present in the Oil Sands Region. Since these compounds are not present in the reference area, MFO induction was not expected in the reference population.

Mean hepatic MFO activity in longnose sucker from the Oil Sands Region was approximately 11 to 14 fold higher than in reference fish (Golder 1999). A similar level of induction was documented in 1995 (Golder 1996a). Induced MFO activity in fish within the Oil Sands Region is not surprising, but does provide a positive indication of exposure in the oil sands population and a lack of exposure in the reference population.

Reference Area

Some differences in habitat composition and availability between the oil sands and reference portions of the Athabasca River were found in 1998 (Golder 1999).

These differences were expected because of the distance between the two areas and natural, longitudinal changes in river and valley characteristics such as gradient, flow volume, confinement and substrate. However, the longitudinal river distance between the reference and oil sands areas was necessary to minimize mixing of the two fish populations. The differences in habitat were not believed to be sufficient to exclude the use of the Duncan Creek site as a reference area. The availability of the dominant bank habitat types is similar enough to provide a useful reference site to evaluate potential impacts from oil sands activities.

Some concern was expressed regarding differences in the composition of the two fish communities. The main differences in fish abundance between the oil sands and reference areas were the absence of lake whitefish and low abundance of walleye and goldeye in the reference area. However, longnose sucker was present in relatively high abundance in the reference area. The 1998 RAMP report concluded that the population in the Duncan Creek area would provide a good reference to compare population and fish health parameters. Since differences in several parameters between the two populations were measured in 1998, several cycles of monitoring will be required in order to understand the annual variability in both populations. Once understood, patterns in these differences can actually be used as a tool to detect changes in the Oil Sands Region.

Suitability of Longnose Sucker

Longnose sucker was identified as an optimal sentinel species in several studies due to an intermediate life span, fast growth rate, high fecundity, early maturation and its important role in the aquatic food web (Munkittrick 1992). These characteristics provide the maximum amount of information with the fastest response time to changes in the aquatic ecosystem. This species is present in sufficient abundance in both the Oil Sands Region and the reference area. The fish captured during the fall appear to inhabit the Athabasca River for a substantial portion of the year, thus ensuring adequate exposure to the Oil Sands Region, and the reference population are sufficiently removed from this area that mixing between the two populations is not expected to occur. Finally, the variability of the various parameters examined in these fish is of a magnitude that would allow differences due to true oil sands-related effects to be observed. Indeed, statistically significant differences between the two populations were found in 1998. Depending on the nature of the effect, an oil sands-related effect could be manifested in either larger or smaller differences than those already detected; therefore, it is the nature of these differences that must be monitored in the future.

7.2.5 Sentinel Species in Tributary Watercourses

The tributary sentinel species component was designed to provide information about the sustainability of regional fish resources in relation to fish health by examining specific indicator species. The objective of this component was to examine population, growth, health and reproductive parameters of an indicator species (slimy sculpin) in two major tributaries of the Athabasca River (i.e., the Muskeg and Steepbank rivers) in relation to regional conditions. Within this objective was the goal of determining the variability in the measured parameters relative to refining the study design of a long-term sentinel species monitoring program.

As described in the Athabasca River component, the sentinel species is used as an indicator of ecosystem health. The sentinel fish species is used to assess potential effects of stressors (e.g., industrial development) on fish populations. The performance (e.g., growth, condition and reproductive parameters) of the sentinel species inhabiting a particular site of interest (e.g., Oil Sands Region) is characterized relative to historical performance data and/or the performance of other populations. During the 2001 RAMP study (Golder 2002c), populations of slimy sculpin in the lower Muskeg River and lower Steepbank River were evaluated in relation to an upstream population, populations from other tributaries and RAMP data from 1999 (Golder 2000a).

For the sentinel species program, sampling sites within the area of current or future oil sands developments are termed ‘exposure’ sites, even though the sites may not be subject to the influences of oil sands activity at the present time. Sampling sites located outside the area of development, either upstream from exposure sites or on other tributaries, are termed reference sites since 2001. The exposure sites for monitoring in the Oil Sands Region included the lower Muskeg River and the lower Steepbank River. The reference sites included the upper Steepbank River, the Horse River and the Dunkirk River. Sampling conducted in 1999 included the two exposure areas and the Steepbank River reference site.

7.2.5.1 Methods

An assessment of habitat differences may be important in understanding differences in population parameters; therefore, the discussion below first examines habitat variability between the study sites and its potential influence. The differences between the exposure populations and the reference populations as well as the changes that occurred over time in the exposure populations were summarized and described. The differences and changes that were observed were placed into context by undertaking a preliminary examination of possible trends. An explanation of the significance of the observed differences then follows.

7.2.5.2 Results and Discussion

Reference Areas

The response of slimy sculpin in the Oil Sands Region will be assessed by observing changes in the exposure populations over time relative to slimy sculpin populations from the reference sites. Despite efforts to select reference sites that were as similar as possible to the exposure sites, differences in the physical habitat characteristics were evident, particularly for sites located on different river systems (Golder 2000a, 2001a). Differences in slimy sculpin abundance and habitat conditions among sites can make the interpretation of any differences observed in whole-organism characteristics less clear. Differences in physical habitat parameters (e.g., flow, water velocity, habitat type, substrate size, water chemistry and background levels of organic compounds), productivity, species composition and population density can all affect growth, health and other population parameters. Due to differences in habitat characteristics, any observed differences in whole-organism characteristics may be a function of habitat or anthropogenic influences, or both.

The assumption of the study design for the tributary sentinel species component of RAMP is that slimy sculpin from the three reference sites, in combination with populations from the exposure sites, represent the natural condition and range of variability for the slimy sculpin populations within the region. The multiple reference sites are used to ensure that the full range of natural variability in fish characteristics is defined for the region with respect to range and year-to-year variability, and to increase the understanding of the ecology of slimy sculpin in Athabasca River tributaries.

Findings After Two Years

Differences observed over the two years of monitoring are summarized in Tables 7.15 and 7.16. Each exposure area sampled in 2001 was compared to all three reference areas as well as to the same exposure area sampled in 1999. The magnitude of any difference that was statistically significant is presented as the percentage difference. For a given parameter and exposure site, it was considered possible that the performance of the exposure population differed from regional variability and had changed over time if all of the following criteria were met:

- the exposure site was significantly different from all three reference sites in a consistent manner (i.e., lower than all reference sites or higher than all reference sites);

- the 1999 and 2001 data for the exposure site was significantly different and the direction of the response was the same as when compared to the reference sites (i.e., higher or lower); and
- the 1999 and 2001 reference site data showed a different response than the exposure site over the same period.

Table 7.15 Summary of Differences (as %) Observed in Slimy Sculpin Between the Muskeg River Exposure Site in 2001 Relative to Reference Sites in 2001 and the Exposure Site in 1999

Sex	Parameter	Reference Areas 2001			Exposure 1999
		Dunkirk River	Horse River	Steepbank River	Muskeg River
female	total length (mm)	ns	30.00	14.54	4.74
	body weight (g)	ns	24.77	ns	23.76
	Condition factor	ns	12.68	ns	24.30
	age (y)	-40.35	-35.53	-27.63	-36.46
	Fecundity	ns	-13.02	-10.55	59.43
	LSI	ns	15.24	-21.02	27.53
	GSI	-46.99	-42.41	-31.32	-13.25
male	total length (mm)	ns	30.67	13.73	6.53
	body weight (g)	ns	16.91	ns	30.59
	condition factor	ns	17.48	ns	30.43
	age (y)	ns	-32.53	-26.11	-41.03
	LSI	ns	52.20	ns	ns
	GSI	-18.40	-22.21	-18.65	ns

Note: GSI = Gonad Somatic Index; LSI = Liver Somatic Index; ns = not significantly different.

Table 7.16 Summary of Differences (as %) Observed in Slimy Sculpin Between the Steepbank River Exposure Site in 2001 Relative to Reference Sites in 2001 and the Exposure Site in 1999

Sex	Parameter	Reference Areas 2001			Exposure 1999
		Dunkirk River	Horse River	Steepbank River	Muskeg River
female	total length (mm)	-8.61	21.65	7.18	-12.27
	body weight (g)	ns	23.19	ns	14.53
	condition factor	ns	12.93	-5.31	15.13
	age (y)	ns	ns	ns	ns
	Fecundity	15.42	ns	ns	73.47
	LSI	ns	24.62	-14.59	25.94
	GSI	-49.59	-45.24	-34.69	-26.92
male	total length (mm)	ns	26.32	9.94	-7.34
	body weight (g)	ns	ns	ns	12.62
	condition factor	ns	10.26	ns	13.25
	age (y)	60.53	ns	32.03	ns
	LSI	33.18	58.66	ns	42.24
	GSI	-26.87	-30.29	-27.09	-21.30

Note: GSI = Gonad Somatic Index; LSI = Liver Somatic Index; ns = not significantly different.

Based on both temporal and spatial comparisons in relation to the evaluation criteria, the Muskeg River exposure population showed no consistent differences for male fish and differences in two parameters for female fish. For male fish, most parameters showed no significant differences between the exposure site and one or more of the reference sites (Table 7.15). For relative gonad size (GSI) in males, the exposure site GSI was significantly smaller than the GSI for all three reference sites but had not changed from 1999, indicating that the exposure site may represent the lower range of variability for this parameter. For females, age and GSI were found to be significantly lower in the exposure population relative to all three reference populations. In addition, both parameters were lower at the exposure site in 2001 relative to 1999 but had not declined in the Steepbank River reference site over the same period.

For the Steepbank River exposure population, temporal and spatial comparisons indicated that one parameter was consistently different for both sexes. The GSI of both males and females was significantly smaller than in any of the reference populations (Table 7.16). In addition, there was a decrease in GSI for both sexes from 1999 to 2001 at the exposure site, with no decrease at the Steepbank River reference site for the same time period. For both sexes, all other parameters showed either no significant difference between the exposure site and one or more of the reference sites, or inconsistent differences (i.e., both positive and negative differences).

Examining Trends

The GSI and age of some exposure fish were clearly lower in 2001 than those of all three reference populations. In addition, the GSI of one male exposure population and both female exposure populations decreased over time, while GSI increased slightly for female reference fish and did not change for male reference fish. Overall, the data suggest that the lower GSI values at the Muskeg River (female fish) and Steepbank River (female and male fish) exposure sites may reflect a change relative to natural variation.

Rather than representing a change in relative gonad size, the differences in GSI between the exposure and the reference populations could reflect natural differences that exist among these populations. Based on the data collected to date, there are other factors that may explain the apparent changes in GSI.

One factor accounting for the smaller GSI in females at the Muskeg River exposure site may be the difference in age structure among populations. The mean adult age in the Muskeg River exposure population was significantly different (younger) than in all reference populations, and decreased significantly at the exposure site between 1999 and 2001. In 2001, year-1 fish were the dominant age class at the Muskeg River exposure site. In contrast, year-2 fish were the dominant age-class in all three reference populations. As a consequence of two thirds of adult exposure fish being one year of age, a smaller relative gonad size for this population would be expected, especially since first-time spawners typically have smaller gonads. Though patterns in age difference were different in Steepbank River fish (with exposure males being older than some reference populations), there was generally a shift towards younger dominant age classes in 2001 compared to 1999 (as seen in Muskeg River exposure fish) (Figures 7.40 and 7.41). The dominant age class went from four years to two years over that period. In contrast, the reference population shifted to age two being dominant in 2001, from age one in 1999.

Another factor that may affect GSI for exposure fish relative to reference fish is the bigger size of the exposure fish. Slimy sculpin from the two exposure sites were as big or bigger than reference fish with increases in weight and condition from 1999 to 2001 (Tables 7.15 and 7.16). Exposure populations appeared to be directing more energy towards growth than reference fish, which could explain the smaller GSI in both exposure populations. In addition, the actual gonad size (i.e., not corrected for carcass weight) in both male exposure populations was larger than in reference populations. Though this was not the case with females, the actual amount of gonadal development in the male fish from the exposure populations (including the younger fish from the Muskeg River) was higher than in reference fish, despite the lower GSI values.

Figure 7.40 Mean (± SE) of Several Key Parameters for Female Slimy Sculpin from the Steepbank River Exposure and Reference Sites and the Muskeg River Exposure Site, 1999 and 2001.

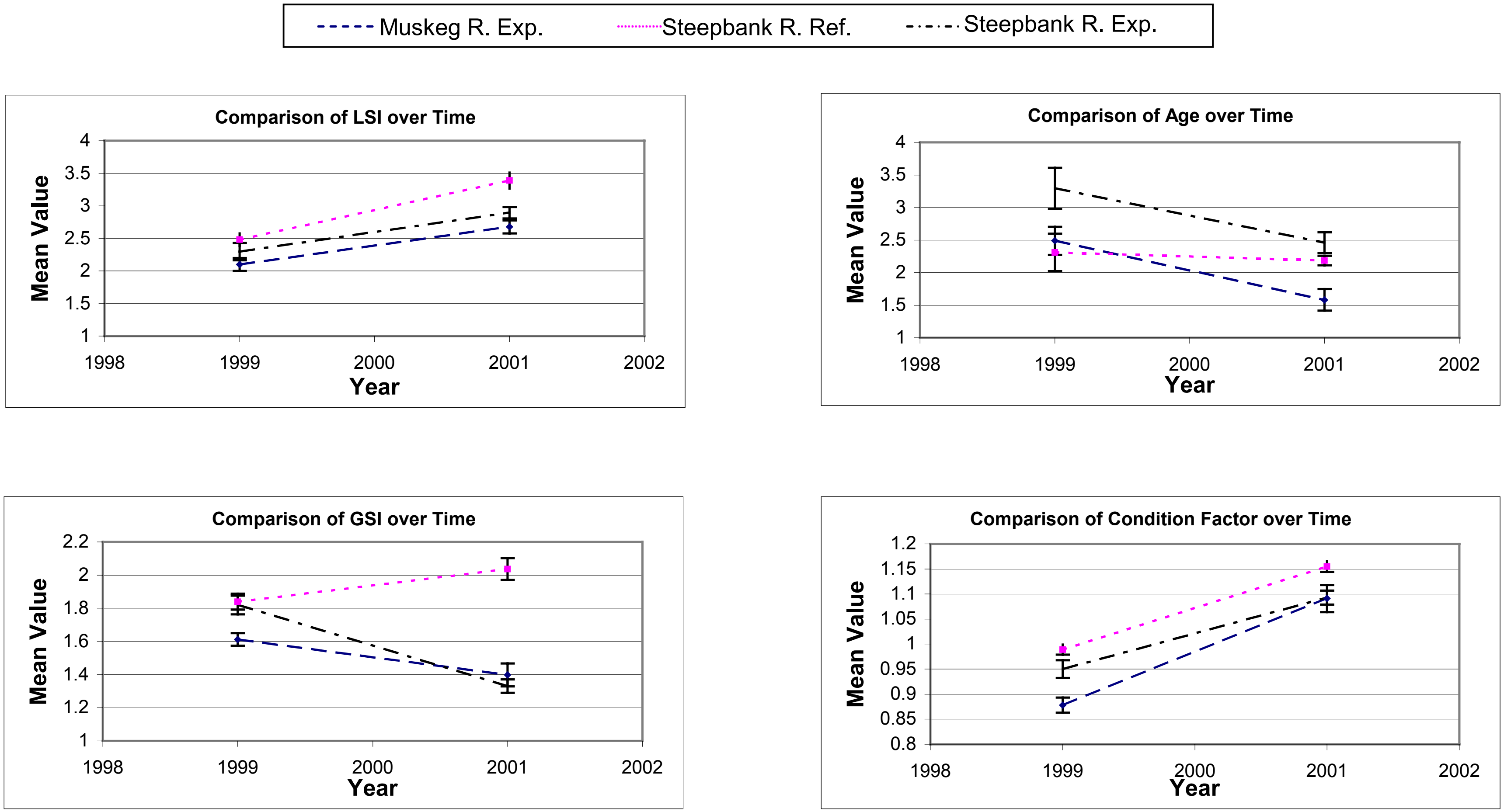
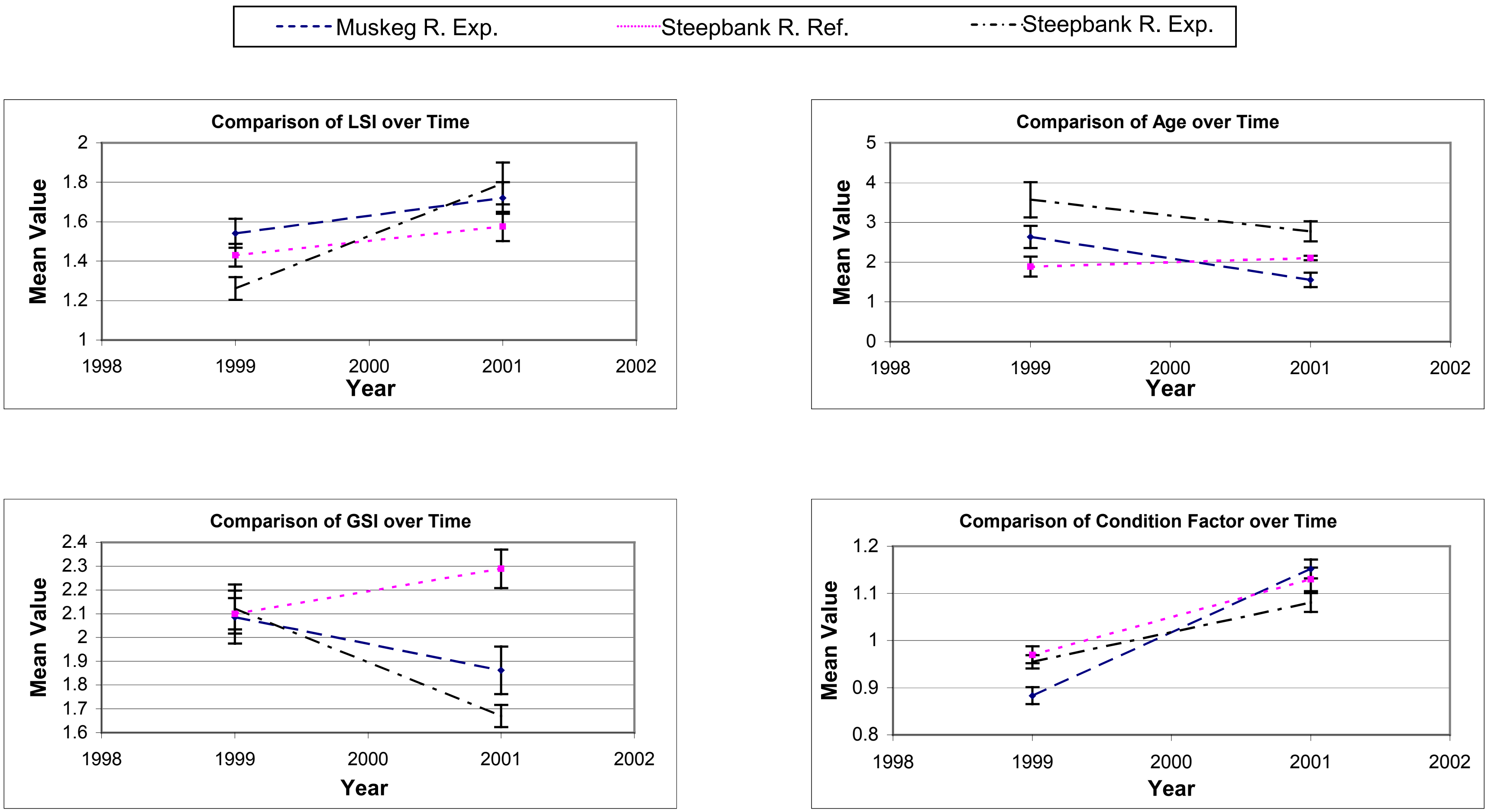


Figure 7.41 Mean (± SE) of Several Key Parameters for Male Slimy Sculpin from the Steepbank River Exposure and Reference Sites and the Muskeg River Exposure Site, 1999 and 2001.



The observed differences between exposure and reference populations that were determined to be significant may occur naturally, or may represent a deviation from natural variation. Further years of data would be required to make this assessment. As a result, conclusions regarding potential changes in the reproductive potential of sentinel species populations would be premature. Now that RAMP is employing three reference areas, such apparent deviation from natural trends will be more convincing. A technique that should be used in the future to assess whether a change has occurred is the analysis of trends. This analysis would allow the investigator to detect changes over time in the oil sands populations that do not correspond to natural changes over the same period. Trend analysis is not possible with only one or two years of data.

Figures 7.40 and 7.41 graphically illustrate how trend data can be presented. Following several years of data, the variability among years can be observed, and any deviation from this trend can be assessed statistically (Underwood 1992, 1993). Understanding the temporal (in this case, annual) variability is key to detecting deviations and, thus, change. As an example, the GSI of both male and female exposure fish appear to be following a similar trend in time, and one that is different than that of the reference population (Figures 7.40 and 7.41).

Significance of Observed Differences

In many studies, a statistically significant difference in biological measures is used as evidence that a change has occurred. Indeed, several industry-wide monitoring programs have adopted this approach (Environment Canada 1998, 2002). Unfortunately, extrapolation from statistical significance to ecological significance is difficult because statistical significance depends upon sample size, and may not relate to the size of the impact.

The approach proposed by Kilgour et al. (1998) was used to determine the ecological significance of the observed differences. They define ecologically-relevant differences as observations from impact locations that fall outside the normal range of variation based on reference-location data. They also define the normal range as the region enclosing 95% of reference-location observations. The 95% region can then be expressed generically as standard deviations in univariate responses. For example, in single responses that are normally distributed, the region defined by $\mu \pm 1\ \sigma$ incorporates about 67% of the population, and $\mu \pm 1.96\ \sigma$ incorporates about 95% of the population. These calculations were performed with the RAMP data, and all mean values of exposure population parameters fell within the normal range based on the three reference populations; however, GSI in female fish was close to the lower boundary of the normal range. Accordingly, these populations should be monitored more frequently.

7.2.6 Muskeg River Fish Counting Fence

The purpose of the counting fence was to provide basic data on the species composition and abundance of large-bodied fish in the Muskeg River basin. Biological parameters measured included population size and age structure, fish condition and growth. In addition, the counting fence provides information about the year-to-year variability in these parameters.

7.2.6.1 Methods

Data from 1998 and 2001 (Golder 1999, 2002c) were compared to data reported in earlier counting fence studies to assess variability. Previous studies on the mainstem Muskeg River and Jackpine Creek, the largest tributary to the Muskeg River, were examined as indications of fish presence in the watershed. Details of the various studies were considered when assessing the comparability of the data; these included fence location, timing of fence installation, length of study, season and discharge conditions during the study period. Consideration was given to how differences in these factors affect conclusions regarding fish abundance estimates.

7.2.6.2 Results and Discussion

The results of fish counting fence studies are presented for the mainstem Muskeg River (Table 7.17) and Jackpine Creek (Table 7.18). Additional studies were attempted for the Muskeg River, but fence installations were unsuccessful due to high flows (RRCS 1974; Bond and Machniak 1979).

Table 7.17 Summary of Fish Counting Fence Results for Large-Bodied Species, Mainstem Muskeg River

Species	Spring/Summer 1976[a]		Spring 1977[b]		Spring 1995[c]		Fall 1995[c]		Spring 1998[d]		Spring 2001[e]	
	Upstream	Downstream	Upstream	Downstream	Upstream	Downstream	Upstream	Downstream	Upstream	Downstream	Upstream	Downstream
Arctic grayling	305	78	161	11	14	49	2	74	0	2	0	0
bull trout	0	0	3	0	0	0	0	0	0	0	0	0
burbot	1	2	1	0	0	0	0	0	0	0	0	0
lake cisco	0	0	1	0	0	0	0	0	0	0	0	0
lake whitefish	3	14	7	6	0	0	0	0	0	0	0	0
longnose sucker	2,837	2,191	1,641	1,004	308	36	0	21	0	13	11	1
mountain whitefish	33	101	50	17	0	0	0	0	0	1	0	0
northern pike	131	155	433	59	126	3	0	117	0	0	32	3
walleye	4	3	8	5	1	0	0	0	0	0	0	0
white sucker	2,839	1,669	2,970	1,385	299	1	0	89	0	2	71	8
Total	**6,153**	**4,213**	**5,275**	**2,487**	**748**	**89**	**2**	**301**	**0**	**18**	**114**	**12**
Overall Total	**10,366**		**7,762**		**837**		**303**		**18**		**126**	

[a] Bond and Machniak 1977 – fish fence operated near the river mouth from April 28 to July 30, 1976.
[b] Bond and Machniak 1979 – fish fence operated near the river mouth from April 28 to June 15, 1977.
[c] Golder 1996a – fish fence operated 16.5 km upstream of the river mouth from May 6 to 31 and from September 19 to October 28, 1995.
[d] Golder 1999 (RAMP) – fish fence operated 16.5 km upstream of the river mouth from May 8 to 14, 1998.
[e] Golder 2002c (RAMP) – fish fence operated near the river mouth from April 28 to May 26, 2001 (wash-outs affected operations on four days between April 29 and May 10, and only partial channel blockage was possible for the period May 11 to 19).

Table 7.18 Summary of Upstream Fish Trap Results for Jackpine Creek

Species	1973[(a)]	1981[(b)]	
	Near Creek Mouth	5.5 km Above Creek Mouth	14.2 km Above Creek Mouth
Arctic grayling	6	904	82
longnose sucker	1	583	1
northern pike	0	1	0
white sucker	1	814	41
Total	**8**	**2,302**	**124**

(a) Lombard 1973 – hoop net operated from April 29 to May 13, 1973.

(b) O'Neil et al. 1982 – hoop trap/fence operated from May 2 to 18 (5.5 km) and May 5 to 19 (14.2 km), 1981.

The counting fence studies (Tables 7.17 and 7.18) indicate that migrations of longnose sucker, white sucker and Arctic grayling, and smaller migrations of northern pike and mountain whitefish occur in the mainstem Muskeg River and Jackpine Creek. Fewer lake whitefish, walleye, lake cisco, burbot and bull trout were captured.

The captures at the counting fence appear to indicate that fewer fish were present in the Muskeg River watershed in recent years (i.e., 1995, 1998 and 2001), in comparison to past years (i.e., 1976, 1977 and 1981). The total number of fish captured declined from 10,366 in 1976 to 18 in 1998, with a slight increase to 126 in 2001. However, this variability was likely due, in part, to changes in the counting fence location and changes in the duration and season of fence operation.

Counting Fence Location

Two fence sites have been used on the mainstem Muskeg River: 1) near the river mouth (i.e., 1976, 1977 and 2001), and 2) 16.5 km upstream of the river mouth (1995 and 1998). The most fish and greatest diversity occurred when the counting fence was installed near the river mouth and for longer periods in 1976 and 1977.

As reported by Golder (2003b), the mainstem of the Muskeg River was divided into six reaches with differing habitat characteristics. These reaches were numbered sequentially beginning with the lowermost section of the river. The fence site located 16.5 km upstream of the river mouth was at the upper boundary of Reach 3. Reaches 1 to 3 (situated downstream of the fence site) were moderate to high gradient sections and provided a wide diversity of habitat types, including potential spawning habitat for fish species that prefer swift flowing rocky habitat. Reach 4 (located upstream of the fence site) was a low gradient section dominated by slow moving water. Infrequent riffle areas provided a small amount of possible spawning habitat. Further upstream, Reaches 5 and 6 consisted mainly of beaver impoundments.

Fish species occurrence was higher in the lower 16.5 km of the Muskeg River (Golder 2003b) due to greater habitat diversity and the proximity of the Athabasca River. Several species from the Athabasca River (e.g., lake whitefish, lake cisco, yellow perch) use the lower section of the Muskeg River on an occasional basis. Therefore, the number of fish species that could potentially be captured was higher at the fence site located at the river mouth.

Spawning activity is believed to occur in the lower three reaches of the river for a number of species, based on the habitat conditions. Only a portion of the spawning run may continue beyond the lower 16.5 km of the river. Therefore, the number of fish that could potentially be captured at the 16.5 km site may be lower than at the river mouth.

Historical data (Golder 2003b) provide a limited amount of information concerning spawning in the watershed relative to the counting fence sites. Although good quality rocky spawning habitat is present in the lower three reaches of the Muskeg River, spawning investigations were not conducted for this segment or in the mainstem of the river. Spawning has been confirmed at isolated sites in the lower reaches for longnose and white sucker from incidental observations. Spawning activity has been documented in the upper watershed (above 16.5 km) in Jackpine Creek and Muskeg Creek. Jackpine Creek has been identified as a significant spawning tributary for Arctic grayling and suckers, with a small amount of northern pike spawning suspected to occur. Muskeg Creek has been identified as a spawning area for suckers.

Study Season, Timing and Duration

Most of the counting fence studies were conducted in the spring to document upstream spawning migrations. The fall 1995 investigation was an exception. Fall counting fence results are not directly comparable to spring fence data and are not suitable for assessing fish abundance for spring spawning species. For the spring counting fences, timing of installation relative to ice-out is important. Installation immediately after ice-out would be expected to capture large numbers of fish, particularly Arctic grayling. Study duration (i.e., the number of days the fence remained in place following ice-out) would also influence the total number of fish that could be captured at the fence site.

River Discharge

Examination of the relation between flow records and capture was inconclusive, as fish movements were recorded at a variety of flow levels. Discharges during the combined fence studies ranged from 0.5 to 12.2 m^3/s, with varying flows during each study period. Fish movements were found to be more dependant on seasonal timing than discharge, with most upstream movement occurring between ice-out and the middle of May, regardless of flow regime.

Study Comparability

The counting fence studies in 1976 and 1977 were comparable because both fences were located near the Muskeg River mouth and included the majority of the spring migration period. Direct comparison of the numbers of upstream migrants between the two years appears to be acceptable; however, due to the much longer duration of the 1976 fence study, direct comparison of downstream numbers may not be acceptable.

The spring 1995 fence, although it covered a good portion of the spring migration period, was located 16.5 km upstream of the river mouth. As such, it may have captured only some of the fish migrating upstream into the Muskeg River watershed. However, the fence would have captured fish moving upstream into the upper reaches of the Muskeg River or destined for Jackpine Creek or Muskeg Creek. The fall 1995 fence was also located 16.5 km upstream of the river mouth but is not comparable to other studies, which all occurred in the spring.

Due to the influences of study timing and duration, the results from the 1998 counting fence study were entirely inconclusive regarding the level of fish use of the Muskeg River watershed. The fence was installed well after ice-out and was only left in place for a short duration (i.e., seven days). No upstream migrants were recorded. The fence was installed too late to assess upstream movements and was not left in place long enough to assess downstream movements. Therefore, the results of the 1998 study were largely discounted.

The 2001 counting fence study was located near the river mouth and was in place for an extended period immediately after ice-out. However, the 2001 fence results are not comparable to the 1976 and 1977 studies, because the fence was breached on several occasions (i.e., only partial coverage of the channel was possible for a portion of the study) and the fence did not monitor the full spring migration. Therefore, the 2001 results were inconclusive.

Variability in the number of fish captured in the various counting fence studies is addressed by species in the following sections, taking into consideration differences in study design between years. Population parameters were compared between years for northern pike and white sucker, the only species for which 30 or more fish were captured and measured during the RAMP counting fence studies (Table 7.17).

Arctic Grayling

The largest number of Arctic grayling caught in the mainstem Muskeg River was 305, in spring 1976 (Table 7.17). In the following spring, 161 upstream migrants were captured. This may indicate that some variability in the number of Arctic grayling in this watershed exists but it may indicate that a portion of the run was missed in 1977. The largest number of Arctic grayling captured at a counting fence in the Muskeg River watershed was 904. These fish were captured during the upstream migration in Jackpine Creek during spring 1981 (Table 7.18). This large number of Arctic grayling captured in Jackpine Creek may be a reflection of a larger number of fish in the Muskeg River watershed in 1981, compared to 1976 and 1977.

Bond and Machniak (1979) felt that a substantial portion of the Arctic grayling run was missed in both 1976 and 1977. In both years, the fence was installed several days after ice-out, at which time the Arctic grayling run was well under way. Therefore, the numbers of fish entering the Muskeg River watershed in 1976 and 1977 would have been higher than the number captured. On the other hand, O'Neil et al. (1982) believed that fence installation in 1981 was early enough to capture the majority of the run in Jackpine Creek. Therefore, the differences in the number of fish captured in 1976 and 1977 compared to 1981 would be less. Due to this uncertainty, the amount of variability in the numbers of Arctic grayling using the Muskeg River watershed in the past could not be conclusively determined.

In the spring of 1973, Lombard (1973) captured in a hoop net six Arctic grayling entering Jackpine Creek. It was not reported if the net covered the entire channel; therefore, it is not known to what extent the 1973 operation would be comparable to the 1981 counting fence, when a much larger number of fish was captured. Lombard (1973) suggested that the low numbers caught in 1973 may have been due to the presence of a large beaver dam downstream of the trapping site that appeared to be a barrier to fish.

The number of Arctic grayling recorded in the spring of 1995 at the upper fence site (14 upstream and 49 downstream) indicate that the fence was installed too late to capture the upstream migration, as the majority of fish were captured returning downstream. A total of 123 fish were captured as they left the upper

Muskeg River watershed in the spring and fall of that year (Table 7.17). Arctic grayling recorded in 1995 ranged from 240 to 380 mm in fork length (Golder 1996a). These results indicate that, as of 1995, a spawning run of Arctic grayling was still present in the Muskeg River watershed.

In spring 2001, the counting fence was installed at the mouth of the Muskeg River immediately after ice-out in an attempt to provide data comparable to the 1976 and 1977 studies. However, the integrity of the fence was breached on a few occasions. In addition, only part of the channel was blocked for a nine day period. In 2001, no Arctic grayling were captured even though the fence was operational for a period that would typically include at least a portion of the Arctic grayling run.

In summary, the counting fence results from the mainstem river and Jackpine Creek have been highly variable. Estimates of the number of Arctic grayling using the watershed ranged from a high of 904 fish in 1981 to zero in 2001. We suspect that some of the variability may have been an artifact of sampling.

Northern Pike

Northern pike was the most abundant sport fish species captured during the various counting fence studies in the mainstem Muskeg River (Table 7.17). The largest number, 433, was captured while fish moved upstream in the Muskeg River during spring 1977. In 1976, 131 northern pike were captured as they entered the watershed.

In spring 1995, 126 northern pike were captured as they moved upstream past the upper fence site (16.5 km above the Muskeg River mouth). How comparable the 1995 results are to the captures made in 1976 and 1977 fences would depend on the portion of the northern pike run that typically continues upstream past the upper fence site. Captures at the Jackpine Creek counting fence (Table 7.18) indicated that few northern pike enter this tributary. However, past studies have shown that suitable habitat for northern pike occurs in the upper mainstem river (Golder 2003b). Similar numbers of northern pike were captured in the spring and fall, 1995; this indicates that most of the fish likely remained in the upper river for the summer. The number of northern pike recorded at the upper fence site in 1995 was similar to the number recorded in 1976 at the lower fence site, suggesting that the 1995 and 1976 runs may have been comparable in size.

In spring 2001, the counting fence was located at the Muskeg River mouth and captured 32 northern pike. Because the fence did not operate efficiently in 2001, it is likely that only a portion of the upstream migration was captured. The results did, however, confirm that northern pike were present in 2001.

Figure 7.42 presents the length frequency distributions for northern pike from the counting fence studies that had a sufficient number of individuals. A high degree of variability is apparent in the size of northern pike comprising the spring runs in the Muskeg River watershed. In 1976, the fish were primarily 401 to 550 mm in length (Bond and Machniak 1977) while in 1977, most fish were less than 401 mm (Bond and Machniak 1979). In both years, the spring run consisted mainly of immature or maturing fish. A variety of fish sizes were recorded in 1995, but the proportion of the population consisting of larger fish was greater than in either 1976 or 1977. In 2001, most of the fish were greater than 500 mm, indicating a greater portion of the run likely consisted of adult fish than in previous years. Statistical comparison of length frequency distribution was conducted using the non-parametric multiple comparisons for non-parametric repeated-measures analysis of variance test (Appendix III). No significant differences were found between years.

Patterns in age distribution (Figure 7.43) are similar to length frequency comparisons, with a larger proportion of the population consisting of older fish in 1995 and 2001, compared to 1976 and 1977. It may be that more adult northern pike were present in the Muskeg River watershed in recent years and that more spawning activity is occurring in the basin. This is supported by the northern pike radiotelemetry study in the spring of 2000, when the majority of northern pike captured in the Muskeg River were adult fish in spawning condition (Golder 2001a).

The various length-weight regressions for northern pike are compared in Figure 7.44. The regression lines for the historical studies were provided as regression equations in the relevant reports, but the raw data were not available to allow statistical comparisons. In general, the condition of northern pike was comparable among years, with fish of a given length achieving similar weights. The weights of male northern pike less than 480 mm in length were somewhat higher in 1995 than in other years. A comparison of growth rates for aged fish from the counting fence studies show that northern pike length-at-age was similar in 1976, 1977 and 1995 (Figure 7.45). The data from 2001 indicates that size-at-age was somewhat higher for younger fish and lower for older fish than in the previous years.

Figure 7.42 Length Frequency Distributions for Northern Pike, Muskeg River Counting Fence Studies, 1976 to 2001

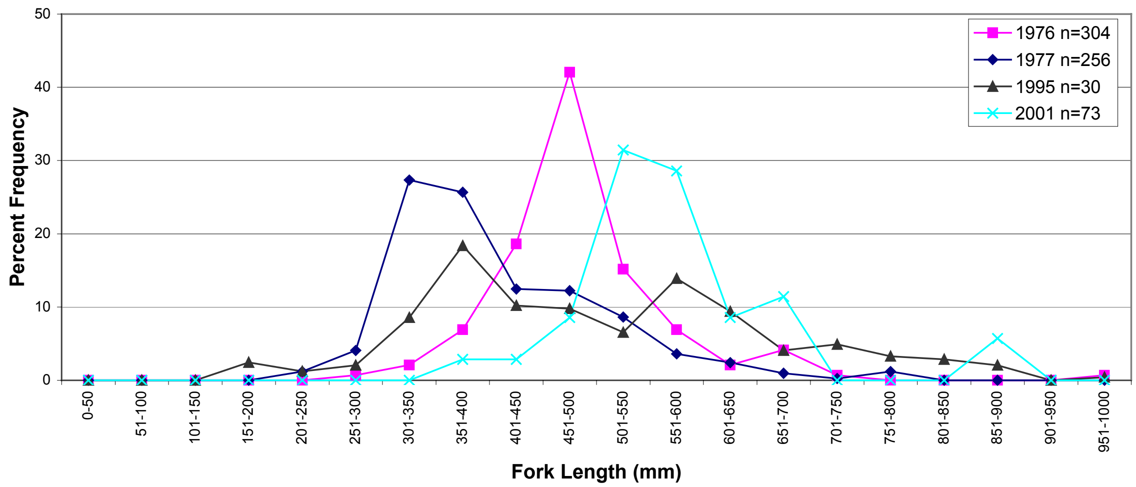


Figure 7.43 Age Frequency Distributions for Northern Pike, Muskeg River Counting Fence Studies, 1976 to 2001

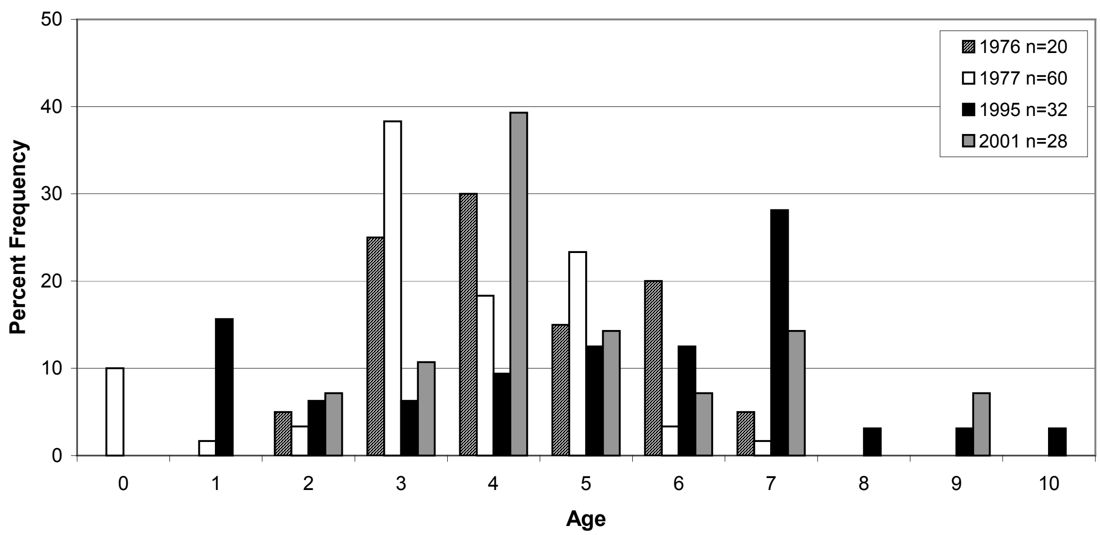


Figure 7.44 Length-Weight Regression Analyses for Northern Pike, Muskeg River Counting Fence Studies, 1977 to 2001

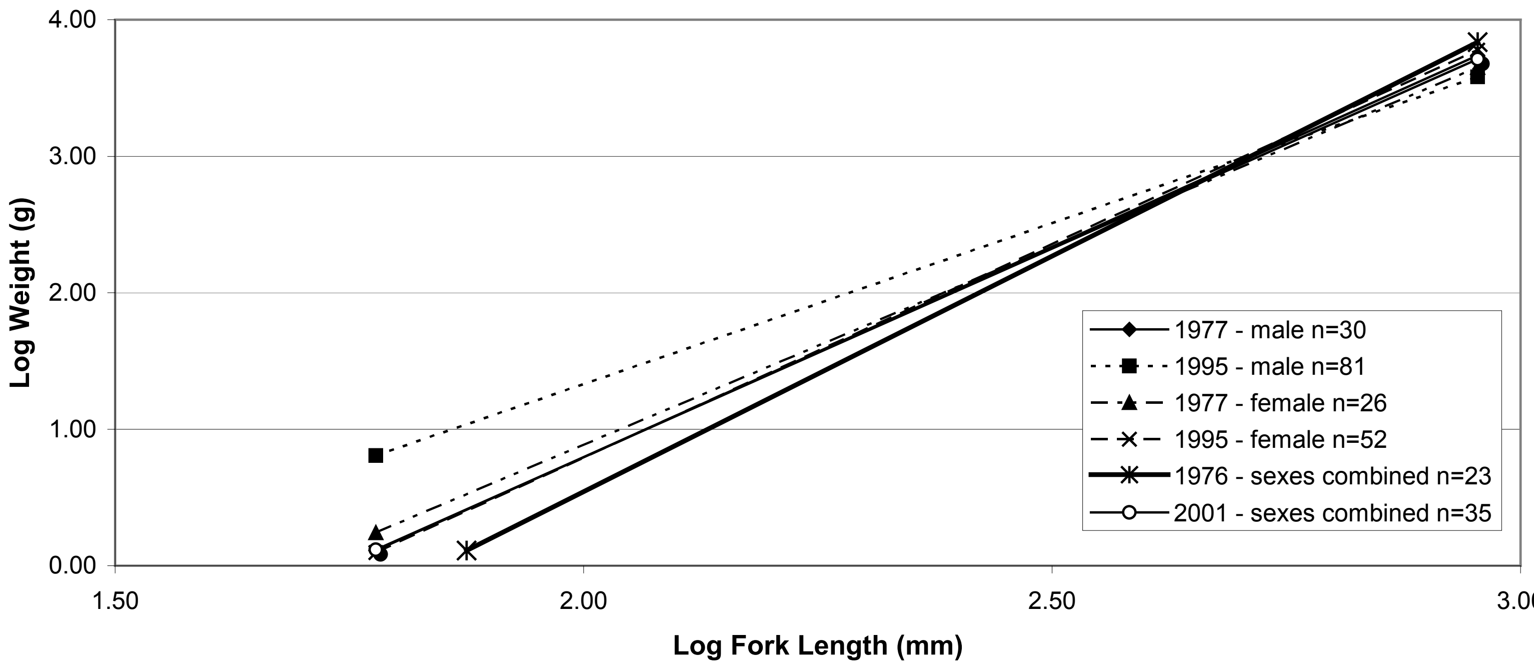
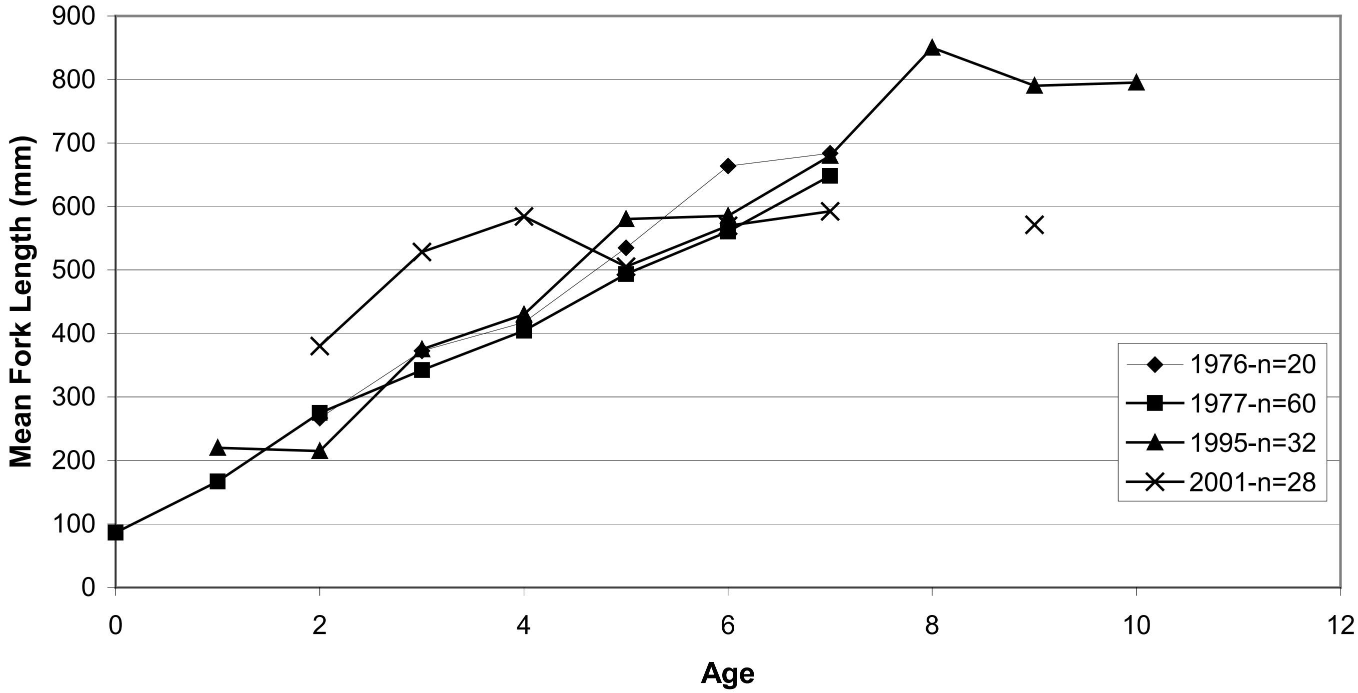


Figure 7.45 Length at Age Analyses for Northern Pike, Muskeg River Counting Fence Studies, 1976 to 2001



In summary, the number of northern pike captured in counting fence studies in the Muskeg River watershed varied from zero to 433 fish, although a portion of this variability was due to differences in study design between years. It appears that northern pike abundance was higher in 1976, 1977 and 1995 compared to the RAMP years. Comparison of the condition and growth of northern pike using the Muskeg River watershed was similar to previous years. In addition, fish using the watershed appear to be generally older, suggesting increased use of the Muskeg River by spawning adults.

Longnose Sucker

The counting fence results indicate that longnose sucker is one of the most abundant large-bodied species in the Muskeg River watershed. A high of 2,837 longnose sucker was captured as they moved upstream in the Muskeg River in spring 1976 (Table 7.17). In a comparable study in 1977, the number of fish captured in the spring (1,641) was 23% lower, indicating some annual variability in the number of fish in the watershed.

In spring 1995, 308 longnose sucker were captured as upstream migrants at the upper fence site (km 16.5), much fewer than captured in 1976 and 1977 at the lower fence site. In the 1981 Jackpine Creek counting fence study (Table 7.18), 583 longnose suckers were captured. Therefore, runs of at least this magnitude can occur at the upper fence site. Although the results were somewhat inconclusive, it appears that the number of longnose sucker using the Muskeg River watershed in 1995 was considerably lower than in 1981, and possibly 1976 and 1977.

A small number of longnose sucker (11) were captured moving upstream in the lower Muskeg River in 2001. The number of fish recorded in 2001 was considerably lower than was observed in 1976 and 1977, and was also lower than the number captured at the upper fence site in 1995. Although the results of the 2001 study are inconclusive because of breeches in fence integrity, the results indicate that longnose sucker were less abundant in 2001 than in 1976, 1977 and 1981.

White Sucker

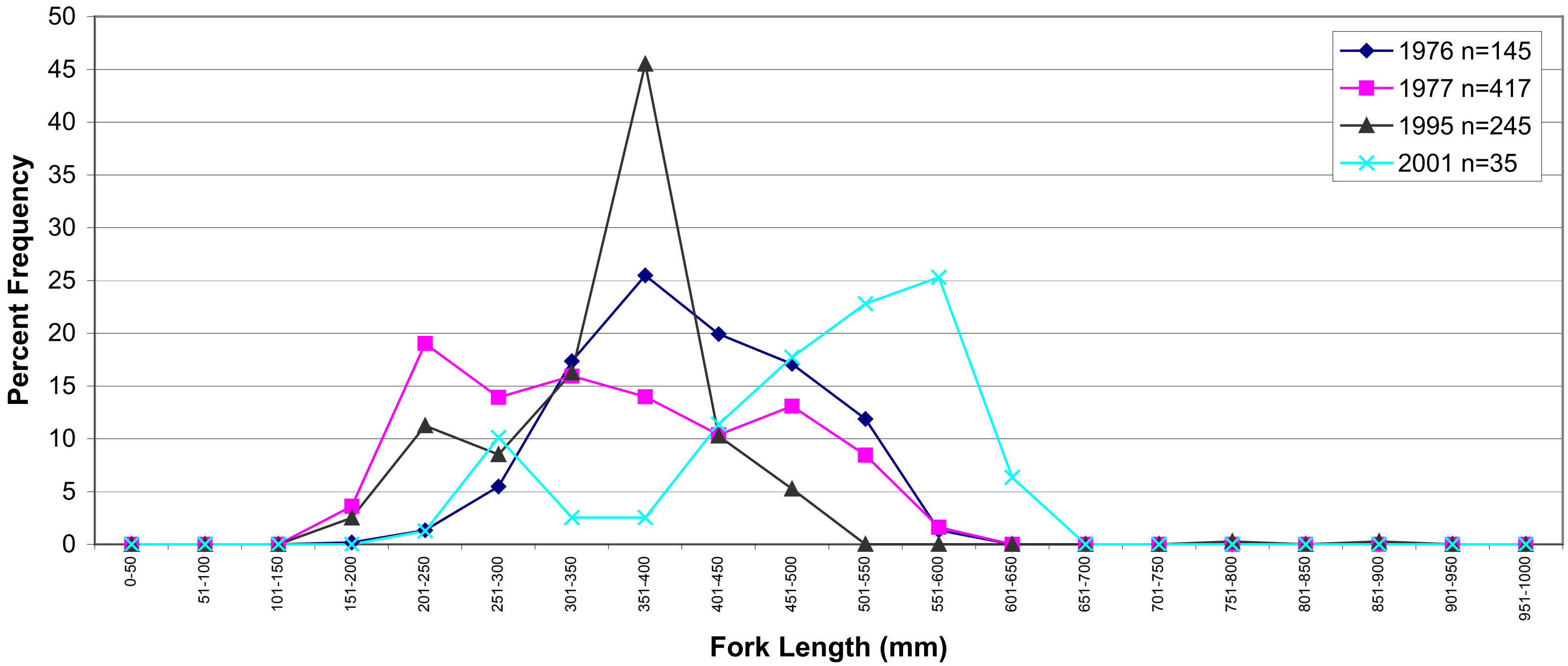
The counting fence results indicate that white sucker is one of the most abundant large-bodied species in the Muskeg River watershed. High numbers were captured entering the Muskeg River in 1976 (2,839) and 1977 (2,970) (Table 7.17).

In spring 1995, 299 white sucker were captured at the upper fence site (km 16.5), much lower numbers than were recorded in 1976 and 1977 at the lower fence site. In the 1981 Jackpine Creek counting fence study (Table 7.18), a spawning run of 814 white suckers was documented. Therefore, a run of at least this magnitude would have occurred at the upper fence site in 1981. Although these results are somewhat inconclusive, it appears that the number of white sucker in the Muskeg River watershed in 1995 was lower than in 1981, and possibly lower than in 1976 and 1977.

In total, 71 white sucker were captured in the upstream trap located in the lower Muskeg River during 2001. The catch was considerably lower than that observed in 1976 and 1977, and was also lower than the number captured at the upper fence site in 1995. Although the 2001 counting fence was breached, the results indicate that white sucker were less abundant in 2001 than in 1976, 1977 and 1981.

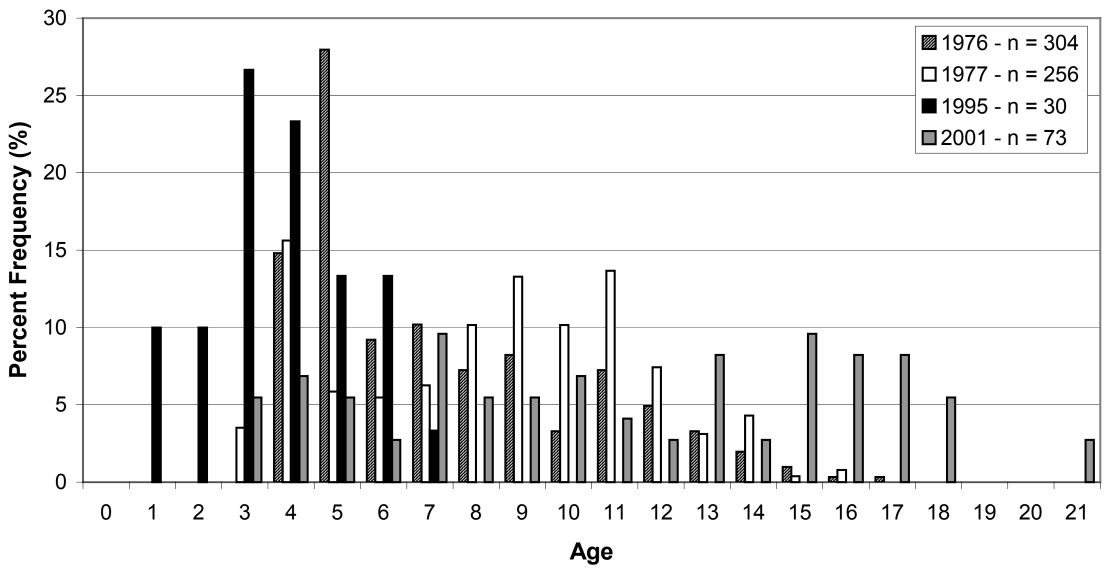
Figure 7.46 compares the length frequency distributions for white sucker captured at the various counting fences (i.e., studies that had sample sizes, $n>30$). The distribution of length of the catch varied between years. In 1976, most white suckers in the spring run were in the 301 to 500 mm size range. In 1977, this size range was well represented, but individuals less than 301 mm in length also made a significant contribution. Bond and Machniak (1979) described an early run of immature white sucker in 1977 that was not observed in 1976; this suggested that this component of the run may have been missed in 1976. In 1995, the size distribution was comparable to 1977, with small and large fish present. The white sucker captured in 2001 were generally larger (i.e., mainly between 401 and 650 mm). Statistical comparison of length frequency distributions indicated that differences between years were not significant (Appendix III).

Figure 7.46 Length Frequency Distributions for White Sucker, Muskeg River Counting Fence Studies, 1976 to 2001



The age distribution data (Figure 7.47), although variable among years, indicate that white sucker in the Muskeg River watershed were typically three years of age or older; age one and two fish were documented in 1995. The major peaks in age distribution during the various studies were: eight to 11 years old in 1976, four and five years old in 1977 and three to four years old in 1995. In 2001, the age distribution was more evenly spread among ages, but a larger proportion of the sample was older (ages 15 to 18) compared to previous years.

Figure 7.47 Age Frequency Distributions for White Sucker, Muskeg River Counting Fence Studies, 1976 to 2001



Length-weight regressions were determined for white sucker captured in the various counting fence studies (Figure 7.48). It is apparent that the condition of white suckers from the Muskeg River, as indicated by the weight achieved for a given size, was very similar for all years studied. Growth rates based on size-at-age (Figure 7.49) were generally similar between years. There were some differences in the 2001 data which indicate that growth rates for this species have been more variable in recent years, with fish seven or younger having higher growth rates than previous years, and fish aged nine, 10 and 11 having experienced lower growth rates than previous years.

Figure 7.48 Length-Weight Regression Analyses for White Sucker, Muskeg River Counting Fence Studies, 1976 to 2001

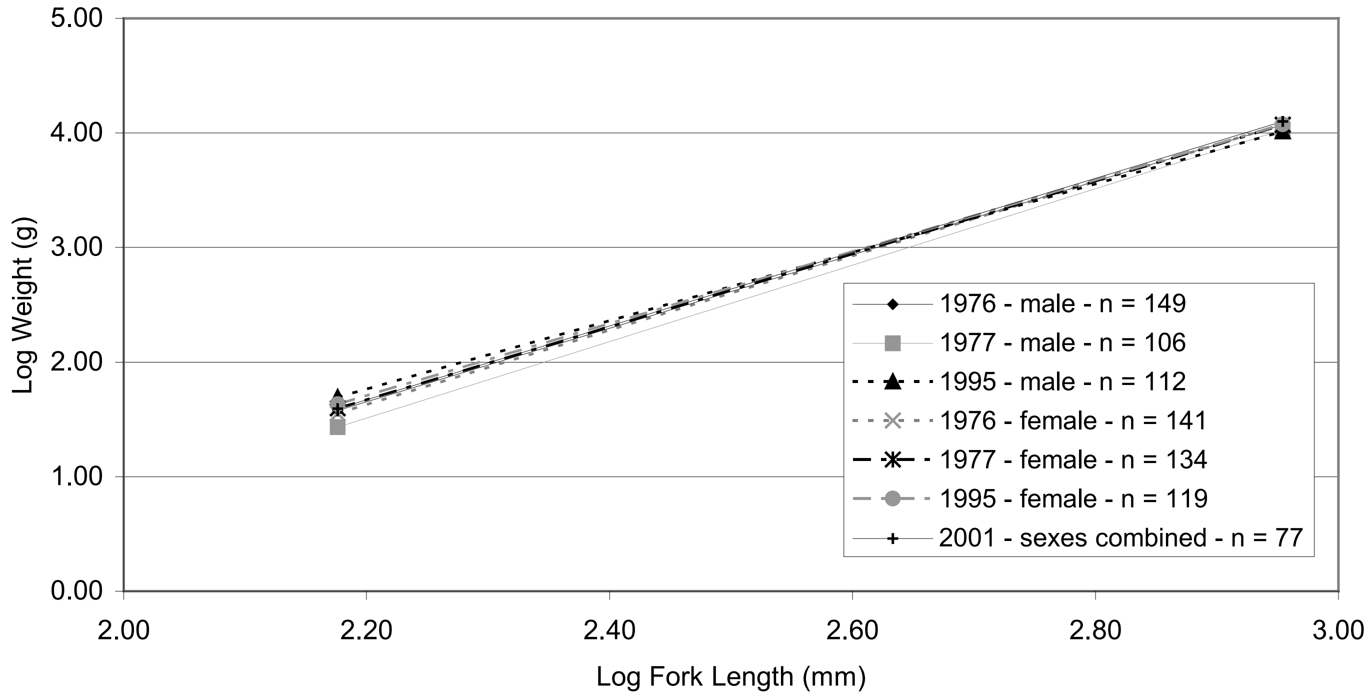
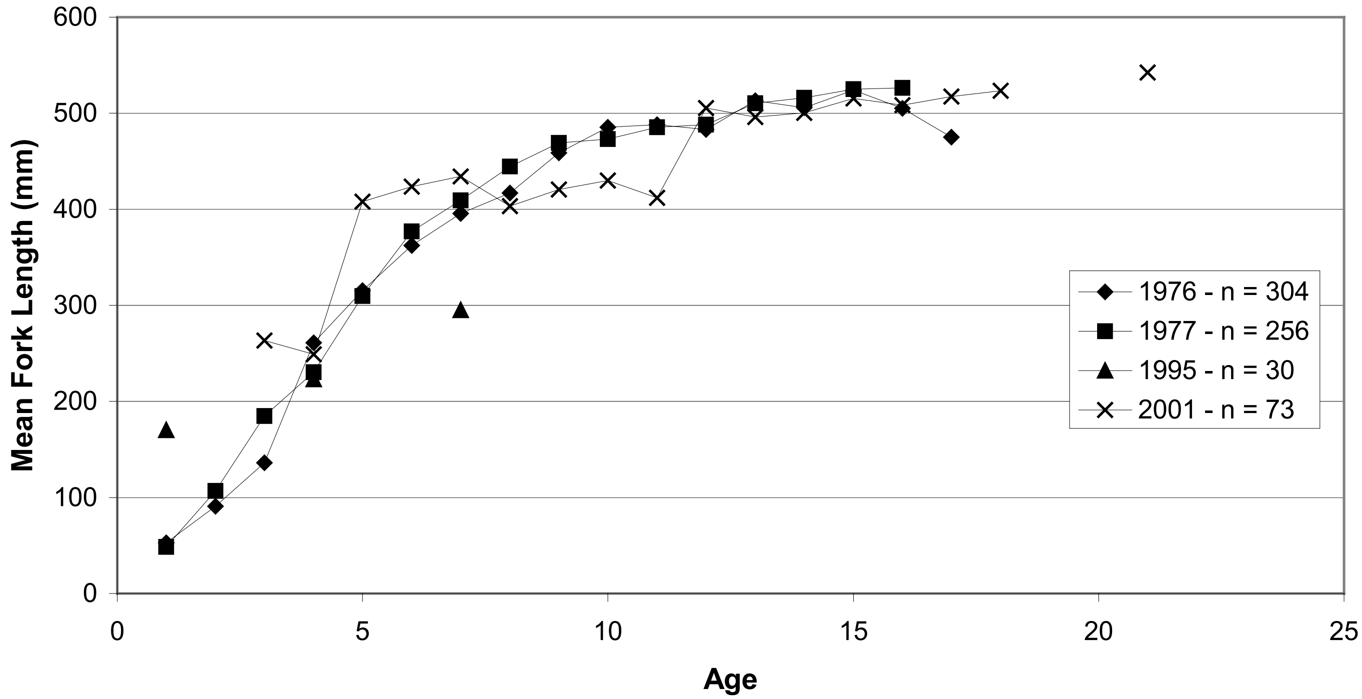


Figure 7.49 Length at Age Analyses for White Sucker, Muskeg River Counting Fence Studies, 1976 to 2001



Mountain Whitefish

Mountain whitefish were captured in low to moderate numbers during the 1976 and 1977 counting fence operation in the Muskeg River. Highest numbers were recorded in 1976, when 33 fish were captured moving upstream into the watershed and 101 fish were captured leaving the river. A slightly higher number (50) was recorded moving upstream in 1977, with a smaller number (17) observed moving downstream. This species was seldom recorded in subsequent studies when the fence location was moved to 16.5 km upstream of the river mouth (Table 7.17). Although small numbers of mountain whitefish are known to occur in Jackpine Creek in some years (Golder 2003b), it appears that most mountain whitefish in the watershed utilize the lower portion of the Muskeg River. Low numbers for this species captured since 1977 likely reflect the location of subsequent counting fences rather than variations in fish abundance in the watershed.

Other Species

Five other fish species were captured by the counting fence (Table 7.17). In order of decreasing abundance these species were lake whitefish, walleye, burbot, bull trout and lake cisco. These species were rare (44 fish). These species also are primarily restricted to the lower reaches of the river and are mainly associated with the Athabasca River. As such, the number of species recorded in the counting fence studies was reduced in 1995 and 1998, when the fence was moved from the mouth to 16.5 km upstream. Of the incidental species, only walleye were captured at the upper fence site (one individual).

7.2.7 Conclusions and Recommendations

Fisheries inventory in the Athabasca River

Data generated by the Athabasca River inventory is best suited for assessing abundance and features of populations of large-bodied fish species, rather than fish community structure because biases are associated with the primary sampling technique: electrofishing. In comparing the RAMP inventory with historical data, it appears that species composition and relative abundance for large-bodied species has remained relatively unchanged over the years. However, the relative abundances of the six main large-bodied fish species have shown some variability in recent inventories (1995 to 1999). For goldeye, northern pike, longnose sucker and white sucker, this interannual variability likely has not been associated with any specific changes in abundance over time. Walleye and lake whitefish numbers appear to have declined in recent years, although additional data are required to determine if the decline represents a true population trend, is within the range of natural variability or is due to between year differences in the sampling program.

It is recommended that the inventory program continue to include spring and fall sampling. Five of the six most abundant large-bodied species (walleye, goldeye, northern pike, longnose sucker and white sucker) typically occur in highest abundance in the spring and sampling in this season may be sufficient to monitor trends in relative abundance. In contrast, lake whitefish are abundant only in the fall, hence the need for a fall sampling program. In addition, more than one sampling season is required to provide sample sizes large enough for analysis of population parameters. The summer sampling program is not as important to achieving the objectives of the inventory program.

It is recommended that the timing of the fall sampling program be standardized to early to mid-October to minimize sampling related influences on the assessment of lake whitefish abundance in the Athabasca River.

Fisheries Inventory in the Muskeg River

The existing Muskeg River data base provides a basis for tracking species composition, and to a lesser extent relative abundance, of large-bodied fish species. Although historical data are available for the watershed, very little of it is directly comparable to the RAMP inventory data because of differences in sampling locations, technique, season and effort. The available data indicate little change in species composition, with the exception of the possible decline in abundance of Arctic grayling. Although not captured in the 2001 sampling program, Arctic grayling are still believed to be present in low abundance based on an angler report. Some variability in species abundance was observed between 1997 and 2001 (i.e., increasing numbers of most species, except Arctic grayling and white sucker).

To increase the effectiveness of monitoring fish species composition and relative abundance and the assessment of year to year variability, the use of standardized sampling areas is recommended. To account for longitudinal differences in habitat conditions and fish distribution in the portion of the lower Muskeg River included in the RAMP survey (i.e., below the Jackpine Creek confluence), it is recommended that sampling be conducted in representative sections of each of the discrete habitat reaches (1, 2, 3 and 4 as defined in historical reports; Golder 2003b).

Athabasca River Fish Tissue Analysis

Organic compounds (i.e., PAHs) were generally not detected in fish tissues in the Athabasca River in 1998 or 2001, with the exception of two compounds detected in 1998 only. Lack of detection of the organic parameters is likely due to the metabolization of PAHs by fish.

Fish tissue samples from 1999 and 2001 were analyzed for 30 inorganic parameters for the two years combined. Of these parameters, 23 were detected in 1998 and/or 2001. For the parameters for which data concerning fish health or human consumption are available, only mercury concentrations for walleye were of concern. Mercury concentrations for all walleye tissue samples were above the subsistence consumption guideline of 0.2 mg/kg, and the 2001 sample from female walleye was close to the occasional consumption guideline of 0.5 mg/kg. These concentrations are within the natural range of mercury levels for fish in the Athabasca River region. Based on the available data, mercury concentrations in fish upstream of the Oil Sands Region ranged from 0.33 to 0.79 mg/kg, and have historically ranged from 0.15 to 0.79 within or downstream of the Oil Sands Region.

The chemical concentrations measured in fish tissue to date are well below effects levels for fish health and most are well below the RBC. At present, the main focus for this component of the program would be human health and comparison of tissue concentrations with consumption guidelines for mercury. Since mercury concentrations currently show no deviation from regional/historical data, the screening level approach employed by RAMP is considered suitable. For a human health risk assessment, individual fish data are preferred. Therefore, the recommendations for the fish tissue component of RAMP comprise the following:

- collection of fish within the Oil Sands Region of the Athabasca River (reference area not needed);
- collection of tissue from *adult* lake whitefish and walleye only;
- discontinuation of analysis for PAHs; and
- analysis of *individual* samples (10 of each species, with an approximate gender balance within the 10) for mercury and other inorganic parameters.

Sentinel Species in the Athabasca River

The evaluation of data from the sentinel species program in the Athabasca River concluded that monitoring longnose sucker should continue. The following key findings led to this conclusion:

- The abundance of this species in both the exposure and reference areas is sufficient to allow for a reasonable fishing effort with minimal consequences to the integrity of the population.
- The radiotelemetry studies indicate that longnose sucker captured in the Oil Sands Region of the Athabasca River during the fall will likely have been sufficiently exposed to the Oil Sands Region.
- The analysis of MFO activity indicates that longnose sucker captured in the Oil Sands Region had been in the area for a considerable amount of time. Conversely, MFO activity in the reference population indicates that reference fish were not exposed to the Oil Sands Region.
- The variability of both longnose sucker populations is within the range of variability observed in other Alberta populations, including populations where effects have been shown.
- Statistically-significant differences between exposure and reference populations were seen in 1998, thereby demonstrating that the variability of the data is not so high as to mask any differences present.
- Longnose sucker have been shown to be a useful sentinel species in several studies, and this species demonstrates many of the characteristics associated with a good sentinel species.

Variability estimates from 1998 should be used to calculate the sample size required to detect a difference between exposed and reference fish. For example, a ±25% difference in gonad weight relative to body weight or length (i.e., relative gonad weight) between fish from reference and exposed areas has been adopted as a target effect size, using a power = 0.80, in other effects monitoring programs (Environment Canada 1998).

Excessive precision should be avoided when specifying target effect size (ES) and calculating sample sizes for future monitoring. For example, a range of effect size (i.e., 20 to 30%) would be more appropriate. The lower limits for this target ES were set by two considerations (Environment Canada 1998):

1) Many fish surveys would not have sufficient statistical power to detect smaller effects (e.g., <20% and certainly <10%), except over many assessment cycles and/or with larger sample sizes. As the target ES

becomes smaller, and required sample sizes larger, the effects of sampling mortality on the population will eventually exceed any population-level effects from reproductive effects induced by exposure.

2) Differences in relative gonad weight of <20% may occur naturally between unexposed and relatively similar areas. If the target ES is too small, then the risks of false positives (detecting a natural difference between areas and attributing it to oil sands activity) increase.

Sentinel Species in tributary Watercourses

The most dramatic and consistent difference measured in the exposure populations of slimy sculpin was the significantly smaller relative gonad sizes (i.e., GSI) in both males and females of the two exposure populations relative to the three reference populations. This difference was coupled with a decrease in female GSI in both exposure populations and male GSI in the Steepbank River exposure population from 1999 to 2001, compared to a small increase in reference populations. The average age of female fish was also significantly smaller in the Muskeg River exposure population than in reference fish and had decreased over time.

Factors related to the GSI findings were examined, including a consideration of life-history characteristics of the various populations. For example, the exposure fish populations were dominated by much younger fish in 2001 compared to 1999, whereas the opposite occurred in the reference populations, with the dominant age classes being older in 2001 than in 1999. Further analysis of the data indicated that the lower GSI values were not abnormal for these populations; they were close to the lower boundary of what would be expected.

Before the observed differences in GSI can be assumed to represent a change from natural variation, confirmation of the effect is required. Given the possibility of significant annual variability in many of the parameters being measured, we recommend that the slimy sculpin fish survey be repeated as soon as possible.

Muskeg River Fish Counting Fence

Based on a review and evaluation of RAMP and historical counting fence data, it is apparent that the results are inconclusive with respect to numbers of fish present in the Muskeg River watershed. Because of differences in study objectives, study design (related to fence location, timing of fence installation relative to ice-out and duration of fence monitoring) and year-to-year variation in flows (which dictate study success), it is difficult to derive specific conclusions regarding population trends over the last 25 years.

Results indicate that populations of most of the main fish species known to use the Muskeg River watershed (Arctic grayling, longnose sucker and white sucker) have declined in recent years (i.e., lower numbers captured in the 1995, 1998 and 2001 studies compared to 1976, 1977 and 1981 studies). Northern pike numbers appeared to be somewhat lower in the 1998 and 2001 surveys compared to 1976, 1977 and 1995 studies, although this change was less evident than changes in numbers of other species.

The ability of the RAMP fisheries program to monitor and assess variability in fish abundance in the Muskeg River watershed will depend on the study design implemented. The counting fence technique is considered the most suitable sampling technique for estimating fish (relative) abundance in the Muskeg River watershed, at least for large-bodied species. However, to define the size of fish populations over the monitoring period, standardization of sampling effort will be required.

The most comprehensive counting fence studies were conducted in 1976 and 1977 (Bond and Machniak 1977, 1979); these studies should be used as the model for future studies. Standardization should include fence location, timing and duration as follows:

- The counting fence should be located near the Muskeg River mouth in order to maximize capture rates and diversity of fish species entering the watershed (i.e., to account for less abundant species known to use only the lower mainstem).
- The counting fence should be installed as soon as possible after ice-out to capture as much of the spring spawning run as possible and to maximize the potential of capturing Arctic grayling.
- The counting fence should be monitored for a duration of several weeks to document the majority of the spring run (at a minimum, the fence should be in place until mid May).

The above protocol was attempted in spring 1974 (RRCS 1974), in fall 1978 (Bond and Machniak 1979) and in spring 2001 by RAMP; however, fence operation at these times was unsuccessful due to high flows. It is evident that detailed pre-planning and sufficient resources will be required to ensure operation of the fence at higher discharge levels.

7.3 DETECTING AND ASSESSING REGIONAL TRENDS

7.3.1 Fisheries Inventory in the Athabasca River

7.3.1.1 Regional Trends

The RAMP fisheries inventory data for the Athabasca River, in combination with historical data, indicate that the relative abundance of large-bodied fish is variable, as is their age and growth. In most cases, the variability shows no consistent changes over time that would indicate trends.

Species diversity appears to be lower in recent years compared to historical studies because of the absence of several small-bodied species in the recent inventories. However, this difference is likely due to changes in sampling techniques between the historical studies (i.e., multi-technique community sampling) and recent studies (i.e., boat electrofishing surveys). Over time, species composition for large-bodied species has remained the same in the Oil Sands Region, with the fauna dominated by lake whitefish, walleye, goldeye, longnose sucker, white sucker and northern pike.

Assessments of relative abundance based on species composition and CPUE indicate some variability on a seasonal and year-to-year basis. For goldeye, northern pike, longnose sucker and white sucker, the current level of abundance appears to be within the natural range of variability. For walleye and lake whitefish, the results indicate, or appear to indicate, a recent decline in abundance. Additional years of data are needed using standardized sampling time and methods to determine if the apparent changes in abundance for these two species are trends or the result of natural and sampling variability.

7.3.1.2 Ability to Detect Trends

The existing inventory program for the Athabasca River is considered sufficient to identify trends in relative abundance (as represented by CPUE) and population parameters (size-at-age, condition factor, weight-at-length) for large-bodied species, with the recommended measure of standardizing the sampling periods, particularly during the fall. It is not considered necessary to continue the summer sampling portion of the inventory component, although both the spring and fall sampling periods are important to evaluating trends for all large-bodied species.

7.3.2 Fisheries Inventory in the Muskeg River

7.3.2.1 Regional Trends

The amount of available inventory data for the Muskeg River is too limited to assess trends in species composition or relative abundance for fish from this river. Although historical data are available, these data are not compatible with RAMP data because of differences in sampling locations and methods. The main difference between historical and current surveys was that historical studies primarily used small fish collection methods, whereas RAMP used boat electrofishing, which is selective towards capture of large-bodied fish species. The historical data identified 23 fish species for the Muskeg River, but the recent inventories found only 11 species. Although some species were known to be rare, several common small-bodied fish species were absent from the recent inventories. This absence is likely an artifact of the sampling techniques used and not an indication of reduced species diversity in the river. Other RAMP sampling activities for the Muskeg River show that these small-bodied fish species are still present.

The two years of RAMP inventory data was insufficient to evaluate trends and cumulative effects in fish composition and relative abundance. Small increases were observed from 1997 to 2001 in overall CPUE and the CPUE for most species, but the number of years of data was insufficient to assess the significance of these changes or the degree to which they represent natural variability. One possible exception was the declining trend in Arctic graying abundance.

One of the goals of the inventory program in the Muskeg River basin was to determine the presence or absence of Arctic grayling. The most significant change during the inventories was the apparent lack of Arctic grayling in the Muskeg River in 2001 compared to 1997 and previous years. Based on angler report, Arctic grayling were believed to be present in the Muskeg River in 2001, but in extremely low abundance. Results of the RAMP fish counting fence component (Section 7.2.6) also showed an absence of Arctic grayling in the Muskeg River in 2001, although the counting fence results were considered inconclusive. The counting fence study was also designed to evaluate the abundance of large-bodied species in the Muskeg River and the discussion for the counting fence study (Section 7.3.6) indicates a general decline in Arctic grayling abundance in the Muskeg River since 1981.

Trends in population parameters such as length frequency or length-weight regression could not be addressed due to the small sample sizes for all species.

7.3.2.2 Ability to Detect Trends

Additional years of inventory data will improve the ability to identify trends in species composition and relative abundance (as represented by CPUE) of large-bodied fish species in the lower Muskeg River. However, year-to-year comparisons of the inventory data will require standardization of the data collection methods with respect to sampling effort and location. Recommendations presented in Section 7.2.7 regarding standardization of the sampling program and inclusion of representative portions of available habitat reaches are also suitable for improving the ability of the program to help detect trends. Although relative abundance of fish species can be assessed by the inventory component, it is not considered as quantitative as other sampling techniques. The inventory data should be used in support of the fish counting fence information, which is better able to assess trends in fish abundance for large-bodied species.

7.3.3 Athabasca River Fish Tissue Analysis

7.3.3.1 Regional Trends

The available data were assessed for potential or emerging trends in fish tissue chemical concentrations over time within the Oil Sands Region. The RAMP fish muscle data from 1998 and 2001 (listed in Section 7.2.3.2) were assessed for potential trends in chemical concentrations. Chemical concentrations in muscle of male goldeye, longnose sucker and walleye collected from the Athabasca River in 1995 were also available (Golder 1996a). These data were used for comparison with the 1998 and 2001 data when consistent differences in pairs of species-gender combinations from 1998 and 2001 appeared to exist. Consistent differences may indicate an emerging trend in tissue concentrations over time.

The RAMP fish tissue data were screened according to the process outlined in Section 7.2.3.1. The final list of parameters for the trends analysis contained those that were analyzed in both 1998 and 2001 and detected in at least one of those years.

In order to assess trends in the concentration of each parameter among years, fish species and gender were matched, where possible, for site, gender and species. From the available data, paired comparisons between 1998 and 2001 could only be made for the Athabasca River Oil Sands Region for four fish gender-species combinations: male and female walleye, and male and female lake whitefish. Fish tissue data from 1995 could be matched with male walleye only. All other fish (northern pike, longnose sucker and goldeye) could not be matched between years, and therefore could not be included in the trend analysis.

With only four pairs of comparisons, and the limited time period (six years), the assessment of long-term trends in fish tissue chemical concentrations will, at this stage, be inconclusive. However, the available data were assessed to detect potential or emerging trends.

The tissue chemical concentrations were qualitatively examined for consistent differences between the years 1998 and 2001 for all four paired gender-species comparisons. Those parameters that showed a consistent difference were examined in more detail for possible confounding effects, such as different detection limits between years, or variability in laboratory analyses. Any parameters with possible confounding effects were not considered further at this time. The remaining parameters were graphed for 1998 and 2001, with the addition of the male walleye data from 1995 included for discussion.

A statistical analysis of the available RAMP fish muscle data was not appropriate at this time due to the limited number of years of data (two years), and pairs of species-gender comparisons between years. Moreover, variability between and within years could not be assessed due to the single composite data points from 1998 and 2001.

Chemical Screening

The results of the chemical screening are shown in Table 7.19. This table shows the list of parameters detected in either or both of 1998 and 2001, and carried forward to the qualitative assessment of potential or emerging trends.

Calcium, potassium, sodium and magnesium were not considered further in the trends assessment, as these elements are essential ions for cellular function, and are unlikely to be indicators of regional trends in fish tissue quality over time. Calcium is an essential nutrient for bone growth and strength and muscle contraction. Potassium is required for nerve impulses, and magnesium is an essential component of bones and is required for enzymatic reactions (Puls 1994).

Table 7.19 Summary of RAMP Fish Tissue Concentrations for 1998 and 2001 Carried Forward to the Trends Assessment

Parameter	Male Walleye		Female Walleye		Male Lake Whitefish		Female Lake Whitefish	
	1998	2001	1998	2001	1998	2001	1998	2001
aluminum	0.9	< 4	1.2	< 4	0.6	< 4	1.5	7
barium	0.09	0.09	0.08	0.15	< 0.08	< 0.08	< 0.05	0.14
cadmium	< 0.08	0.11	< 0.08	< 0.08	< 0.08	0.09	< 0.08	0.08
calcium	693	160	611	100	89	120	188	100
chromium	< 0.2	0.5	< 0.2	< 0.2	< 0.2	0.5	< 0.2	0.5
copper	0.3	0.32	0.92	0.36	0.18	0.45	0.51	0.32
iron	5	11	5	15	5	16	12	10
lead	< 0.04	0.15	0.1	< 0.04	< 0.04	0.08	0.06	0.04
magnesium	279	289	264	261	201	299	212	243
manganese	0.17	0.24	0.18	0.12	0.16	0.22	0.24	0.21
mercury	0.26	0.36	0.22	0.46	0.08	0.11	0.09	0.11
nickel	0.1	0.56	0.75	0.26	< 0.08	1.22	< 0.08	0.65
phosphorus	2,030	2,460	1,930	1,210	1,460	2,250	1,390	2,210
potassium	4,470	3,520	4,490	3,550	4,240	3,580	3,700	3,000
selenium	0.3	0.6	0.2	0.4	0.2	0.5	0.2	0.5
sodium	321	227	320	215	535	327	491	305
strontium	0.6	0.11	0.47	0.1	0.16	0.12	0.42	0.12
tin	2.98	0.49	3.02	0.12	3.62	0.48	3.73	0.83
vanadium	< 0.08	0.14	< 0.08	< 0.08	< 0.08	0.17	< 0.08	0.12
zinc	3.3	4.3	3.8	7.4	3.8	3.3	3.4	4.8

Notes: Data from Golder (2002c) – all data in mg/kg.
"-" = Not analyzed.

Qualitative Observations and Discussion

The qualitative assessment of the remaining parameters indicated a consistent difference between the four pairs of species-gender combinations between 1998 and 2001 for aluminum, mercury, selenium, strontium and tin.

The consistent difference in aluminum concentrations was likely to have been the result of different detection limits used by the laboratory in 1998 (0.2 mg/kg) and 2001 (4 mg/kg). Therefore, a trend in aluminum concentrations between 1998 and 2001 could not be confirmed and aluminum was not considered further in the assessment of potential trends.

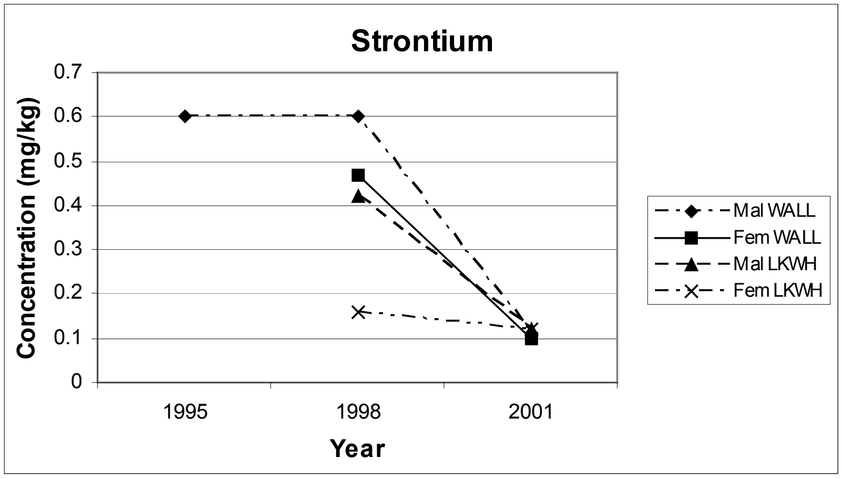
The consistent difference in tin concentrations is likely to have been the result of the presence of tin in the digestion medium (peroxide) used by the analytical laboratory in 1998 (R. Jones, EnviroTest Laboratories pers. comm. 2002). This contamination problem was discovered in 1999, and corrective measures were employed. Hence the reported tissue tin concentrations for 2001 are correct. The analytical laboratory has suggested that all tin tissue concentrations in 1998 were likely to have been below the detection limit (R. Jones, EnviroTest Laboratories pers. comm. 2002).

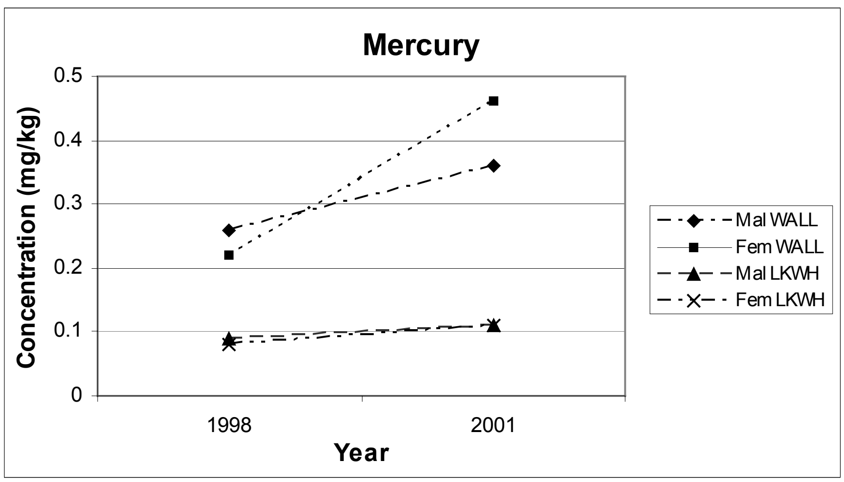
Tissue concentrations from 1998 and 2001 of the remaining parameters (mercury, selenium and strontium) were plotted, with the 1995 data included, where possible (Figure 7.50). The graphs show that for selenium and strontium the 1995 data do not appear to follow the same trend line as that between 1998 and 2001. Without additional years of data, it cannot be determined whether the data for these chemicals represent variability or "noise" around an average tissue concentration or an emerging trend.

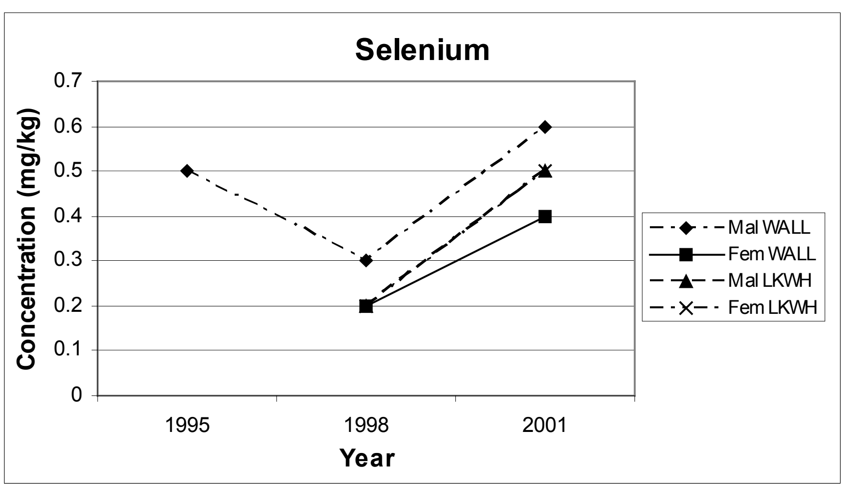
There were no mercury muscle tissue data for male walleye from 1995. However, historical tissue mercury data (NRBS 1996) from individual lake whitefish and walleye (gender not specified) are available for the Athabasca River Oil Sands Region. In 1992, tissue mercury concentrations in walleye in the Athabasca River upstream of the Oil Sands Region were found to range from 0.34 to 0.79 mg/kg (n=6; summarized in NRBS 1996). Walleye tissue concentrations in areas downstream of the Suncor operation in 1984 were reported to range from 0.15 to 0.74 mg/kg, with a mean of 0.39 mg/kg (n=19; NRBS 1996). Similarly, lake whitefish tissue mercury concentrations in areas downstream of the Suncor operation in 1984 were reported to range from 0.05 mg/kg to 0.17 mg/kg, with a mean of 0.08 mg/kg (n=10; NRBS 1996). Earlier data from 1975 (AOSERP 1977) reported mean walleye whole body mercury concentrations of 0.38 mg/kg in the Muskeg River mouth and also in the Athabasca River near Embarras.

The tissue mercury concentrations for both walleye and lake whitefish measured as part of RAMP in 1998 and 2001 appear to be consistent with data dating back to 1984, and do not appear to indicate an upward or downward trend in concentration at this time.

Figure 7.50 Concentrations of Metals in Fish Tissues, Athabasca River, 1995 to 2001







7.3.3.2 Ability to Detect Trends

The current program for assessing concentrations of contaminants in fish tissue in the Athabasca River is considered adequate to provide a general assessment of fish health and the suitability of fish for human consumption. Most parameters are below detection limits or below effects levels and a general screening program is sufficient for monitoring purposes at this time. Mercury levels are moderately high relative to consumption guidelines, but all data indicate that this is an historical condition in the region with no recent increase. Therefore, the general screening level program is also considered suitable at this time for this parameter. The changes recommended for the tissue program to improve the characterization of variability are also recommended to improve the ability of the program to detect trends.

7.3.4 Sentinel Species in the Athabasca River

7.3.4.1 Regional Trends

Trend analysis is not possible as there is currently only one year of longnose sucker data (1998) under the sentinel species component of the study in the Athabasca River. The available data were examined relative to using longnose sucker as a sentinel species for future trend analysis.

7.3.4.2 Ability to Detect Trends

With respect to using longnose sucker as a sentinel species, the analysis of the variability in the 1998 data indicates that changes or trends should be detectable if longnose sucker monitoring continues. In order to characterize the annual variability in these populations, and thus provide the ability to detect trends, it is recommended that the frequency of monitoring be increased to every two years.

7.3.5 Sentinel Species in Tributary Watercourses

7.3.5.1 Regional Trends

Since there are only two years of data for three of the collection sites for slimy sculpin and only one year of data for the two other sites, additional data will be required before an analysis of trends can be undertaken for the tributary sentinel species program. A preliminary analysis of the data over the two time periods that were sampled was conducted to explain the temporal variability in the slimy sculpin data (Section 7.2.5.2). These data illustrated the high variability that can be expected over time.

7.3.5.2 Ability to Detect Trends

The variability in the 1999 and 2001 data indicates that changes or trends will be detectable if slimy sculpin monitoring continues. In order to characterize the annual variability in these populations, and thus provide the ability to detect trends, it is recommended that the frequency of monitoring be increased to every two years.

7.3.6 Muskeg River Fish Counting Fence

7.3.6.1 Regional Trends

Examination of historical counting fence data as well as the RAMP data provided some indication of variability in fish abundance for large-bodied species in the Muskeg River watershed (Section 7.2.6). The variability in abundance could not be determined from the various counting fence studies due to differences in study design between years. Establishing the range of natural variation is important to allow detection of regional trends and cumulative effects. Nonetheless, the data indicated that trends in abundance of the four main species using the Muskeg River watershed (i.e., Arctic grayling, longnose sucker, white sucker and northern pike) may exist. Since comparisons of the counting fence data were considered inconclusive, additional fisheries information provided by RAMP was used to assess trends in fish abundance in the watershed. This additional information was collected during fisheries programs conducted by RAMP in the Muskeg River and Jackpine Creek, and included fish inventories, spawning surveys and collections of fish for the tissue, sentinel species and telemetry programs.

The counting fence results for the Muskeg River watershed (Tables 7.17 and 7.18) indicate that Arctic grayling, longnose sucker and white sucker numbers declined in recent years relative to the higher numbers recorded in 1976, 1977 and 1981. Some decline in northern pike abundance may also exist, but this trend is less evident. All four species were captured at the counting fence in 1995 in low to moderate abundance. Northern pike abundance in 1995 was similar to that in 1976 and Arctic grayling may have been present in 1995 in comparable numbers to the 1977 study. Arctic grayling, longnose sucker and white sucker were less abundant in the watershed in 1995 than in 1981. Results from 1998 and 2001 RAMP counting fence operation were inconclusive, but indicate that numbers for these species have declined since 1995.

Arctic grayling were captured in extremely low numbers at the counting fence in 1998 and none were captured in 2001. Fish sampling in the Muskeg River watershed for other RAMP activities also indicated an obvious decline of Arctic grayling in the watershed. Historical information shows that Arctic grayling were present in the mainstem Muskeg River and Jackpine Creek and utilized the watershed for spawning, nursery, rearing and summer feeding activities (Golder 2003b). There is evidence of continued Arctic grayling presence in the watershed since 1995, but other sampling indicate this species now occurs in extremely low abundance.

A few Arctic grayling were captured during the 1997 inventory, in the 1998 counting fence and in the 1999 sentinel species study. Arctic grayling were also captured in low abundance in both the Muskeg River and Jackpine Creek in 1997 for other programs (Golder 1997b). Arctic grayling were not captured during RAMP sampling in the Muskeg River in 2000 (i.e., fish sampling for the telemetry study) or in the Muskeg River or Jackpine Creek during the 2001 inventory or tissue collections. A small number of Arctic grayling were reported captured by a local angler in 2001, indicating the species was still present in the watershed. Based on all the available sampling results, it is apparent that Arctic grayling continue to use the Muskeg River watershed but that numbers have declined significantly since 1995. The species is now present in extremely low abundance.

Longnose sucker and white sucker were both captured in the counting fence study in 1995, but indications were that abundance was lower in the watershed in 1995 than in 1976, 1977 or 1981. Both species were captured in low numbers in 1998 and 2001. It appears that the abundance of these two species in the watershed has declined, beginning sometime after 1981.

The number of northern pike captured in the Muskeg River counting fence in 1995 was likely lower than in 1977, but was similar to, or higher than 1976. Northern pike were not captured in 1998 at the counting fence but were captured in 2001. These data do not strongly indicate a declining trend in northern pike abundance in the watershed.

RAMP monitoring data, along with historical data indicate that one factor that may have affected fish abundance in the Muskeg River watershed is the level of beaver activity, as it affects fish passage and habitat conditions for species which prefer swift flowing, rocky habitats for spawning. Changes in habitat conditions have occurred in the Muskeg River watershed in recent years that would affect potential use of the watershed by Arctic grayling, longnose sucker and white sucker. These habitat changes have affected portions of the Muskeg River tributaries known to have provided spawning areas for these three species.

Areas with good spawning potential and a few actual spawning sites have been identified for Arctic grayling, longnose sucker and white sucker in the Muskeg River watershed (Golder 2003b). In the mainstem Muskeg River, spawning potential was considered high in the lower 16.5 km where the higher gradient provides a variety of habitat types with rocky substrate. Isolated areas of low quality spawning habitat were also reported in the mainstem river in the low gradient section extending from 16.5 to 80 km upstream of the river mouth. Suitable spawning habitat for Arctic grayling, longnose sucker and white sucker was reported to occur in the section of Jackpine Creek extending from 5.5 to 14.9 km upstream of the creek mouth. Muskeg Creek was the only other tributary in the watershed with rocky habitat. The middle and upper portions of Muskeg Creek were considered to provide potential spawning habitat for longnose and white sucker.

During the 2000 RAMP fisheries program, a spawning survey was conducted for the lower 35 km of the Muskeg River and the lower 21 km of Jackpine Creek (Golder 2001a) to document spawning activity for key species. Numerous beaver dams were recorded during the survey in both Jackpine Creek and in the mainstem Muskeg River. Although beaver activity was reported historically from Jackpine Creek, it was concluded that available spawning habitat in Jackpine Creek had been reduced, compared to historical reports, as a result of increased beaver activity causing the interruption of stream flow and the accumulation of silt and organic material. On the other hand, the spawning potential in the mainstem Muskeg River was thought to be very similar to the historical reports.

Similar degradation of tributary spawning habitat has been reported from Muskeg Creek (Golder 2003b). White sucker spawning activity was identified in the upper portion of the creek in 1985 (Louma et al. 1986). When the creek was reexamined in 1988, increased beaver activity reduced water velocities and increased sedimentation (RL&L 1989). By 1995, the upper section of Muskeg Creek consisted entirely of beaver impoundments with fine sediments, eliminating the spawning potential (Golder 1996a).

Degradation of potential spawning habitat for Arctic grayling, longnose sucker and white sucker has apparently occurred in the two known spawning tributaries in the Muskeg River watershed since the years with reportedly high spawning runs. This habitat change is undoubtedly a factor in the decline in use of the watershed by these three species. This change appears to have the greatest effect on Arctic grayling populations, which may have relied primarily on Jackpine Creek for spawning. The highest numbers of Arctic grayling in the watershed were recorded in Jackpine Creek in 1981, with the 1981 run in Jackpine Creek higher than the numbers of fish recorded entering the Muskeg River watershed in

1976 and 1977. This may be due to a larger number of fish using the watershed in 1981 and/or to the 1976 and 1977 counting fences missing the early portion of the spring run. Still, the large number of fish present in Jackpine Creek in 1981 indicates that the majority of Arctic grayling entering the Muskeg River watershed in the past utilized Jackpine Creek for spawning.

Northern pike spawning habitat requirements are quite different and include low velocity habitat with submerged vegetation. Historically, northern pike use of the Jackpine and Muskeg creek drainages for spawning has been limited, although some northern pike spawning was reported for the lower-most portion of Jackpine Creek (Golder 2003b). Increased beaver activity in these two tributaries would not likely have a significant effect on northern pike use of the watershed and may explain why their abundance has not been affected to the same extent as for the other three species.

RAMP activities have occurred during a time that has been identified as a low flow period in the hydrological cycle (see Chapter 3), which may have allowed for an increase in the number of beaver dams in the Muskeg River watershed. In addition to increased impoundment by beavers resulting in degradation of potential spawning habitats, beaver dams may form barriers to fish passage, reducing access to the watershed or to spawning tributaries (Golder 2001a). Several of the dams were impassable to fish. Although beaver activity was reported as common in the Jackpine and Muskeg creek drainages in the past, beaver activity appears to have increased, which likely has resulted in reduced mobility of fish within the watershed.

7.3.6.2 Ability to Detect Trends

The counting fence is considered the best technique for monitoring the abundance of large-bodied fish species in the Muskeg River watershed. The standardization of fence location, timing and duration, as recommended in Section 7.2.7, would allow direct comparison of data between years. It would also allow direct comparison of RAMP data to the most suitable historical data to determine variability and identify trends. It is believed that, with an improved study design, the counting fence would determine the number of large-bodied fish using the Muskeg River watershed in the years the fence is deployed and between year comparisons would identify trends in fish abundance.

It appears that the condition of spawning habitat in two tributary watercourses, and access to these watercourses are factors that have affected use of the Muskeg River watershed by Arctic grayling, longnose sucker and white sucker. If these factors are as influential as suspected, monitoring of potential spawning habitat in the watershed would be helpful in evaluating any observed trends in fish use.

7.3.7 Conclusions and Recommendations

7.3.7.1 Fisheries Inventory in the Athabasca River

Species composition, relative abundance and population parameters related to growth and age generally appear to be similar among the RAMP inventories, other recent inventories and historical data. There appears to be a recent decline in abundance of walleye and lake whitefish, but this may be an artifact of differences in sampling in the most recent RAMP inventories. Additional data are required to determine if the apparent changes continue and become a trend.

Recommendations to improve the ability of the program to detect changes in relative abundance include the following:

- continued inventory sampling in the spring and fall to assess all major large-bodied species (summer sampling is not considered necessary); and
- standardization of the fall sampling to occur from early to mid October to provide comparability of lake whitefish abundance estimates among years.

It is important that the sampling methodology for the inventory be maintained despite the need to conduct other sampling programs simultaneously (e.g., tissue collection).

7.3.7.2 Fisheries Inventory in the Muskeg River

The inventory data for the Muskeg River span too few years to assess trends and historical data for this watershed are not comparable to the current program. Nonetheless, the RAMP inventory indicates a recent decline in Arctic grayling abundance in the Muskeg River compared to historical information, a conclusion supported by the results from the counting fence. Arctic grayling still appear to be present in the Muskeg River but are relatively rare.

To increase the between year comparability of the inventory data, the counting fence should be placed near the Muskeg River mouth, installed immediately after ice-out and operated until at least mid-May (Section 7.2.7).

7.3.7.3 Athabasca River Fish Tissue Analysis

The current RAMP data are insufficient to define whether tissue chemical concentrations are showing trends over time. Differences between chemical residues in fish tissue occured between 1998 and 2001 for selenium and strontium, but data from 1995 do not follow the same pattern. It is recommended that RAMP continue with the fish tissue chemical analyses in the Athabasca River region for male and female walleye and male and female lake whitefish to determine trends in these species-gender combinations. The recommendations for program design (Section 7.2.7) for number and types of tissue samples to be collected and parameters to be analyzed also apply to the assessment of trends in tissue concentrations over time.

7.3.7.4 Sentinel Species in the Athabasca River

Analysis of changes or trends in the health of the Athabasca River sentinel species is not possible at this early stage in the RAMP monitoring program. Longnose sucker appears to be a suitable sentinel species for the Athabasca River and, if this species is reinstated in the sentinel program, trends in fish health should be detectable with additional years of adequate data.

It is recommended that the frequency of sentinel species monitoring be increased from every three years to every two years to better define variability and identify trends.

7.3.7.5 Sentinel Species in Tributary Watercourses

Analysis of trends in the health of the sentinel species in tributary watercourses is not possible at this early stage in the RAMP monitoring program. Additional years of data are required for both exposure and reference populations to define regional variability and determine if differences observed to date represent trends or natural variability.

The existing program, except the sampling frequency, is considered suitable for assessing variability and trends. An increase in the frequency of sentinel species monitoring from every three years to every two years is recommended to better define variability and identify trends.

7.3.7.6 Muskeg River Fish Counting Fence

Based on captures at the counting fence, fish abundance in the Muskeg River watershed appears to have declined in recent years and Arctic grayling, longnose sucker and white sucker are less abundant. Reduced abundance of these species may be due, at least in part, to increased beaver activity, which also may be associated with low flows in the Oil Sands Region. An increase in the number of beaver dams appears to have resulted in degradation of spawning habitats in Jackpine Creek and Muskeg Creek and has reduced fish passage in the Muskeg

River mainstem and in these two tributaries. Reduced use of the watershed by northern pike may also have occurred, but due to between-year sampling differences, this is not clearly indicated by the available data.

The standardization of counting fence location, timing of installation and duration of operation is recommended to enhance the ability to identify year-to-year variability (Section 7.2.7) and trends. It is recommended that known spawning habitats in the lower Muskeg River, lower Jackpine Creek and Muskeg Creek be monitored for the extent and condition of habitat relative to historical reports. It is also recommended that the number and location of beaver dams be determined for the Muskeg River, Jackpine Creek and Muskeg Creek in years when the counting fence is deployed.

7.4 MONITORING TO VERIFY EIA PREDICTIONS

An objective of the RAMP fisheries program is to use the information generated by RAMP to verify predictions made in EIAs regarding impacts and cumulative effects on fish and fish habitat. Typically, two types of predictions have been made in oil sands EIAs:

1) Predictions regarding the fish habitats and populations expected to develop in compensation works designed to mitigate the loss of natural watercourses or waterbodies caused by development.

2) Predicted effects to fish populations or fish habitats in natural watercourses or waterbodies that will persist after development.

The first type of prediction is not relevant to RAMP and it is assumed that specific monitoring programs will be developed for compensation works on a case by case basis by the proponent.

The second type of prediction is included under the RAMP mandate. These predictions were examined in a general context to assess whether the current RAMP fisheries program is collecting the necessary data to be able to verify the predictions as some point in the future.

Table 7.20 presents the general aspects of predictions associated with oil sands developments that are related to fish populations, including the watercourse for which a prediction was made, the aspect of the fishery which the prediction addresses and the fish species or guilds identified as KIRs for the watercourse.

Predictions are presented for the watercourses included in the current RAMP program.

Table 7.20 EIA Predictions Relative to Fish Populations

Watercourse/Waterbody	Aspect of Fishery Involved in Prediction	KIR Fish Species or Guilds
Athabasca River	fish habitat	walleye, lake whitefish, northern pike, goldeye, longnose sucker, trout-perch
	fish species composition	
	fish abundance	
	fish health (including acute and chronic toxicity)	
	fish tissue tainting	
	fish and fish habitat biodiversity	
Muskeg River Watershed	fish habitat	Arctic grayling, northern pike, longnose sucker, lake chub, slimy sculpin
	fish abundance	
	fish health	
	fish tissue tainting	
	fish and fish habitat biodiversity	

Fish habitat monitoring in the Athabasca River was conducted to a limited extent during the first two years of RAMP (i.e., fish habitat association component). This component has since been discontinued. Predictions for fish habitat in the Athabasca River are mainly related to small-scale disturbances associated with construction of structures such as water intakes, or concerns regarding instream flow needs due to water withdrawal activities. Small-scale disturbances are best addressed by individual monitoring programs specifically designed for the construction activity. The instream flow needs (IFN) of the Athabasca River is currently being addressed by a Cumulative Environmental Management Association (CEMA) program. Therefore, monitoring of habitat in the Athabasca River is not seen to be an immediate concern for RAMP.

Monitoring fish habitat in the Muskeg River watershed has not been a part of the RAMP fisheries program to date. Monitoring of potential spawning habitat for Arctic grayling, longnose sucker and white sucker was recommended as part of the counting fence study to help assess trends in fish use of the watershed during the spring spawning run.

Fish species composition, fish abundance and fish biodiversity are being addressed to some extent by the RAMP fish inventory components and by the Muskeg River counting fence study. However, the inventories primarily employ a sampling technique (i.e., boat electrofishing) that is known to be size-selective. The current inventories provide an index of species composition and relative abundance for large-bodied species but are not considered suitable for assessing populations of small-bodied forage fish. For example, in the Athabasca River fall inventories from 1997, 1998 and 1999, the number of fish recorded for small-bodied species combined ranged from 41 to 735 individuals. In contrast, the fall 1999 sampling for the small-bodied sentinel species component that targeted trout-perch recorded a total of 4,109 individuals for all small-bodied species combined. In addition, RAMP inventories have recorded only 19 of the 29 fish species documented to occur in the Athabasca River in the region and 11 of the 24 species documented in the Muskeg River watershed. Most of the missing species are small-bodied fish. Obviously, the current inventory technique using boat electrofishing is inadequate to assess the full fish communities in these watercourses. An inventory approach using multiple sampling techniques and targeting all fish species and life stages would be more suitable for monitoring species composition, relative abundance and biodiversity.

Fish health is monitored by two components of the RAMP fisheries program: the sentinel species component; and the tissue analysis component. The sentinel species component examines health parameters for large-bodied and/or small-bodied species, as representative of regional conditions. The tissue analysis provides an analysis of acute and chronic toxicity effects for selected species, based on tissue concentrations of contaminants. These components are considered adequate for monitoring fish health conditions in the Oil Sands Region.

All species included as sentinel species or in the tissue analysis component are included in the list of KIR species identified in Table 7.20. However, not all KIR species have been included as target species in the fish health assessment. With respect to the Athabasca River, some tissue analysis has been conducted for goldeye, but they are no longer included in the tissue component. Northern pike have not been used in the fish health assessment in the past, but are considered for inclusion in the tissue analysis component in the future (Golder 2002f). As well, longnose sucker is under review as a sentinel species and it is recommended that this species continue to be included in this monitoring component. For the Muskeg River, Arctic grayling have been included in the study plan for the tissue analysis component, but population levels during the RAMP period have been too low for this species to be used. Longnose sucker have not been included in the fish health assessment but was targeted in the telemetry study. The inclusion of slimy sculpin as a sentinel species is considered to represent the forage fish guild in the Muskeg River making it unnecessary to also include lake chub.

Analysis of the quality of fish tissues relative to tainting (flavour impairment) was not addressed in the first five years of the RAMP fisheries program. However, analysis of tissue samples for tainting compounds has been included in the 2002 version of the tissue analysis component (Golder 2002f). In addition, Canadian Oil Sands Network for Research and Development (CONRAD) is examining the tainting issue to develop an appropriate sampling and analysis methodology.

Additional Monitoring

In addition to the information presented in Table 7.20, EIA predictions have been made for watercourses and waterbodies not included in the current RAMP fisheries program. It is recommended that these areas be taken into consideration when components are added to the fisheries program, as appropriate for the schedule of development.

7.5 SUMMARY

The different components of the RAMP fisheries program are not conducted on an annual basis and, as a result, the components currently have one, two or three years of data. For most components, it is too early in the program to determine variability in the data or if the observed measures represent trends. For some components, the methodology or sampling design has changed between sampling years, which has made it difficult to determine if observed variability has been due to changes in fish populations or is attributable to sampling differences. Therefore, recommendations related to standardizing methods and times or increasing frequency are presented to improve the ability of the program to define variability and identify trends or cumulative effects.

The following potential trends are identified at this point in the RAMP fisheries monitoring program:

- reduced abundance of walleye and lake whitefish in the Athabasca River in the Oil Sands Region;
- reduced abundance of Arctic grayling, longnose sucker, white sucker and possibly northern pike in the Muskeg River watershed; and
- changes in one of the health parameters (i.e., relative gonad size) for slimy sculpin in the Muskeg and Steepbank rivers.

The relative abundance of walleye and lake whitefish in the most recent Athabasca River inventories was lower than previous inventories. However, additional data are required to determine if this change in abundance persists or if the differences are due to sampling differences.

Both the Muskeg River inventory and counting fence studies indicate a reduction in Arctic grayling in the Muskeg River watershed since 1981. This species is still present in the watershed but in extremely low numbers. Captures at the counting fence also indicates decreased abundance of longnose sucker and white sucker. It is possible that northern pike relative abundance, as well, has declined but the evidence is weak. An apparent increase in beaver activity during the RAMP years may have provided an increased number of beaver dams, resulting in reduced flows, increased sedimentation and reduced fish passage in the spawning tributaries.

Differences in age and gonad size of slimy sculpin populations in the lower Muskeg and Steepbank rivers have occurred over time and in relation to reference populations. With only two years of study, additional data are required to determine if the observed differences are the result of natural variability or represent an emerging trend.

Longnose sucker appear to be a good candidate as a sentinel species and should be reinstated in the fisheries component for the Athabasca River.

8 CONCLUSIONS AND RECOMMENDATIONS

As the Oil Sands Region experienced rapid growth from 1997 to 2001, changes to RAMP were made annually. These changes not only affected RAMP's objectives, and organizational structure, but the study area and study design as well. Potential sampling methods, sentinel species and reference lakes and streams were also evaluated during this period.

The purpose of the Regional Aquatic Monitoring Program (RAMP) Five Year Report is to analyze the data available from the initial five years of sampling (1997 to 2001) and, in many cases, other relevant data available for the Oil Sands Region. This chapter provides the conclusions and recommendations derived from the results of this analysis. It also addresses whether the program has met the following three fundamental program objectives that are most relevant to aquatic monitoring, based on the data collected from 1997 to 2001:

- collecting scientifically defensible baseline and historical data to characterize variability in the oil sands area;
- monitoring aquatic environments in the oil sands area to detect and assess cumulative effects and regional trends; and
- collecting data against which predictions contained in Environmental Impact Assessments (EIAs) can be verified.

The Conclusions and Recommendations chapter is organized by monitoring component:

- hydrology and climate;
- water quality;
- sediment quality;
- benthic invertebrates; and
- fish populations.

Components of the RAMP program that did not have sufficient data, such as the aquatic vegetation and acid sensitive lakes components were not included in the Five Year Report.

8.1 CLIMATE AND HYDROLOGY

8.1.1 Characterizing Existing Variability

Data from the Environment Canada Climate Station at Fort McMurray Airport were used to formulate the following conclusions related to the natural variability of precipitation and temperature in the Oil Sands Region:

- The first five years during which RAMP operated included four consecutive years of below-average precipitation between 1998 and 2001, which was the longest span of below-average precipitation since 1953.
- Snowfall is more variable than rainfall, and total precipitation is less variable than rainfall.
- Mean annual temperatures at Fort McMurray Airport are more likely to be influenced by winter temperatures, which are more variable than annual mean temperatures, than by summer temperatures, which are less variable.

Data from the long-term Environment Canada Hydrologic Monitoring Stations at the Athabasca, Steepbank, Muskeg, Beaver, MacKay and Firebag rivers and Jackpine Creek were used to derive the following conclusions related to the natural variability of water yields, floods and low flows:

- Annual water yields at the six smaller streams were highly correlated to the measured annual precipitation at Fort McMurray Airport.
- Annual precipitation for the years 1972 to 1976 were all above average, with 1973 the wettest recorded since 1945. Since no annual hydrologic monitoring data are available for the Muskeg River basin before 1974, it is not possible to calculate water yields, flood discharges and low flows for this wet year. The highest observed flood was recorded in 1997 on Jackpine Creek and the highest observed water yields were recorded in 1997 on the Muskeg, Mackay, Firebag and Athabasca rivers and Jackpine Creek.
- The Athabasca River has the highest mean annual water yield and, with the Firebag River, the lowest coefficient of variation of any of the local long-term monitored watersheds. Relatively large water yields were also observed for the Firebag River, where large surficial aquifer storage attenuates precipitation inputs to the watershed and sustains unusually large baseflows over the winter months.
- The Athabasca River (large watershed) and Firebag River (large storage capacity) had relatively low flood unit discharges, as did the Muskeg

River (large storage capacity). The MacKay and Steepbank rivers and Jackpine Creek had flood unit discharges approximately twice as large, while the small, steep watershed of the Beaver River resulted in the highest flood unit discharges.

- The second- and fifth-lowest precipitation years on record at Fort McMurray Airport occurred in 1998 and 1999, respectively. In 1999, these consecutive dry years produced the lowest-recorded water yields and flood discharges on the Steepbank, Muskeg, Beaver and MacKay rivers and Jackpine Creek.
- The Athabasca River (large watershed) and Firebag River (large storage capacity) had relatively high low-flow unit discharges. The Steepbank, Muskeg and MacKay rivers had significantly smaller low-flow unit discharges, while the small watersheds of the Beaver River and Jackpine Creek produced the lowest low-flow unit discharges.

The following recommendations apply to long-term monitoring stations used to assess natural variability:

- Winter measurements at the Environment Canada Muskeg, McKay and Firebag rivers stations have been undertaken by RAMP and this supplementary monitoring should continue. Consideration should be given to reactivating continuous winter monitoring on the Steepbank River and undertaking periodic manual measurements on Jackpine Creek and the Beaver River, which frequently freeze to the bottom and cease to flow over the winter.
- Monitoring on the Ells, Tar and Calumet rivers was reinitiated by RAMP in 2001 in support of the CNRL Horizon environmental impact assessment (EIA); these stations should continue to be operated to collect baseline data and to measure effects after the start of project construction. Consideration should be given to reactivation of the remaining stations (Dover River, Joslyn Creek, Pierre River, Asphalt Creek and Unnamed Creek) to allow collection of long-term data in advance of project developments in the area.

8.1.2 Detecting and Assessing Regional Trends

8.1.2.1 Temporal Trends

Long-term climatic and hydrologic data from the Oil Sands Region north of Fort McMurray were used to identify the following temporal trends in climate and hydrology:

- Annual precipitation data from Fort McMurray Airport did not display any significant trend. However, they did display some degree of serial dependence, which may be related to the El Nino/La Nina phases of the Southern Oscillation.

- Mean annual temperature data exhibited a warming trend over the monitoring period of 1944 to 2001. The data also displayed some degree of serial dependence, which again may be related to the Southern Oscillation.
- Water yield data did not display any significant temporal trend for any of the streams examined, as would be expected since water yield is highly correlated to annual precipitation.
- Flood data for all long-term regional stations were without trend. Only maximum mean daily discharge data for the MacKay River displayed serial dependence at a 5% level of significance.
- Low flow data did not display any significant temporal trend, except for the Beaver River, where an upward trend in low flows may be affected by the observed warming trend.

8.1.2.2 Spatial Trends

Spatial trends in precipitation and temperature are subtle and are influenced by geographic factors. They should not be affected by the activities of local industry.

Spatial trends in annual water yields, flood discharges and low flows are dependent on climatic conditions and physical characteristics of the tributary watershed. The only spatial trend detected is a mild rain shadow effect in the east slope basins of the Birch Mountains. No other trends have been identified.

Data from the long-term climatic and hydrologic stations in the Oil Sands Region have been used to calibrate a regional hydrologic model that provides predicted baseline characteristics for selected nodes in the region. Ongoing data collection at existing long-term and short-term stations will better define natural variability and variation due to local geographic and geologic conditions. If required to assess the hydrologic changes at a particular location, measured stream discharge and precipitation data could be used in a calibrated water balance model to estimate changes to stream discharge attributable to developments within the watershed. Accurate model results would be highly dependent on accurately quantifying the temporal and areal variation of precipitation in the modelled watershed.

8.1.3 Monitoring to Verify EIA Predictions

Whether RAMP climatic and hydrologic monitoring stations can be used to verify EIA predictions was addressed by examining the following questions:

- Are RAMP climatic and hydrologic monitoring stations located at appropriate sites?
- Are monitoring periods sufficient (e.g., are the data adequate to construct an annual water balance and describe annual precipitation and runoff hydrographs)?
- Is RAMP collecting or otherwise obtaining data required to differentiate natural variability from changes due to human activities?

All of the RAMP climatic and hydrologic monitoring stations examined in this report are located in appropriate locations. The following recommendations for data collection apply:

- The existing year-round monitoring at many stations should continue. Additional continuous winter monitoring is recommended at RAMP hydrologic monitoring stations S1 and S6, and periodic manual winter discharge measurements are recommended at RAMP hydrologic monitoring stations S2, S9, S10 and S11.
- Station deactivation should only be considered if the upstream watershed is closed-circuited or diverted to the extent that discharges at the station become negligible.
- Operation of tipping bucket rainfall gauges at RAMP hydrologic monitoring stations, where possible, is recommended to supplement data from the Aurora Climate Station and provide more information on the areal extent and variation of precipitation events.
- It is recommended that intensive precipitation monitoring be undertaken on small natural watersheds to measure the temporal and areal variation of precipitation inputs. This monitoring would include a network of rainfall and snowfall gauges as well as regular snowcourse surveys along a defined traverse within each watershed. These precipitation measurements would be more detailed than any previously undertaken within RAMP, and would be used, in conjunction with stream gauging data from the watershed outlet, to allow more detailed analysis of watershed response to rainfall and snowfall.

Though this report makes no attempt to differentiate man-made changes to stream discharges or lake levels based on measured data, it would be possible to undertake this type of assessment, based on measured climatic and hydrologic data. The short-term hydrologic stations operated by RAMP were generally installed to provide baseline data for EIAs and/or to meet regulatory reporting requirements during mine operations. These stations should continue to gather baseline data for as long as possible to provide data for characterizing the natural behaviour. When developments are initiated, the stations should continue to collect data to quantify changes in the streams. If required, stream discharge data would be combined with precipitation data, hydrologic models and knowledge of mine layout and activities in an additional study (i.e., beyond the RAMP core program) to construct a water balance used to assess water quantity impacts of development at the station and on downstream waterbodies.

8.2 WATER QUALITY

8.2.1 Characterizing Existing Variability

Existing variability in water quality in the RAMP study area was examined, in part, by determining the following:

- which substances are typically found together and/or follow consistent patterns with respect to other similar substances (e.g., do water quality samples with high colour levels typically contain high concentrations of dissolved iron?);
- how total suspended solids (TSS) concentrations influence total metal and total phosphorus levels; and
- if a small number of key parameters could be identified to reduce statistical testing requirements and to simplify subsequent analyses.

8.2.1.1 Parameter Correlations

Water quality data collected by RAMP between 1997 and 2001 were combined with comparable information from other sources to form one large water quality data set for the lower Athabasca River watershed. Principal component analysis (PCA) was used to evaluate potential correlation among the water quality parameters across the entire data set, as well as across two subsets focusing on the Athabasca River and tributaries to the Athabasca River. Analysis of available data from the lower Athabasca River watershed revealed the following patterns:

- Total metals, TSS and dissolved metals were all generally positively correlated with the same Overall principal component (PC), reflective of the fact that total metal concentrations include both the dissolved metal fraction and that associated with suspended materials.

- Total metal concentrations tended to follow consistent, positively correlated trends, whereby samples containing high levels of one metal (e.g., total aluminum) also generally contained high levels of other total metals (e.g., cobalt, nickel and vanadium).
- Manganese and iron were positively correlated, along with colour and dissolved organic carbon (DOC), to Overall PC3, reflective of the fact that iron, manganese and DOC tend to impart colour to water.
- High total dissolved solids (TDS) and total alkalinity measurements were recorded for samples containing high levels of calcium, magnesium, chloride and other major ions.
- Barium, strontium, lithium and boron were typically present in the dissolved form, with minor suspended fractions.

To investigate the influence of TSS on total metal and total phosphorus levels, data from the Athabasca River, tributaries to the Athabasca River and the four wetlands sampled by RAMP were examined separately. Conclusions specific to Athabasca River water quality that extend beyond those discussed above include the following:

- The brown, opaque colour of the Athabasca River results from suspended particles, as reflected by the common correlation of total metals, including iron and manganese, TSS and colour to the same principal component.
- Although 12 of the 19 total metals included in this study exhibited statistically significant correlations with TSS, only total aluminum, arsenic, iron and manganese concentrations appear to be strongly influenced by TSS levels (i.e., $R^2 > 0.50$).
- Total phosphorus (TP) concentrations also tend to be strongly influenced by TSS levels in the Athabasca River.

Other conclusions that can be drawn from the results for the Athabasca River tributaries and wetlands include the following:

- The deep, translucent, tea stained colour common to Athabasca River tributaries, the Muskeg River and other waterbodies within the RAMP study area results from DOC, dissolved iron and other dissolved ions (Golder 2002g and AENV 2002a). Hence, the common correlation of these parameters to the same principal component.
- Total metal and TP concentrations in the Athabasca River tributaries are generally less influenced by TSS levels than those in the Athabasca River, with only nine of the 20 parameters examined in this study

demonstrating significant TSS correlations and corresponding regression equations explaining less than 50% of the observed variation.

- Total metal and TP concentrations in Shipyard, Isadore's, McClelland and Kearl lakes are largely independent of TSS levels.

8.2.1.2 Influence of Instream Flow

The potential influence of instream flow on water quality was examined first by using flow and corresponding water quality data from the Athabasca River. This analysis was then repeated using similar information from tributaries of the Athabasca River sampled by RAMP to determine if common relationships were present in the two data sets. Conclusions that can be drawn from the results of this investigation include the following:

- DOC, TSS, total Kjeldahl nitrogen (TKN) and total metal concentrations in the Athabasca River tend to increase as flow increases.
- In contrast, major ion concentrations in the Athabasca River tend to increase during periods of low flow, as the contribution of groundwater inflow increases relative to surface water inputs.
- Water quality in the Athabasca River tributaries follows similar trends; dissolved ion concentrations tend to peak during periods of low flow, and TP, TSS and total metal concentrations generally increase as flow increases.
- In both the Athabasca River and the Athabasca River tributaries, average daily flow tends to be a slightly better predictor of instream concentrations than 14-day averaged flow.

Based on the amount of scatter observed within the tributary data set, it is recommended that future work concerning flow relationships in Athabasca River tributaries focus on rivers and creeks of similar size that experience similar flow regimes.

8.2.1.3 Fall Versus Winter Water Quality

A statistical comparison of fall and winter water flow and water quality was completed using data collected from the long-term monitoring stations positioned in the Athabasca River and the lower Muskeg River. Significant seasonal variations were observed between fall and winter water flows and water quality, with the magnitude of change ranging, on average, from < 3 to > 900 %. In the past, routine water quality monitoring completed by RAMP has been conducted in the fall.

Future mine water releases, including seepage from external facilities and in-pit deposits, are expected to flow year-round. They will day-light, at least in part, in smaller tributaries. As a result, additional winter sampling was recommended in areas experiencing a high level of development. Adding winter sampling to the existing fall sampling will preserve the advantages of the fall sampling. Additional winter sampling should be considered under the following conditions:

- relevant EIAs have shown that they are or will be receiving seepage input; and
- existing operators are not already collecting sufficient winter data as part of their approval requirements.

An instream loading analysis is also recommended. This modelling would be waterbody specific. It would include an examination of parameter loading rates under winter and fall conditions, with the goal of establishing the season in which the largest changes in instream loading rates and, consequently, instream concentrations are expected to occur.

8.2.2 Detecting and Assessing Regional Trends

8.2.2.1 Temporal Trends

The investigation into temporal trends in the water quality data set included an examination of long-term (i.e., 1976 to 2001) and short-term (i.e., 1997 to 2001) temporal variability observed at several locations within the Athabasca and Muskeg rivers, respectively. The two long-term, Athabasca River sites are situated upstream of Fort McMurray and near Old Fort. The two short-term, Muskeg River sites are located upstream of Muskeg Creek and in the lower section of the Muskeg River between Jackpine Creek and the river mouth. These locations were selected, because they are positioned upstream and downstream of current oil sands development within their respective watersheds.

Based on the long-term temporal analysis completed, cumulative development located downstream of Fort McMurray has not resulted in the degradation of water quality within this stretch of the river since its initiation in the mid to late 1970s. Similarly, with the possible exception of pH, development within the Muskeg River watershed has not resulted in significant temporal variations in water quality in the lower sections of the Muskeg River since the initiation of RAMP in 1997.

It is recommended that the continuous pH monitoring data described in AENV (2002a) be further analyzed to determine if the significant decline in pH levels is the result of flow variation and/or oil sands development.

8.2.2.2 Spatial Trends

Ordination plots derived from the three PCAs were used to determine the following general spatial patterns within the water quality data set:

- metal and TSS concentrations in the Athabasca River are typically higher than those observed in its tributaries;
- major ion levels tend to vary to a smaller extent in the Athabasca River mainstem, in comparison to sampled tributaries located downstream of Fort McMurray;
- total metal concentrations in the Muskeg River are generally lower than those in the other tributaries sampled by RAMP; and
- McClelland and Kearl lakes are unique with reference to each other and to Shipyard and Isadore’s lakes in terms of their metal, TSS and major ion content, whereas the latter two lakes tend to contain similar metal, TSS and major ion levels.

More detailed examination of the Athabasca River revealed that water quality within the river does not appear to have been affected by cumulative development situated downstream of Fort McMurray since 1976. With the exception of sulphate, development also does not appear to have affected water quality in the Muskeg River. Sulphate levels have significantly increased downstream of current oil sands facilities since the initiation of development.

The increased sulphate levels observed downstream of development in the Muskeg River after April 1, 1998, likely resulted from the discharge of high sulphate waters through the Alsands Drain. It is recommended that the source of the sulphate entering the Alsands Drain be identified to determine (1) if it is associated with the area being dewatered or if other types of water were discharged to the Alsands Drain, and (2) if the release of high sulphate waters is expected to continue. It is also recommended that a review of available toxicological information for sulphate be undertaken to determine if an ecological threshold can be established for the Muskeg River beyond which detrimental ecological effects may be expected to occur.

8.2.2.3 Ability to Detect Change

As the program is currently designed, RAMP collects three years of seasonal water quality data (one sample per season) to define baseline conditions prior to development. However, a minimum of four data points per season are required for the Seasonal Kendall test. Test resolution also improves with increased sampling. It is recommended that the RAMP Water and Sediment Subgroup of the Technical Subcommittee consider expanding this period of baseline characterization from three to more than five years. This expansion would allow the subcommittee to determine if temporal trends detected after the initiation of development were already occurring under baseline conditions. More than five years of baseline data would also allow for "before and after" comparisons to test for potentially significant step changes, with more reasonable estimates of baseline variance than can be provided with only three baseline samples.

This recommendation should not affect the amount of baseline data required to complete the water quality component of an EIA, since available baseline data can be effectively supplemented by using information from comparable waterbodies and/or probabilistic distributions developed from existing data to predict impacts in an EIA.

The current program's ability to detect significant spatial variations in water quality was examined using power analysis. The relative difference required for water quality near Old Fort to be deemed significantly different from that observed upstream of Fort McMurray was estimated to range from ± 815% for Athabasca PC1 to approximately ± 6% for TDS. However, because, of unequal replication in the RAMP water quality sampling program, the minimum detectable differences discussed herein are likely under-estimates of the actual differences required to conclude that concentrations near Old Fort are statistically different from those observed upstream of Fort McMurray.

8.2.3 Monitoring to Verify EIA Predictions

Whether the information collected by RAMP can be used to verify EIA predictions was addressed through an examination of the following questions:

- Are RAMP water quality sites situated in appropriate locations (e.g., at or near EIA water quality assessment nodes or other relevant areas)?
- Are water samples collected by RAMP being analyzed for all of the water quality assessment parameters discussed in recent EIAs?

- Is RAMP collecting or otherwise obtaining the type of information required to differentiate natural variability from changes associated with human activities?

RAMP sample sites are located in appropriate locations. RAMP is also currently testing for all of the water quality assessment parameters discussed in recent EIAs (e.g., TrueNorth 2001; Golder and Cantox 2002) that can reasonably be expected to be in potential oil sands release waters at this time. However, it is recommended that the RAMP Water and Sediment Subgroup of the Technical Subcommittee consider expanding the parameter list to include acrylamide once thickened tailings technology moves beyond the experimental stage.

In waterbodies where historical information is not available, RAMP is not currently collecting sufficient baseline data to determine if, for example, significant temporal variations can be detected prior to development. Hence, it is recommended that the RAMP Water and Sediment Subgroup of the Technical Subcommittee consider expanding the period of baseline sampling from three to more than five years, as discussed above. It is also beyond the scope of RAMP, as it is currently designed, to establish causal links between significant instream water quality variations and on-site oil sands activities. Additional studies would be required to complete this endeavour, should a significant variation be identified.

8.3 SEDIMENT QUALITY

8.3.1 Characterizing Existing Variability

The existing variability in sediment quality was characterized by determining the following:

- if substances of a common nature are typically found together and/or follow consistent patterns (e.g., do sediments with high aluminum content also contain high barium concentration?);
- how sediment chemistry may be affected by sediment composition (e.g., are polycyclic aromatic hydrocarbon [PAH] levels generally higher in sediments with high silt content?); and
- if indicator parameters can be identified to allow for the possible reduction of the standard RAMP sediment test list (e.g., possibly using total recoverable hydrocarbon [TRH] as an indicator of PAH concentrations).

Sediment data collected by RAMP between 1997 and 2001 were combined with comparable information collected by others (Albian 2000; Golder 1996a) to create a sediment quality data set for the lower Athabasca River watershed. Based on the analysis of this data set, sediments collected from the RAMP study area exhibited the following patterns:

- High silt content was generally accompanied by high clay and low sand content.
- Metal concentrations tended to follow consistent, positively correlated trends, whereby sediments containing high levels of, for example, aluminium, also generally contained high levels of cobalt, nickel, vanadium and other metals. Exceptions to this general pattern included mercury and molybdenum, although mercury concentrations tended to be high in sediments with high lead levels.
- PAH concentrations tended to follow similar consistent, positively correlated trends, whereby sediments containing high levels of, for example, pyrene, also generally contained high levels of fluorene, acenaphthene and other parent and alkylated PAHs. Exceptions to this general pattern included naphthalene and C1 naphthalene, two parameters strongly correlated to each other with weaker correlation to other parameters included in the organics analysis.
- With the possible exception of metals with a high proportion of non-detectable results (beryllium, cadmium, uranium, thallium and molybdenum), sediments with high silt and/or clay content generally contained higher metal levels than those with larger amounts of sand and less silt and/or clay.
- PAH levels were not significantly correlated to sediment composition, with the exception of naphthalene and C1 naphthalene. Concentrations of these two compounds were significantly, positively correlated to silt content.

Other conclusions that can be drawn from the results of this study include the following:

- Total organic carbon (TOC) content could not be used effectively to indirectly monitor PAH levels in sediment.
- It may be unnecessary for RAMP to monitor both TRH and total extractable hydrocarbon (TEH), since they are highly correlated to one another.
- The number of PAHs included in the RAMP parameter list could be reduced, in reflection of the high correlation observed between almost all of the parent and alkylated PAHs included in the organics analysis.

- Comparable reductions in the metals parameter list could be pursued for similar reasons. However, limited financial gain would result, because metals are generally analyzed using broad spectrum scans. Thus, the incremental cost associated with adding or subtracting elements to the scan is small.
- The strong correlations observed between TRH and almost all of the PAHs (parent and alkylated) included in the organics analysis suggests that TRH could be used as an indicator of PAH content in areas where naphthalene and C1 naphthalene concentrations are not expected to change as a result of development.

Building upon these conclusions, it is recommended that the “Organics” and “PAH” portions of the standard sediment parameter list be revised, as well as the 2003 to 2009 study plan described in Golder (2002f). Suggested changes include the following:

- dropping TEH from the parameter list;
- reducing standard PAH testing to naphthalene and C1 naphthalene; and
- using TRH as a surrogate for the remaining PAHs, with more extensive PAH analysis occurring only once every two to three years.

In combination, these changes could results in cost savings of approximately $11,700 per year.

8.3.2 Detecting and Assessing Regional Trends

8.3.2.1 Temporal Trends

With the possible exception of metals with a high proportion of non-detectable results (beryllium, cadmium, uranium, thallium and molybdenum), metal and PAH concentrations in sediments have been declining over time. This conclusion is based on metal and PAH concentrations in sediments collected from the mouth of the Muskeg River and in the Athabasca River upstream of both Fort Creek and Donald Creek. These declining trends were not all statistically significant. These results suggest that development within the lower Athabasca River watershed has not resulted in increased sediment metal or PAH concentrations at downstream locations since the initiation of RAMP in 1997. (The mouth of the Muskeg River and the Athabasca River upstream of Fort Creek are both located downstream from oil sands development.)

8.3.2.2 Spatial Trends

Based on the five years of sediment data RAMP has collected since 1997, metal concentrations in sediments from the Muskeg River watershed tend to be lower than those in the Athabasca River, whereas sediment PAH concentrations tend to be comparable between the two systems. Other conclusions that can be drawn from the spatial analysis include the following:

- Mercury, lead and PAH concentrations, excluding naphthalene and C1 naphthalene, are generally lower in Muskeg River watershed sediments than in sediments from the other Athabasca River tributaries sampled by RAMP.
- With the possible exception of metals with a high proportion of non-detectable results (molybdenum, cadmium, beryllium, uranium and thallium), metal concentrations are generally higher in sediments collected upstream of the Embarras River and in the Delta than in samples collected between Fort McMurray and Fort Creek.
- The variation in metal levels in the Athabasca River is a reflection of differing sediment composition (i.e., higher proportion of silt and/or clay upstream of the Embarras River and in the Delta).
- PAH concentrations vary over the length of the Athabasca River, with no clear spatial pattern.
- Shipyard, Kearl and Isadore’s lakes sediments generally contain higher metal levels and a greater proportion of silt and clay in comparison to those in the other waterbodies sampled by RAMP.

8.3.2.3 Ability to Detect Change

Currently, RAMP collects three years of sediment data (one sample per year) to define baseline conditions prior to development. The Mann-Kendall test for trend requires at least five samples to detect a significant upward or downward trend with a 95% test threshold (i.e., theta = 0.05). More than five samples are required to improve test resolution substantially. Therefore, it is recommended that the RAMP Water and Sediment Subgroup of the Technical Subcommittee consider expanding this period of baseline characterization from three to more than five years. This expansion would allow the subcommittee to determine if temporal trends detected after the initiation of development were already occurring under baseline conditions. More than five years of baseline data would also allow for “before and after” comparisons to test for potentially significant step changes, with more reasonable estimates of baseline variance than can be provided with only three baseline samples.

The current program's ability to detect significant spatial variations in sediment quality was examined using power analysis. The focus of the power analysis was to determine the effect size, or relative difference, that could be detected (i.e., deemed significant) based on the data collected to date and with increased sampling effort. The relative difference required for sediment metal or PAH concentrations to have been deemed significantly different from those observed upstream of Donald Creek was estimated to range from 180% for PAH PC1 to >900% for metal PC3 at a power of 80%.

Conservative calculations indicate that effect sizes will decline with increased sampling effort, ranging from 94% for PAH PC1 to 672% for metal PC3 at a power of 80%. However, these results were produced assuming that within site variability remains unchanged, an unlikely scenario. Therefore, effect sizes are expected to decline to a greater extent than shown here with increased sampling effort. To expedite that rate of data collection, it is recommended that a consistent sampling schedule be maintained with minimal alteration to established sample sites.

8.3.3 Monitoring to Verify EIA Predictions

The issue of whether the information collected by RAMP can be used to verify EIA predictions was addressed through an examination of the following questions:

- Are RAMP sediment sample sites situated in appropriate locations (e.g., at or near EIA water quality assessment nodes and other relevant depositional areas)?
- Does the RAMP sediment analytical test list include all of the parameters discussed in relevant sections of the EIA?
- Is RAMP collecting or otherwise obtaining the type of information required to differentiate natural variation from changes associated with human activities?

RAMP sample sites are located in appropriate locations, and the RAMP parameter list includes all of the parameters discussed in relevant sections of recent EIAs (e.g., TrueNorth 2001; Golder and Cantox 2002). RAMP does not, however, currently collect sufficient baseline data to detect significant temporal trends prior to development. Hence a recommendation was made that the RAMP Water and Sediment Subgroup of the Technical Subcommittee consider expanding this period of baseline characterization from three to more than five years.

8.4 BENTHIC INVERTEBRATES

8.4.1 Characterizing Existing Variability

Exploratory analysis of the existing variability in benthic invertebrate data generated by RAMP between 1997 and 2001, and available historical data, revealed differences among benthic communities of individual waterbodies. Principal components analysis usually grouped sites by river, implying that each river has characteristic communities. This finding implies that it is unlikely that data from one river could be used as reference site data for detecting effects in other rivers. Grouping of sites by lake was not apparent.

Principal components analysis did not detect strong correlations between benthic community structure and environmental variables. Weak but significant correlations were found between local habitat variables and benthic communities in lakes (e.g., depth) and the Clearwater River (substrate and current velocity). Benthic community variability was not significantly correlated with habitat variables in the Steepbank, MacKay and Muskeg rivers. There was some indication that flow may be an important controlling factor in erosional sections of rivers, but there was insufficient data to demonstrate this with certainty. The results reflect, in part, the limited amount of available data (only a few years) and the variable spatial coverage among years.

Preliminary estimates of baseline ranges in key benthic community variables were similar in all three rivers. Abundance variables had greater ranges (±100 to 200% of the mean) than richness (±6 to 21% of the mean). Invertebrate abundances in major groups were more variable among rivers and years than total abundance. There are insufficient data to derive definitive baseline ranges at this time. Therefore, estimates of baseline ranges should be updated in future years as RAMP accumulates more data.

8.4.2 Detecting and Assessing Regional Trends

Long-term trends were examined by three methods:

- benthic community variables for sites with multiple years of data were examined by graphical presentation;
- benthic community structures were compared between 2000 and 2001, since these were sampled using a common method; and
- the Clearwater River data were analyzed for upstream-downstream trends.

The following conclusions can be drawn from the visual assessment of the available data for locations with multi-year data:

- Long-term trends in major tributaries of the Athabasca River were not detected. Changes identified in this assessment were likely the result of changes in sampling design.
- At this time, there are insufficient data to statistically test for long-term trends.

The following conclusions can be drawn from the comparison of 2000 and 2001 data:

- When the data for Shipyard Lake were compared, all benthic community variables were significantly different between years, with lower values in 2001. There is no obvious explanation for these findings other than differences in dissolved oxygen and aquatic macrophyte cover between the two years.
- Total abundance was significantly lower in 2001 in the MacKay River, but there were only minor, non-significant differences in richness and PC1 scores between years. Since there was no change in development in the MacKay River basin between these years, the differences may reflect natural variation, possibly related to hydrological factors.
- Results for the lower erosional reach of the Muskeg River were generally similar to those described for the MacKay River. Total abundance and PC2 scores were significantly lower in 2001. Only small differences were found in richness and PC1 scores, neither of which was statistically significant.
- Farther upstream in the Muskeg River just above the change in dominant habitat type from erosional to depositional, differences in community structure between years consisted of a small, non-significant change in total abundance, a small increase in richness, a relatively large increase in PC1 scores, and declines in abundances of Oligochaeta and Sphaeriidae in 2001. Differences in richness, PC1 scores, and abundances of Oligochaeta and Sphaeriidae were significant.
- Benthic communities in the Steepbank River were similar in 2000 and 2001. None of the variables compared between years differed significantly.

The following conclusions can be drawn from upstream – downstream comparisons:

- Analysis of upstream-downstream trends could only be completed for the Clearwater River. There were significant differences in three of the five benthic community variables between reaches sampled in the Clearwater River upstream and downstream of the Christina River. These results suggest that differences exist in community structure under baseline conditions, which may reflect the influence of the Christina River.

- Historical data collected in the MacKay, Muskeg and Steepbank rivers were examined visually. Increasing abundance with distance upstream appears commonly in major tributaries in the Oil Sands Region. Total abundance showed this trend in at least one year in all three rivers (MacKay, Muskeg and Steepbank) and abundances of major taxa frequently did as well. The same trend was not apparent in richness in the MacKay and Muskeg rivers, but was seen in the Steepbank River.
- Changes in benthic community structure along rivers have been widely observed and are expected.

The current sampling designs of 15 samples collected from a reach and 10 samples collected from a lake have adequate power, when analyzed using analysis of variance (ANOVA), to detect meaningful differences among years and between reaches. The benthic program could be adjusted to be more cost-efficient without loss of statistical power. Additionally, adjustments to the current design may be warranted to ensure that representative data are collected at each site within a reach.

The recommended approach for adjusting the sampling design is based on study designs used in pulp mill environmental effects monitoring (EEM) and consists of collecting a larger number of smaller samples at each site (analyzed in the laboratory as composites) and reducing the number of sites based on power analysis results. Additionally, establishing permanent monitoring site locations would standardize among site variation, potentially resulting in greater power to detect differences among years. Because the program is still in its initial phase, adjusting the sampling design would not entail loss of an unacceptably large amount of information. Data analysis methods should also be revisited once data are available for a larger number of years.

8.4.3 Monitoring to Verify EIA Predictions

The conclusions and recommendations of this section can be summarized as follows:

- North of Fort McMurray, all regionally significant waterbodies that will persist through development are monitored, or will be monitored by RAMP.

- Although EIA predictions encompass a greater number of waterbodies than are monitored by RAMP, practical constraints require that monitoring be limited to waterbodies of regional significance.
- RAMP monitors some rivers and streams that will be lost to development (Calumet and Tar rivers and Fort Creek). Monitoring these watercourses beyond the baseline period is unlikely to be of value and monitoring reaches upstream of planned developments will also be of little value because there will be no future upstream-downstream comparisons.
- Planned monitoring south of Fort McMurray is of much lower intensity relative to the area to the north, which is partly justified by the lower density of planned developments and lower magnitudes of predicted impacts.
- The monitoring reaches planned in the Hangingstone and Christina rivers are generally appropriate. The location of the upstream monitoring reach in the Christina River should be reconsidered because it is downstream of the PanCanadian Christina Lake Thermal Project.
- To achieve consistency in monitoring effort among southern in-situ oil sands developments, monitoring locations would be required in the immediate vicinity of all planned developments.
- The reaches monitored in the Clearwater River are superfluous, because they are too far downstream from the sources of potential effects to be useful and represent a duplication of effort. Therefore, the monitoring effort allocated to this river may be shifted closer to developments, where monitoring is currently not planned by RAMP.
- As the benthic program evolves, it will be important to track the progress of each development to maximize the efficiency of monitoring and the potential to detect effects.

8.5 FISH POPULATIONS

Due to a limited number of years of data for each component of the fish program and changes in sampling design between years for some components, it is difficult to determine what portion of observed variability in fish populations is attributable to sampling differences. It was concluded that additional data would be required to determine if the small number of apparent changes that were observed for fish populations represent trends outside the range of natural variability. Recommendations for the fish program generally relate to standardizing sampling methods and times or increasing sampling frequency to improve the ability of the program to define variability and identify trends or cumulative effects.

8.5.1 Characterizing Existing Variability

Existing variability was examined for the following aspects of fish populations in the Oil Sands Region:

- relative abundance and biological data for regionally important fish species in the Athabasca River based on three years of RAMP inventory data and comparable historical data from 1975 to 1996;
- relative abundance and biological data for fish species in the lower Muskeg River based on two years of RAMP inventory data and comparable data from 1997 collected for an EIA;
- concentrations of contaminants in muscle tissue of selected fish species from the Athabasca River in relation to suitability for human consumption and fish health effects based on two years of RAMP tissue analysis data and comparable historical information dating back to 1975;
- health parameters for longnose sucker based on one year of RAMP sentinel species data and information from fish health studies conducted in the Athabasca River and other watercourses;
- health parameters for slimy sculpin in the lower Muskeg and Steepbank rivers based on two years of RAMP tributary sentinel species data; and
- relative abundance and biological data for large-bodied species in the Muskeg River based on two years of RAMP counting fence data and comparable historical information dating back to 1976.

Analysis of RAMP fisheries data in comparison to historical information and recent data collected for oil sands EIAs indicated the following:

- Relative abundances and biological characteristics of the main large-bodied fish species in the Athabasca River were variable, but the variability was not associated with any specific changes over time, with the possible exception of walleye and lake whitefish abundances which appear to have declined in recent years.
- Species abundance in the Muskeg River was variable but data indicate little change in species composition, with the exception of a decline in abundance of Arctic grayling.
- Organic compounds (i.e., PAHs) were generally not detected in fish tissues in the Athabasca River, with the exception of two compounds detected in 1998 only.
- With the exception of mercury in walleye, inorganic chemical concentrations measured in fish tissues from the Athabasca River to date

would likely not affect the suitability of fish for human consumption nor affect fish health;

- Mercury concentrations in all walleye tissue samples from the Athabasca River were above the subsistence consumption guideline and one sample was close to the occasional consumption guideline. However, these concentrations were within the historical range of mercury levels for fish tissue in the Athabasca River in the Oil Sands Region and beyond.
- Health parameters of longnose sucker populations in the Athabasca River are within the range of variability observed in other Alberta populations, including populations successfully used for effects assessments.
- Statistically-significant differences were found between exposure and reference populations of longnose sucker in the Athabasca River, thereby demonstrating that the variability of the data is not so high as to mask any differences present.
- Exposure populations of slimy sculpin in the lower Muskeg and Steepbank rivers had significant differences in age and relative gonad size (i.e., gonad somatic index [GSI]) in males and/or females relative to reference populations, coupled with a decrease in age and GSI over time. Further analysis of the data indicated possible explanations for the lower GSI.
- Counting fence results indicated that populations of most of the main large-bodied fish species known to use the Muskeg River watershed (Arctic grayling, longnose sucker and white sucker) may have declined in recent years. Northern pike numbers appeared to be somewhat lower in the recent surveys, but this change was less evident than changes in the numbers of other species.

Based on the analysis of variability in the fish population data, the following recommendations were developed for the RAMP fisheries program:

- The Athabasca River inventory program should continue to include spring and fall sampling in order to monitor all six of the main large-bodied species in the region and provide sample sizes large enough for analysis of population parameters. The summer sampling program is not as important to achieving the objectives of the inventory program.
- The timing of the fall sampling program for the Athabasca River inventory should be standardized to a short duration from early to mid-October. This would minimize sampling related influences on the assessment of lake whitefish abundance.
- Standardized sampling areas should be used for the Muskeg River inventory to account for longitudinal differences in habitat conditions

and fish distribution in the portion of the lower Muskeg River included in the RAMP survey (i.e., below the Jackpine Creek confluence). It is recommended that sampling be conducted in representative sections of each of the four discrete habitat reaches that occur in this section of river.

- Because mercury is the only parameter to occur in concentrations above recommended guidelines and because mercury concentrations currently show no deviation from regional/historical data, the screening level approach employed by RAMP should be considered suitable for monitoring contaminants in fish tissues.
- Fish tissues samples should be collected from adult lake whitefish and walleye only, and from within a single section of the Athabasca River within the Oil Sands Region.
- Tissue samples from individual fish from the Athabasca River (10 of each species, with an approximate gender balance) should be analysed rather than composite samples. Samples should be analysed for mercury and other inorganic parameters. Analysis of tissue samples for PAHs should be discontinued.
- Longnose sucker should be reinstated as a sentinel species for the Athabasca River and variability estimates should be used to calculate the sample size required to detect a difference between exposed and reference fish, based on an appropriate target effect size.
- Given the possibility of significant annual variability in many of the parameters being measured for slimy sculpin, the tributary sentinel species program should be repeated as soon as possible.
- The Muskeg River counting fence should be standardized with the fence located near the Muskeg River mouth, fence installation occurring as soon as possible after ice-out, and the counting fence monitored for a duration of several weeks to document the majority of the spring run. At a minimum, the fence should be in place until mid May.

8.5.2 Detecting and Assessing Regional Trends

Variability in the fish population data was examined for possible changes or trends, identified as differences in current conditions relative to historic conditions or as a consistent increase or decrease in a measured variable over time. A small number of potential tends were identified, but specific conclusions were not possible due to variations in sampling procedures between years:

- Additional data are required to determine if the apparent declines in walleye and lake whitefish abundances in the Athabasca River in recent years represent population trends, are within the range of natural variability, or are due to between year differences in the sampling program.

- Although the inventory data for the Muskeg River span too few years to assess trends, the data indicate a recent decline in Arctic grayling abundance in the Muskeg River compared to historical information. This conclusion is supported by the results from the Muskeg River counting fence.
- Current RAMP data are insufficient to determine whether tissue chemical concentrations in the Athabasca River are showing trends over time. Differences between chemical residues in fish tissue occurred between 1998 and 2001 for selenium and strontium; however, data from 1995 do not follow the same pattern.
- Analysis of trends in the health of longnose sucker in the Athabasca River was not attempted at this early stage in the monitoring program. If longnose sucker continues to be a sentinel species, trends in fish health for this species should be detectable with additional years of adequate data.
- Analysis of trends in the health of sentinel species in tributary watercourses is not possible at this early stage in the RAMP monitoring program. Additional years of data are required for both exposure and reference populations to define regional variability and determine if differences observed to date represent trends or natural variability.
- Muskeg River counting fence data indicate that Arctic grayling, longnose sucker and white sucker abundance appears to have declined in recent years. Reduced abundance of these species may be due, at least in part, to increased beaver activity resulting in degradation of spawning habitats and reduced fish passage. Reduced use of the watershed by northern pike may also have occurred, but this is not clearly indicated by the data.

The recommendations related to better defining data variability (Section 8.5.1) are applicable to better defining regional trends. Additional recommendations to improve the ability of the RAMP fish program to detect changes in fish populations, include the following:

- The frequency of sentinel species monitoring in the Athabasca River and in tributary watercourses should be increased from every three years to every two years to better define variability and identify trends.
- Known spawning habitats in the lower Muskeg River, lower Jackpine Creek and Muskeg Creek should be monitored for habitat conditions relative to historical reports. The number and location of beaver dams should be determined for these watercourses in years when the counting fence is deployed.

8.5.3 Monitoring to Verify EIA Predictions

In a general context, the RAMP fish program will allow verification of relevant EIA predictions for the Oil Sands Region, with the following limitations:

- The Athabasca and Muskeg rivers inventory programs do not assess biodiversity because the main sampling technique (boat electrofishing) is size selective and is only suitable for assessing species composition and relative abundance for large-bodied fish populations.
- Analysis of the quality of fish tissues relative to tainting (flavour impairment) was not addressed in the first five years of the RAMP fisheries program.

Recommendations to improve the ability of the RAMP fish program to verify EIA predictions include the following:

- The Athabasca River and Muskeg River inventories should be expanded to include multiple sampling techniques targeting all fish species and life stages for monitoring biodiversity.
- Analysis of fish tissue samples for tainting compounds should be added to the RAMP program (tainting compounds were included in the 2002 version of the tissue analysis component).

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APPENDIX I

RESULTS OF STATISTICAL ANALYSIS FOR ATHABASCA RIVER FISH INVENTORY DATA

Table I-1 Multiple Comparisons for Non-Parametric Repeated-Measures Analysis of Variance for Lake Whitefish and Walleye Length Frequency Data, Athabasca River Inventories, 1995 to 1999

Species	Season	Year	Critical Value[(a)]	Test Statistic				
				1995	1996	1997	1998	1999
lake whitefish	spring	1995	3.858	0				
		1996		0.85	0			
		1997		0.17	1.01	0		
		1998		0.34	0.51	0.51	0	
		1999		0.25	0.59	0.42	0.08	0
	summer	1995	3.633	0				
		1996		0.21	0			
		1997		0	0.21	0		
		1998		0.21	0	0.21	0	
	fall	1995	3.858	0				
		1996		0.25	0			
		1997		0.59	0.85	0		
		1998		0.25	0.51	0.34	0	
		1999		0.25	0.51	0.34	0	0
walleye	spring	1995	3.858	0				
		1996		0.22	0			
		1997		0.07	0.15	0		
		1998		0.30	0.07	0.22	0	
		1999		0.52	0.30	0.45	0.22	0
	summer	1995	3.633	0				
		1996		0.91	0			
		1997		0.73	0.18	0		
		1998		3.10	2.19	2.37	0	
	fall	1995	3.858	0				
		1996		0.75	0			
		1997		1.27	0.52	0		
		1998		0.60	0.15	0.67	0	
		1999		0.37	0.37	0.89	0.22	0

(a) Test statistic indicates significant difference if it is greater than the critical value.

Table I-2 Multiple Comparisons for Non-Parametric Repeated-Measures Analysis of Variance for Goldeye and Northern Pike Length Frequency Data, Athabasca River Inventories, 1995 to 1999

Species	Season	Year	Critical Value[a]	Test Statistic				
				1995	1996	1997	1998	1999
goldeye	spring	1995	3.858	0				
		1996		0.07	0			
		1997		0.22	0.15	0		
		1998		0.60	0.67	0.82	0	
		1999		1.57	1.64	1.79	0.97	0
	summer	1995	3.633	0				
		1996		2.65	0			
		1997		1.19	1.46	0		
		1998		1.28	1.37	0.09	0	
	fall	1995	3.858	0				
		1996		0.45	0			
		1997		0.45	0	0		
		1998		0.30	0.75	0.75	0	
		1999		0.52	0.07	0.07	0.82	0
northern pike	spring	1995	3.858	0				
		1996		1.81	0			
		1997		1.94	0.13	0		
		1998		0.77	1.03	1.16	0	
		1999		1.61	0.19	0.32	0.84	0
	summer	1995	3.633	0				
		1996		0.79	0			
		1997		0.55	1.34	0		
		1998		1.19	1.98	0.63	0	
	fall	1995	3.858	0				
		1996		0.13	0			
		1997		0.13	0.26	0		
		1998		0.06	0.06	0.19	0	
		1999		0.90	0.77	1.03	0.84	0

[a] Test statistic indicates significant difference if it is greater than the critical value.

Table I-3 Multiple Comparisons for Non-Parametric Repeated-Measures Analysis of Variance for Longnose Sucker and White Sucker Length Frequency Data, Athabasca River Inventories, 1995 to 1999

Species	Season	Year	Critical Value[(a)]	Test Statistic				
				1995	1996	1997	1998	1999
longnose sucker	spring	1995	3.858	0				
		1996		1.06	0			
		1997		0.57	0.49	0		
		1998		0.07	0.99	0.49	0	
		1999		0.42	0.64	0.14	0.35	0
	summer	1995	3.633	0				
		1996		1.21	0			
		1997		0.17	1.04	0		
		1998		0	1.21	0.17	0	
	fall	1995	3.858	0				
		1996		0.35	0			
		1997		0.35	0	0		
		1998		0.42	0.07	0.07	0	
		1999		2.05	1.70	1.70	1.63	0
white sucker	spring	1995	3.633	0				
		1996						
		1997		1.45		0		
		1998		1.66		0.21	0	
		1999		0.62		0.83	1.04	0
	summer	1995	3.314	0				
		1996						
		1997		0		0		
		1998		0.40		0.40	0	
	fall	1995	3.633	0				
		1996						
		1997		0.72		0		
		1998		1.35		0.62	0	
		1999		0.41		0.31	0.93	0

[(a)] Test statistic indicates significant difference if it is greater than the critical value.

Table I-4 Length-Weight Relationships for Lake Whitefish by Season from the Athabasca River [the length-weight relationship is: $W = a \times FL^b$ (n, r^2) where W is the fish weight (g) and FL is the fork length (mm)]

Year - Season	A	B	n	r^2	Spring	Summer	Fall
1995 spring			5				
1995 summer	6.92×10^{-4}	2.37	17	0.799			s **
1995 fall	1.17×10^{-6}	3.43	594	0.857		s	
1996 spring	5.67×10^{-6}	3.14	10	0.991		ns **	ns
1996 summer	6.00×10^{-7}	3.53	11	0.846	ns		ns
1996 fall	6.20×10^{-7}	3.51	162	0.859	ns	ns	
1997 spring			3				
1997 summer	1.45×10^{-7}	3.77	13	0.881			ns
1997 fall	1.76×10^{-7}	3.75	60	0.880		ns	
1998 spring			5				
1998 summer			6				
1998 fall	1.22×10^{-7}	3.79	190	0.844			
1999 spring			4				
1999 summer							
1999 fall	5.43×10^{-6}	3.16	64	0.903			

* ns -- No significant difference ($p > 0.05$).
** s -- Significant difference.
Shaded box indicates no relationship developed either due to no data or to small sample size.

Table I-5 Length-Weight Relationships for Walleye by Season from the Athabasca River [the length-weight relationship is: $W = a \times FL^b$ (n, r^2) where W is the fish weight (g) and FL is the fork length (mm)]

Year - Season	A	B	n	r^2	Spring	Summer	Fall
1995 spring	1.00×10^{-5}	3.01	175	0.978		ns *	s **
1995 summer	7.44×10^{-6}	3.05	113	0.989	ns		s
1995 fall	2.45×10^{-6}	3.25	101	0.997	s	s	
1996 spring	3.49×10^{-6}	3.18	89	0.979		s	s
1996 summer	9.33×10^{-6}	3.01	197	0.944	s		s
1996 fall	9.28×10^{-7}	3.39	182	0.970	s	s	
1997 spring	8.79×10^{-7}	3.40	267	0.966		s	s
1997 summer	1.18×10^{-5}	2.98	95	0.984	s		s
1997 fall	2.81×10^{-6}	3.22	101	0.984	s	s	
1998 spring	8.50×10^{-6}	3.02	131	0.963		ns	s
1998 summer	1.65×10^{-5}	2.93	55	0.950	ns		s
1998 fall	4.25×10^{-6}	3.14	55	0.992	s	s	
1999 spring	1.22×10^{-5}	2.97	164	0.977			ns
1999 summer							
1999 fall	4.83×10^{-6}	3.12	21	0.981	ns		

* ns -- No significant difference ($p > 0.05$).

** s -- Significant difference.

Shaded box indicates no relationship developed either due to no data or to small sample size.

Table I-6 Length-Weight Relationships for Goldeye by Season from the Athabasca River [the length-weight relationship is: $W = a \times FL^b$ (n, r^2) where W is the fish weight (g) and FL is the fork length (mm)]

Year - Season	A	B	n	r^2	Spring	Summer	Fall
1995 spring	6.68×10^{-6}	3.09	57	0.926		ns*	ns
1995 summer	4.30×10^{-6}	3.17	159	0.983	ns		ns
1995 fall	1.07×10^{-5}	3.02	57	0.951	ns	ns	
1996 spring	3.45×10^{-6}	3.20	107	0.934		ns	ns
1996 summer	2.38×10^{-6}	3.27	97	0.913	ns		ns
1996 fall	3.56×10^{-6}	3.19	248	0.965	ns	ns	
1997 spring	3.43×10^{-7}	3.60	257	0.933		ns	ns
1997 summer	2.07×10^{-6}	3.29	44	0.985	ns		ns
1997 fall	6.82×10^{-7}	3.49	194	0.981	ns	ns	
1998 spring	2.10×10^{-6}	3.28	74	0.902		ns	ns
1998 summer	6.75×10^{-7}	3.49	56	0.909	ns		ns
1998 fall	1.31×10^{-6}	3.37	36	0.979	ns	ns	
1999 spring	4.63×10^{-7}	3.56	81	0.938			ns
1999 summer							
1999 fall	3.64×10^{-6}	3.19	42	0.932	ns		

* ns -- No significant difference ($p > 0.05$).

** s -- Significant difference.

Shaded box indicates no relationship developed either due to no data or to small sample size.

Table I-7 Length-Weight Relationships for Northern Pike by Season from the Athabasca River [the length-weight relationship is: $W = a \times FL^b$ (n, r^2) where W is the fish weight (g) and FL is the fork length (mm)]

Year - Season	A	B	n	r^2	Spring	Summer	Fall
1995 spring	2.89×10^{-5}	2.78	13	0.956		ns *	ns
1995 summer	1.99×10^{-6}	3.21	23	0.943	ns		ns
1995 fall	7.93×10^{-6}	2.98	9	0.998	ns	ns	
1996 spring	6.90×10^{-6}	3.01	29	0.919		ns	ns
1996 summer	1.22×10^{-5}	2.92	48	0.956	ns		ns
1996 fall	2.36×10^{-6}	3.16	45	0.979	ns	ns	
1997 spring	6.73×10^{-6}	3.00	17	0.990		ns	s **
1997 summer	2.57×10^{-6}	3.17	40	0.965	ns		ns
1997 fall	1.00×10^{-6}	3.31	22	0.987	s	ns	
1998 spring	1.21×10^{-5}	2.90	17	0.953		ns	ns
1998 summer	1.84×10^{-6}	3.21	10	0.990	ns		ns
1998 fall	4.86×10^{-6}	3.05	13	0.981	ns	ns	
1999 spring	1.58×10^{-6}	3.24	24	0.980			ns
1999 summer							
1999 fall	5.94×10^{-7}	3.38	27	0.969	ns		

* ns -- No significant difference ($p > 0.05$).

** s -- Significant difference.

Shaded box indicates no relationship developed either due to no data or to small sample size.

Table I-8 Length-Weight Relationships for Longnose Sucker by Season from the Athabasca River [the length-weight relationship is: $W = a \times FL^b$ (n, r^2) where W is the fish weight (g) and FL is the fork length (mm)]

Year - Season	A	B	n	r^2	Spring	Summer	Fall
1995 spring	2.46×10^{-5}	2.88	49	0.969		s **	s
1995 summer	6.76×10^{-6}	3.12	37	0.987	s		ns *
1995 fall	6.12×10^{-6}	3.13	96	0.996	s	ns	
1996 spring	2.52×10^{-5}	2.89	30	0.906		ns	ns
1996 summer	6.44×10^{-6}	3.11	14	0.982	ns		ns
1996 fall	9.84×10^{-6}	3.03	46	0.982	ns	ns	
1997 spring	6.77×10^{-6}	3.10	149	0.964		ns	s
1997 summer	9.44×10^{-6}	3.04	16	0.987	ns		s
1997 fall	1.38×10^{-6}	3.37	19	0.992	s	s	
1998 spring	5.73×10^{-6}	3.12	44	0.947		ns	ns
1998 summer	1.68×10^{-6}	3.34	6	0.996	ns		ns
1998 fall	2.55×10^{-6}	3.27	108	0.953	ns	ns	
1999 spring	2.25×10^{-5}	2.91	31	0.971			ns
1999 summer							
1999 fall	8.37×10^{-6}	3.07	9	0.974	ns		

* ns -- No significant difference ($p > 0.05$).

** s -- Significant difference.

Shaded box indicates no relationship developed either due to no data or to small sample size.

Table I-9 Length-Weight Relationships for White Sucker by Season from the Athabasca River [the length-weight relationship is: $W = a \times FL^b$ (n, r^2) where W is the fish weight (g) and FL (mm) is the fork length]

Year - Season	A	B	n	r^2	Spring	Summer	Fall
1995 spring	5.58×10^{-6}	3.16	22	0.999		ns *	s **
1995 summer	1.01×10^{-5}	3.06	15	0.993	ns		s
1995 fall	1.53×10^{-6}	3.39	73	0.987	s	s	
1996 spring							
1996 summer							
1996 fall							
1997 spring	4.45×10^{-7}	3.58	161	0.973		ns	ns
1997 summer	7.90×10^{-6}	3.10	11	0.914	ns		ns
1997 fall	4.92×10^{-7}	3.57	34	0.945	ns	ns	
1998 spring	6.64×10^{-7}	3.51	50	0.976		s	ns
1998 summer	8.48×10^{-6}	3.08	6	0.997	s		s
1999 spring	6.64×10^{-8}	2.65	38	1.018	ns	s	
1999 spring	1.11×10^{-6}	3.44	27	0.970			ns
1999 summer							
1999 fall	2.59×10^{-7}	3.67	23	0.982	ns		

* ns -- No significant difference ($p > 0.05$).

** s -- Significant difference.

Shaded box indicates no relationship developed either due to no data or to small sample size.

Table I-10 Critical Values and F-Values for One-way ANOVA Analysis of Condition Factors, Athabasca River Inventories, 1995 to 1999

Species	Season					
	Spring		Summer		Fall	
	Critical Value	F-value	Critical Value	F-value	Critical Value	F-value
goldeye	**2.40**	**7.72**	**2.65**	**5.58**	**2.63**	**54.16**
lake whitefish	n/a		n/a		**2.61**	**70.77**
longnose sucker	**2.41**	**3.25**	n/a		**2.65**	**20.30**
northern pike	2.50	0.71	2.71	0.30	**2.77**	**4.02**
walleye	**2.39**	**13.84**	2.69	2.24	**2.64**	**13.20**
white sucker	**2.64**	**3.20**	n/a		**2.66**	**4.02**

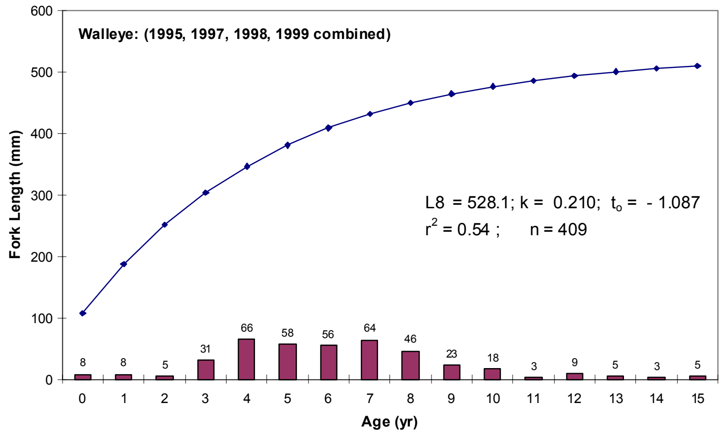
Note: Bold values indicate a significant difference (F-value>crtical value) in annual condition factor ($\alpha = 0.05$)

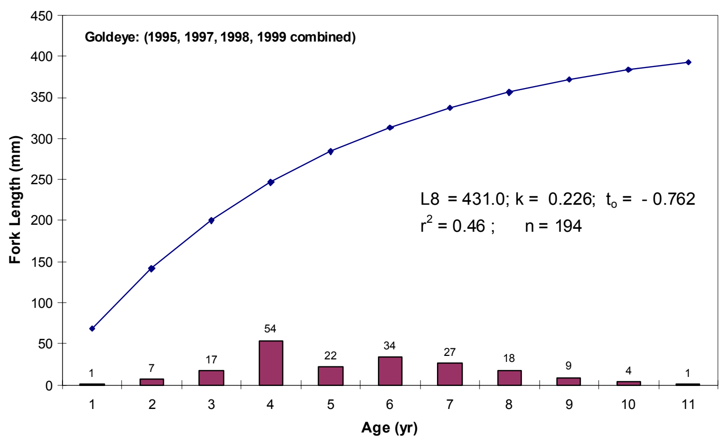
n/a = Season was not analyzed due to small sample size.

APPENDIX II

VON BERTALANFFY GROWTH CURVES FOR THE SIX MAIN LARGE-BODIED FISH SPECIES FOR THE ATHABASCA RIVER OIL SANDS REGION

Figure II-1 Generalized von Bertalanffy Growth Models for Walleye, Goldeye and Lake Whitefish from the Athabasca River Oil Sands Region (bars show *n* values)





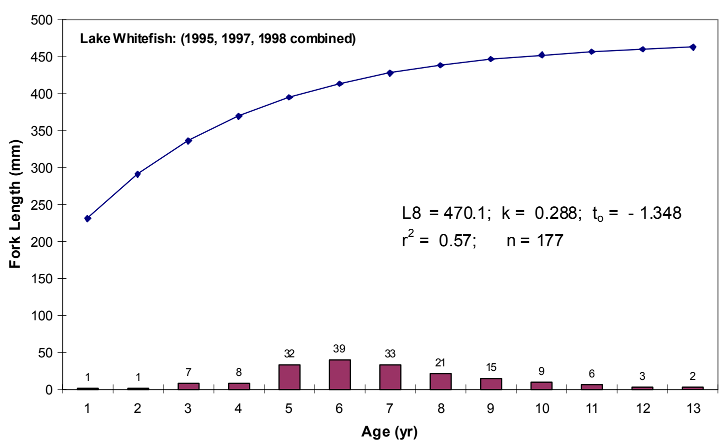
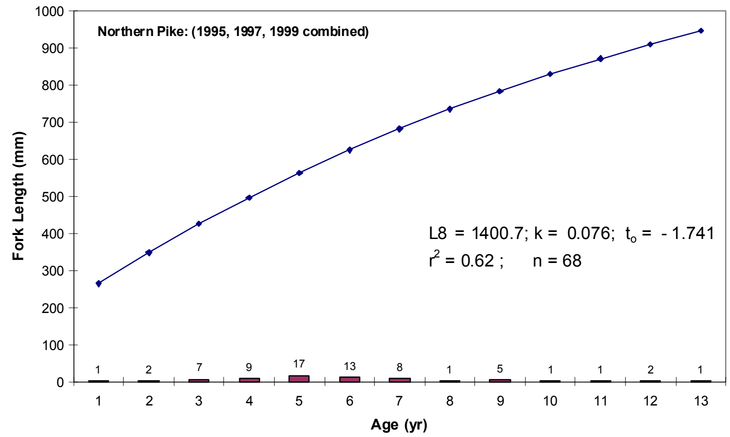
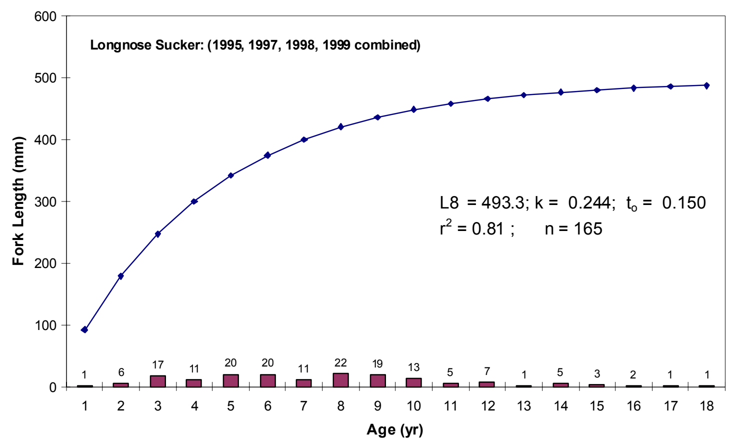
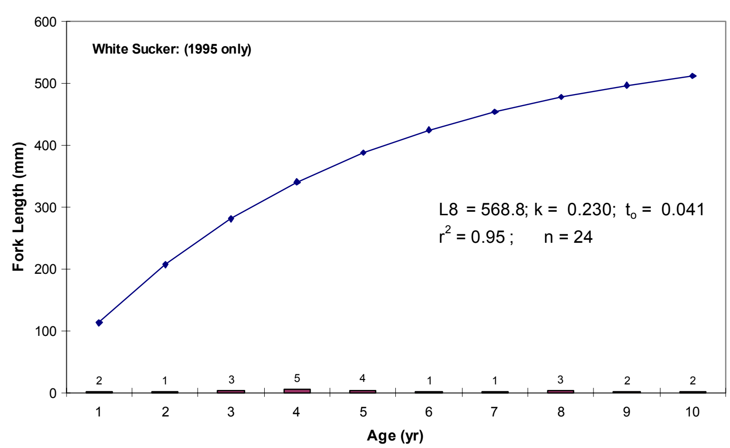


Figure II-2 Generalized von Bertalanffy Growth Models for Northern Pike, Longnose Sucker and White Sucker from the Athabasca River Oil Sands Region (bars show *n* values)







APPENDIX III

RESULTS OF STATISTICAL ANALYSIS FOR MUSKEG RIVER COUNTING FENCE DATA

Table III-1 Multiple Comparisons for Non-Parametric Repeated-Measures Analysis of Variance for Northern Pike and White Sucker Length Frequency Data, Muskeg River Counting Fence Studies, 1976 to 2001

Species	Season	Year	Critical Value[a]	Test Statistic			
				1976	1977	1995	2001
northern pike	spring	1976	3.633	0			
		1977		0.259808	0		
		1995		1.905256	1.645448	0	
		2001		0.779423	1.03923	2.684679	0
white sucker	spring	1976	3.633	0			
		1977		0.259808	0		
		1995		0.086603	0.34641	0	
		2001		0.173205	0.086603	0.259808	0

[a] Test statistic indicates significant difference if it is greater than the critical value.