Regional
Aquatics
Monitoring
Program

RAMP

2003 Technical Report

REGIONAL AQUATICS MONITORING PROGRAM (RAMP)

2003 Annual Report

March 2004

Prepared for:
RAMP Steering Committee

Submitted by

The RAMP 2003 Implementation Team

consisting of

HATFIELD CONSULTANTS LTD.
Jacques Whitford Environment Ltd.
Mack, Slack & Associates Inc.
***and* Western Resource Solutions**

Hatfield Consultants Ltd. Tel: (604) 926-3261 Fax: (604) 926-5389 E-mail: hcl@hatfieldgroup.com

For hardcopy or electronic copies of RAMP reports please contact Hatfield Consultants Ltd.:

Fort McMurray Office

#402-10003 Biggs Avenue

Fort McMurray, AB

CANADA T9H 1T6

Phone: (780) 743-4290

Fax: (780) 743-1164

Contact: Grant Bruce/Daniel Moats

Email: gbruce@hatfieldgroup.com

Vancouver Office

#201-1571 Bellevue Avenue

West Vancouver, BC

CANADA V7V 1A6

Phone: (604) 926-3261

Fax: (604) 926-5389

Contact: Wade Gibbons

Email: wgibbons@hatfieldgroup.com

Or visit the RAMP website at:

http://www.ramp-alberta.org

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

ACKNOWLEDGEMENTS

Funding for 2003 RAMP was provided by Albian Sands Energy Inc. (Albian), Canadian Natural Resources Ltd. (CNRL), ExxonMobil Canada Ltd. (ExxonMobil)/Imperial Oil Resources (Imperial), 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) and Syncrude Canada Ltd. (Syncrude).

The RAMP chairperson during the 2003 program year was Terry Van Meer (Syncrude). Michael Burt (OPTI Canada Inc.) was chair of the Technical Sub-committee, Andrew Cummins (Suncor) was chair of the Finance Sub-committee and Eric Davey (Athabasca Tribal Council) was chair of the Communications Sub-committee.

RAMP is a multi-stakeholder environmental monitoring program that is composed of representatives from industry, provincial and federal governments, local aboriginal groups and environmental organizations. Effective implementation of the RAMP requires a number of contributors. We would like to thank the following:

- Members of the RAMP Steering Committee, Technical Sub-committee, Finance Sub-committee and the Communications Sub-committee;

- Syncrude, Suncor, CNRL, OPTI/Nexen and Alberta Sustainable Resources Development (ASRD) for in-kind contribution towards the fish inventory program;

- Mr. Gary Cooper and North/South Consultants Inc. for their assistance with the Muskeg River fish fence program;

- ASRD for providing fish tissue from Christina Lake and Mr. Robert Grandjambe for providing fish tissue from Lake Claire to supplement the regional lakes tissue analysis program and for Mr. Grandjambe for support of the water/sediment and benthos field programs in the Athabasca River delta;

- Alberta Environment (AENV), Syncrude and Albian for providing water quality data from their ongoing monitoring programs for inclusion in RAMP;

- AENV for conducting field work required for the Acid Sensitive Lakes component; and

- Local residents who provided information related to the Fish Tag Return Program and the Fish Abnormalities Program.

In addition, the 2003 RAMP Implementation Team would like to acknowledge the following contractors who assisted with the program in 2003: Enviro-Test Laboratories (chemical analyses); AXYS Analytical Services Ltd. (chemical analyses); University of Alberta Limnological Laboratory (chemical analysis); Alberta Research Council (chemical analysis); North Shore Environmental Services (fish aging); HydroQual Laboratories Ltd. (toxicity testing); and Dr. Jack Zloty (benthic invertebrate taxonomy).

EXECUTIVE SUMMARY

PURPOSE OF RAMP

The Regional Aquatics Monitoring Program (RAMP) was initiated in 1997 in response to mining development in the Athabasca oil sands region near Fort McMurray, Alberta. RAMP is an industry funded, multi-stakeholder initiative that monitors the health of aquatic environments in the region. The intent of RAMP is to integrate aquatic monitoring activities so that long-term trends, regional issues and potential cumulative effects related to oil sands development can be identified and addressed. The program is frequently adjusted and refined to reflect monitoring results, technological advances and community concerns. In 2003, RAMP was funded by Syncrude Canada Ltd., Suncor Energy Inc. Oil Sands, Albian Sands Energy Inc., Shell Canada Limited, Canadian Natural Resources Limited, ExxonMobil Canada Ltd., Petro-Canada Oil and Gas, Opti Canada Inc., Nexen Canada Ltd. and Devon Canada Corporation.

RAMP incorporated both stressor- and effects-based monitoring approaches. Using impact predictions from the various oil sands environmental impact assessments, specific potential stressors have been identified that are monitored to document baseline conditions, as well as potential changes related to development. Examples include specific water quality variables and changes in water quantity. In addition, there is a strong emphasis on monitoring sensitive biological indicators that reflect and integrate the overall condition of the aquatic environment. By combining both impact assessment approaches, RAMP strives to achieve a more holistic understanding of potential effects related to oil sands development.

The scope of RAMP focuses on key components of boreal aquatic ecosystems, including:

- Climate and hydrology, which monitors changes in the quantity of water flowing through rivers and creeks in the oil sands region;
- Water and sediment quality, which reflect habitat quality and potential exposure of fish and invertebrates in rivers, lakes and some wetlands to organic and inorganic chemicals;
- Benthic invertebrate communities, which serve as biological indicators in rivers/streams and wetlands and are important components of fish habitat;

- Fish populations, which are biological indicators of ecosystem integrity in rivers and lakes and are highly valued resources in the region;

- Water quality in regional lakes sensitive to acidification, which provides an early warning indicator of potential effects related to acid deposition; and

- Wetland aquatic vegetation, which provides an ecological indicator of the health of regional wetlands.

The Regional Municipality of Wood Buffalo in northeastern Alberta defines the RAMP Regional Study Area. Within this area, a Focus Study Area (FSA) has been defined and includes watersheds where oil sands development is occurring or planned. In 2003, RAMP focused on the following aquatic systems:

- Athabasca River and Peace-Athabasca Delta;

- Major tributaries of the Athabasca River including the Clearwater River, Steepbank River, Muskeg River, MacKay River, Ells River, Tar River and Firebag River;

- Select minor tributaries of the Athabasca River (e.g., MacLean Creek, Beaver Creek, Fort Creek, Calumet River, etc);

- Select rivers/streams within Athabasca tributary watersheds (e.g., Jackpine Creek, Wapasu Creek, North Steepbank River, Christina River, etc);

- Wetlands occurring in the vicinity of current or proposed oil sands development; and

- Regional lakes important from a fisheries perspective (Christina Lake, Lake Claire), or known to be sensitive to acidifying emissions.

The following sub-sections briefly summarize the scope and results of each key aquatic component studied as part of the 2003 RAMP.

CLIMATE AND HYDROLOGY

The 2003 RAMP climate and hydrology component monitored climate, water levels and streamflows in the oil sands region, extending the climatic and hydrologic database of the region. Some highlights of the 2003 program and results are summarized below:

- The Aurora Climate Station collected its full suite of climate information during 2003. Additional rainfall, snowfall and temperature data were collected at Calumet River. Barometric pressure was monitored at Muskeg River above Muskeg Creek. Rainfall was monitored at Iyinimin Creek, Tar River, Christina River and McClelland Lake; however, records at all four stations were incomplete because equipment was damaged by wildlife. Rainfall at the Aurora climate station was slightly below normal in 2003. Unusual hydrologic features of the year included uncharacteristically warm temperatures in early January and a relatively wet autumn.

- Spring snow course surveys were conducted on the east slopes of the Birch Mountains for the third consecutive year, and in the Fort Hills Creek area. Snowpack depths were significantly greater in 2003 than in the previous two years, with 74 mm of snow water equivalent measured in the Birch Mountains.

- An inactive streamflow station, Muskeg River above Stanley Creek (S5), was reactivated and a new station, Muskeg River at the Aurora / Albian Boundary (S33) was established in 2003 at Syncrude's request, to comply with monitoring requirements.

- An ice jam flood on the Ells River destroyed the station on the Ells River above Joslyn Creek (S14) in April. The station was re-established in May.

- Twenty-seven water level and streamflow stations were monitored in 2003. The number of stations monitored during the winter increased from nine in the winter of 2002-2003 to twelve in the winter of 2003-2004.

- In a new initiative, the quality of each streamflow measurement made during 2003 and each station's record for the year was defined as excellent, good, fair or poor based on site hydraulic conditions, equipment performance, and record completeness. The quality assessment enables users to better evaluate the reported results.

- Basin run-off volumes measured in large streams with long-term records (Water Survey of Canada) varied significantly between basins, being below normal in the MacKay and Athabasca basins, near normal in the Muskeg, Clearwater and Christina basins, and well above normal in the Steepbank and Firebag basins. Peak flows were below normal in all of the basins except the Clearwater and the Firebag, which were close to normal.

- Total suspended solids (TSS) measurements were made at 26 locations several times during the year, and indicated very low TSS levels throughout the year in most of the monitored streams.

- Water temperature was monitored at two locations (Muskeg River and Calumet River). Temperatures in the range of 15°C were measured from late May to late August, with a maximum temperature of over 20°C recorded at the beginning of August.

Recommendations made based on the 2003 program and an evaluation of overall program effectiveness include:

- Add information about catchment changes, stream diversions, and operational water withdrawals and releases in the RAMP database and reports. This information is essential to enable calculation of natural streamflows, and consequently to verify EIA predictions.

- Conduct a systematic regional snow survey at consistent locations for several years.

- Establish flow monitoring at new locations in the CNRL lease area to replace stations S15 (to be discontinued in 2004) and S19 (potentially discontinued in the near future).

- Improve climate and hydrometric monitoring south of Fort McMurray by upgrading the Christina River rainfall gauge to measure snowfall, and by re-establishing two of the discontinued Petro-Canada Meadow Creek stations.

- Review the value of monitoring stations Stanley Creek near the Mouth (S8) and Shelley Creek near the Mouth (S21). Both stations are located within muskeg lowlands; the stream boundaries at S8 are poorly defined. Beaver activity at S21 results in continual variation in the relationship between water level and discharge, making continuous streamflow monitoring at this site difficult. These stations should be improved, relocated or abandoned.

WATER QUALITY

Water quality was sampled by RAMP at 47 stations throughout the lower Athabasca River watershed in 2003, including several stations on the Athabasca River mainstem from upstream of Fort McMurray to the Athabasca River delta, nine stations in the Muskeg River watershed, four stations in the Clearwater River watershed, three stations in the Steepbank River watershed, two stations each in the MacKay and Firebag rivers, seven stations in other tributaries to the Athabasca River, including McLean Creek, Poplar Creek, Beaver River, Ells River, Tar River, Calumet River and Fort Creek; and three regional lakes, including Kearl Lake, Shipyard Lake, and McClelland Lake.

All stations were sampled in fall, while several stations also were sampled in winter (20 stations sampled), spring (22 stations sampled) and summer (23 stations sampled). At each station, numerous water quality variables were measured, including physical variables, concentrations of major ions, nutrients and BOD, various metals (both total and dissolved fractions), and various aromatic organic compounds, including polycyclic aromatic hydrocarbons (PAHs) at selected stations in the Athabasca River mainstem in fall. Additionally, chronic toxicity of ambient river waters was assessed in fall for the Ells, Tar, and Calumet rivers.

Highlights of 2003 water quality component results, organized by waterbody, include the following:

Athabasca River mainstem and delta:

- Water quality in the Athabasca River downstream of Fort McMurray was generally consistent with previous years, and generally consistent along the river from upstream of Donald Creek to the Athabsasca River delta, suggesting that inputs from tributaries in the oil sands region, regardless of human activities on them, did not clearly affect water quality in the river mainstem;

- Some variables, including chloride and conductivity, increased in concentration with increasing distance downstream in the Athabasca River mainstem, potentially due to tributary inputs or groundwater seepage;

- Results suggested that cross-channel mixing of the Athabasca River is poor, with different water quality characteristics along each bank persisting over tens of kilometers;

- While a clear relationship exists in the Athabasca River between suspended sediment concentrations (TSS) and total metals and total phosphorous as demonstrated in previous RAMP studies, TSS were not correlated with concentrations of dissolved metals or dissolved phosphorous, the most biologically reactive forms of most metals and of phosphorous in aquatic environments.

Tributaries to the Athabasca River:

- Generally, tributaries to the Athabasca River exhibited higher colour, alkalinity, conductivity, concentrations of most dissolved ions and metals, dissolved organic carbon, and lower suspended solids than the Athabasca River mainstem;

- Western tributaries generally exhibited higher concentrations of metals than eastern tributaries, as well as higher colour, conductivity and alkalinity;

- *Beaver River:* This stream, near the Syncrude Mildred Lake facility, exhibited concentrations of several key water quality variables, including sulphate, conductivity, chloride, and several dissolved metals, that were outside the range of natural variability of other tributaries sampled, suggesting a potential effect of human activities in this watercourse;

- *Poplar Creek*: This stream exhibited high chloride, alkalinity, colour and dissolved metals (but similar sulphate concentrations) relative to other tributaries;

- *Tar and Ells rivers*: Although water quality at these stations was broadly similar to other tributary stations, these rivers (yet to experience major development) exhibited moderate chronic effects on fathead minnow survival (IC25 = 78% and 50%, respectively).

Tributary watersheds experiencing development:

- Water quality in watersheds experiencing oil sands development (i.e., the Muskeg, MacKay, Clearwater/Christina, and Steepbank watersheds) was generally similar to other tributaries in the region, suggesting that water quality in these tributaries was typical of regional conditions;

- *Stanley Creek:* Water quality at all stations in the Muskeg River watershed were similar to historical observations except at Stanley Creek, where large increases in concentrations of sulphate, phenol, alkalinity, conductivity and other variables were observed, this may be associated with the commencement of Syncrude's Clean Water Discharge to Stanley Creek in late May 2003;

- *Christina River:* Between upper and lower Christina River stations, chloride concentrations increase from near zero to regionally high concentrations, suggesting a source or sources of chloride in this reach of the Christina River.

Regional lakes:

- Water quality in regional lakes sampled was generally within historical ranges;

- *Shipyard Lake:* Concentrations of boron and sulphate, observed to be increasing during RAMP sampling from fall 1998 to fall 2002, were similar in fall 2003 to fall 1999 values, while summer values from 1999 to 2003 did not indicate increasing temporal trends in either variable.

Recommendations regarding future RAMP water quality programs include:

- Consider reducing or eliminating measurements of PAHs in water in the Athabasca River mainstem, and focus any future efforts to assess PAHs in water on specific tributaries where hydrocarbon concentrations have been or may be expected to be high (e.g., the Ells River);

- Consider collection and analysis of cross-channel composite samples only along the Athabasca River mainstem rather than east bank, west bank, and cross-channel composites at these stations; and

- Consider sampling a second Athabasca River mainstem station in winter, such as ATR-DC-CC (upstream of Donald Creek, cross-channel composite), to provide concurrent data to compare against results from the one downstream station sampled by RAMP in winter (i.e., ATR-DD-CC, located downstream of all development).

SEDIMENT QUALITY

Sediment quality was sampled by RAMP at 36 stations throughout the lower Athabasca River watershed in September 2003, including 14 stations on the Athabasca River mainstem from upstream of Fort McMurray to the Athabasca River delta (with stations along both banks of the river), three stations in channels of the Athabasca River delta, eight stations in the Muskeg River watershed, four stations in the Clearwater River watershed, two stations in the Firebag River, three stations in other tributaries to the Athabasca River, including Ells River, Tar River, and the Steepbank River (sampled in the North Steepbank River only), and two regional lakes, Shipyard Lake and McClelland Lake.

Samples from all stations were analyzed for physical variables (i.e., grain size and moisture), carbon content (including organic and inorganic carbon), concentrations of various metals, general measures of petroleum hydrocarbons (including total recoverable hydrocarbons, total extractable hydrocarbons, and total volatile hydrocarbons) and target (parent) PAHs and alkylated PAHs. Additionally, chronic toxicity of sediment was assessed at 28 of the 36 stations, through 10 day exposures of three organisms, including the amphipod *Hyallela azteca*, the chironomid *Chironomus tentans* and the earthworm *Lumbriculus variegatus*.

Highlights of 2003 sediment quality component results include the following:

- Concentrations of metals were variable among stations surveyed, with particularly high values observed at stations with a high proportion of fine sediment and high carbon content, but generally were similar among stations following adjustment for grain size;

- Concentrations of PAHs, which are naturally high in the oil sands region, were highly variable among all stations, and did not exhibit spatial or temporal patterns that would suggest any effects of development on PAH concentrations in sediments;

- Following adjustment for organic carbon content, concentrations of PAHs in sediments were highest in the Ells River, followed by the east bank of the Athabasca River upstream of Donald Creek, the Muskeg River upstream of Canterra Road crossing, the Athabasca River upstream of Fort McMurray, the mouth of the Christina River, and the Tar River;

- Generally, stations that exhibited high metals concentrations also exhibited high PAH concentrations, likely because of interrelationships between grain size (a key factor affecting metals concentrations) and organic carbon (a key factor affecting PAH concentrations);

- Stations differed with respect to specific proportions of various PAHs present, with several stations exhibiting more highly toxic, high molecular weight PAHs and some being dominated by low molecular weight PAHs;

- Low molecular weight PAHs were found to be strongly, positively correlated with fine sediments and moderately correlated with organic carbon, while high molecular weight PAHs were only weakly correlated with grain size and TOC, consistent with lower volatility and greater resistance to weathering of high molecular weight PAHs;

- Relative concentrations of specific PAHs may provide information regarding whether PAHs at specific stations originated primarily from bitumen (e.g., dibenzothiophenes), or decaying plant materials (i.e., retene);

- At some stations where relatively high PAHs were observed in sediment, exposed bitumen was apparent along the bank, which likely contributed to high PAH values, particularly high molecular weight PAHs, at these stations;

- On the Muskeg River, whose watershed has seen the most oil sands-related development, sediment quality was similar upstream of development and at the river's mouth, and consistent with historical observations; and

- Any observed sediment toxicity appeared to be primarily related to physical characteristics of sediment (i.e., grain size and/or organic carbon) rather than concentrations of metals or PAHs.

Generally, sediment quality was highly variable among stations surveyed, with no effects of oil sands development or operations suggested. Recommendations regarding future RAMP sediment quality programs include:

- Major modification or elimination of sediment quality monitoring in the Athabasca River mainstem, given it currently does not monitor changes in (i.e., potential accumulation of) sediment-borne chemicals at each station from year to year, but rather the chemistry of mobile, newly-deposited sediments at each station;

- To address problematic shortcomings of the sediment quality program in the Athabasca River mainstem, consider: (a) focusing sampling on tributaries to the Athabasca River only; (b) focusing sampling on the

Athabasca River delta, a truly depositional environment; and/or (c) relocating stations on the Athabasca River mainstem to known areas of sediment deposition and downstream of tributaries expected to experience development; and

- Replace analysis of Total Recoverable Hydrocarbons (TRH), Total Extractable Hydrocarbons (TEH) and Total Volatile Hydrocarbons (TVH) in sediments with the CCME four-fraction petroleum hydrocarbon scan, which is more meaningful, widely accepted and includes associated environmental quality guidelines; and

- Eliminate the 10-day *Lumbriculus variegatus* survival and growth test from the RAMP program, given observed effects of exposure to RAMP sediments on *Lumbriculus* growth could not be related to any physical or chemical characteristics of sediment, survival results are not useable due to persistent problems with organism breakage in sandy sediments, there is no formally accepted method for this test, *Lumbiculus* is a terrestrial organism,.

BENTHIC INVERTEBRATE COMMUNITY

The 2003 RAMP benthic invertebrate program involved collection of invertebrate samples and habitat quality data from ten rivers (20 reaches), three channels of the Peace-Athabasca Delta and three lakes in the oil sands development region. Changes in community indices since 1998 were examined visually and differences in community composition (i.e., abundance, richness, diversity and evenness) between reaches on each river system and among lakes were examined statistically among stations and years for lake and river systems where potential existed for effects of oil sands developments.

Over 250 invertebrate taxa were identified in the 2003 survey; these were classified by their general sensitivity to pollution, from highly tolerant to highly sensitive. Community composition in different areas reflected a diversity of pollution sensitivity. No sampling locations suggested impacts of pollution (i.e., through occurrence of only highly tolerant taxa at a given station); no communities were classified as extremely sensitive to chemical exposure due to their composition. Physical habitat characteristics likely were key determinants of community composition.

Composition of invertebrate communities at stations in the Peace-Athabasca Delta were similar and within expected ranges for abundance, richness, diversity, and evenness, and indicated intermediate to high tolerance to chemical exposure. Among lakes studied, the most abundant taxa in all three lakes were highly pollution tolerant. Benthic community structure in Shipyard Lake was less diverse than either Kearl or McClelland Lakes. The composition of the benthic community in Shipyard Lake demonstrated substantial year-to-year variability relative to the other lakes sampled.

No indications of major degradation of benthic habitats were apparent in rivers where mine developments currently exist. Lower reaches of the Clearwater and Christina rivers exhibited higher abundance of pollution-tolerant taxa relative to upstream reaches and reflected substrate composition differences. The invertebrate community of the lower MacKay River, located downstream of current oil sands development, exhibited among the highest numbers of pollution-sensitive taxa of all river reaches sampled in 2003. In the Muskeg River, habitat differences (i.e., erosional versus depositional) were the probable cause for differences in invertebrate communities between the lower reach and lower-to-mid and upper reaches of the river. Invertebrate communities were similar between the lower-to-mid and upper reaches of the Muskeg River.

Data collected from the other rivers studied (i.e., two reaches each on the Firebag, Ells, Calumet and Tar Rivers and one reach on Fort Creek) established pre-development baseline conditions.

Generally, temporal and spatial trends were consistent with those reported in the RAMP Five Year Report. No clearly identifiable long-term trends in benthic community structure were apparent in 2003 at any station surveyed, with the possible exception of lower reaches of the Christina and Clearwater rivers, where communities were less abundant and less diverse in 2003 relative to previous years. However, differences in invertebrate communities at these stations may also be attributable to physical habitat variables.

FISH POPULATIONS

In 2003, RAMP conducted the following monitoring of fish populations: fish population inventory on the Athabasca River, the Clearwater River and the Firebag River; analysis of tissue from target fish species from the Athabasca River, Lake Claire and Christina Lake; and operation of a spring two-way fish counting fence on the lower Muskeg River.

Fish Inventory

Fish inventory activities were conducted in-kind to the RAMP program by participating stakeholder groups, including Syncrude, Suncor, CNRL, OPTI/Nexen and Alberta Sustainable Resource Development. The Athabasca and Clearwater rivers were sampled in both spring and fall; the Firebag River was sampled in spring only. Fish were sampled using boat-based electrofishing and occasionally by seine netting. Of particular focus were the key indicator species of the Athabasca River (i.e., walleye, northern pike, lake whitefish, longnose sucker, goldeye and trout-perch).

In the Athabasca River, a total of 5,546 fish from 20 species were captured. Most abundant species captured by electroshocking in the Athabasca River were (in declining order) walleye, goldeye, white sucker, longnose sucker and northern pike. The total number of fish species observed (20) was near the upper end of the historical range. Proportion of walleye, goldeye, longnose sucker and white sucker relative to the total catch increased in 2003. In spring, relative abundance of northern pike remained consistent in 2003 compared with historical results. Three fish species known in exist in the Athabasca River, but not previously captured during RAMP studies were captured in 2003, including cisco, pearl dace and longnose dace. Length-frequency distributions for key fish indicator species indicate generally consistent results over the long term, with dominant size classes remaining consistent over time. No significant difference in condition was observed among years for any of the five species evaluated.

A total of 3,350 fish from 19 species were captured in the Clearwater River in 2003. Large-bodied fish present included (in declining order of abundance) white sucker, northern pike, walleye and mountain whitefish. Mean condition of walleye and northern pike was similar in both the Clearwater and Athabsca rivers, while longnose sucker exhibited lower condition relative to Athabasca River fish (i.e., lighter for a given length).

A total of 20 individuals from seven species were captured during fish inventory studies in the Firebag River in spring 2003. Emerald shiner and trout-perch were the most abundant species captured. Detailed analyses were not conducted due to the relatively low number of fish captured.

Fish Tissue

Concentrations of mercury in tissues of all target fish species (i.e., walleye, lake whitefish and northern pike) from the Athabasca River, Lake Claire, and Christina Lake exceeded criteria for the protection of human health (occasional consumers, subsistence and recreational fishers and sensitive subpopulations). In the Athabasca River, risks associated with consumption of walleye exceeded guidelines for all segments of the population that consume fish; for lake whitefish, consumption risks generally were limited to subsistence fishers and sensitive subpopulations such as children. Mercury concentrations in fish tissues also were sufficiently high to potentially pose risks to wildlife consuming fish from the Athabasca River, Christina Lake, and Lake Claire.

Elevated mercury levels in fish do not appear to be linked to oil sands development, given concentrations in fish, water, and sediment fell within natural, background ranges of concentrations in the oil sands region prior to development.

Concentrations of other metals or tainting compounds in fish tissue from the Athabasca River were below levels predicted to create risks to human health. Generally, metals concentrations in fish tissues were similar to those observed in 2002, while concentrations of tainting compounds were lower in 2003 relative to 2002. Tainting compounds were generally below detection limits and well below criteria for reduced palatability of fish.

Muskeg River Fish Fence

A two-way fish counting fence was deployed and operated across the lower Muskeg River from May 2 and May 27, 2003, to obtain accurate estimates of fish movement into and out of the river during the spring season, which is spawning time for Arctic grayling, northern pike walleye and sucker species. In addition to the fence, two partial fish fences (i.e., hoop nets), as well as larval drift traps, were deployed in the lower Muskeg River to provide comparative capture methods.

In total, 1,206 fish representing nine fish species and six families were captured. Of the six most abundant species, longnose sucker, white sucker and northern pike accounted for over 99% of all the fish counted. A total of two Arctic grayling were observed passing the fence. Residency in the Muskeg River varied by species: suckers were resident for 0.5 to 13 days; northern pike were resident for 1 to 10 days. Incidence of external abnormalities/pathologies was generally low, but highest for white suckers and lowest for longnose suckers.

Comparison of fish abundance data from 2003 with other successful fish fence studies on the Muskeg River (i.e., 1976 and 1977 and 1995) indicates that abundance of migrant large-bodied fish in the Muskeg River has declined substantially over time. Although 2003 results were similar to those from 1995, abundance of large-bodied fishes in both 1995 and 2003 was substantially lower than in 1976 and 1977. Surveys in 1976, 1977 and 1995 were undertaken prior to oil sands development in the Muskeg River watershed. The number of migrating white sucker captured in 2003 was approximately 10% of that measured in the late 1970s. Numbers of longnose sucker captured in Muskeg River fish fence studies also have decreased over this period. It is possible that low water levels that have been observed over the previous five years throughout the lower Athabasca basin have affected the accessibility of the river to spawning fish. An increase in the number of beaver dams, as a result of lower water levels, may also have reduced access to spawning areas.

The Muskeg River fish fence study continues to be effective in documenting fish use of the river for migration and spawning. However, given the high variability of fish fence data, many years of baseline data would be required to clearly detect development-related changes.

AQUATIC VEGETATION

The RAMP aquatic vegetation program monitored the health of aquatic vegetation communities in regional lakes and wetlands in the oil sands area, specifically Isadore's Lake, Shipyard Lake and Kearl Lake. Field surveys evaluated occurrence, percent cover and vigour of submergent and emergent aquatic macrophyte vegetation. Historical aerial photographs also were assessed to document any changes in spatial distribution of aquatic vegetation communities and open water in these lakes.

Results indicated that vegetation species diversity and similarity measurements differed in 2003 relative to previous RAMP sampling in 2001. However, these changes likely are ascribable to differences in sampling methodology, as sampling in 2003 included only the aquatic portion of each waterbody and excluded vegetation in drier areas that may have been sampled and enumerated in previous years. Analysis of historical aerial photography indicated water levels vary significantly from year to year, particularly in Isadore’s and Shipyard lakes. Any potential change in wetland vegetation resulting from industrial activity may be difficult to detect given the degree of variability in available baseline data.

ACID SENSITIVE LAKES

A total of 50 lakes were sampled in 2003 for the Acid Sensitive Lake (ASL) component of the RAMP program. Critical loads, defined as highest levels of acidic deposition that will not cause chemical changes leading to long-term harmful effects in a lake, were calculated from the Henriksen steady-state model for each lake and year, and compared with modelled potential acidic inputs (PAI) from atmospheric sources. A PAI value higher than the critical load for a given lake suggests that it has the potential for acidification. A total of 13 of the 50 RAMP lakes fell into this category, indicating that these lakes are the most sensitive to acidification and should be monitored accordingly. The majority of these 13 lakes are located south of Fort McMurray in the Stony Mountains area.

There were insufficient monitoring data to detect temporal trends in key chemical variables that would indicate a process of chronic lake acidification. Comparisons between the first three and last two years of monitoring identified 26 lakes where pH increased and six where pH decreased. Total alkalinity increased in 21 lakes and decreased in eight lakes. Most of these changes were small enough to be attributed to analytical error or seasonal variability. Several lakes exhibited larger changes in both variables and deserve additional attention in future monitoring cycles, including Lake 170 (A26) in the Stony Mountains, Lake 470 (L7, northeast of Fort McMurray) and Lake 89 (Whitesand Lake) in the Caribou Mountains.

The addition of Gran alkalinity and dissolved inorganic carbon (DIC) as monitoring variables in 2002 and 2003 permitted the determination of the role of organic acids on the acid-base status of these lakes. Concentrations of free organic acids in the lakes were calculated by the method of anion deficit and by calibration of other published models to regional conditions. Equations were derived that permitted: calculation of free organic anions from field measurements of DOC in regional lakes; concentrations of strong organic acids which remain dissociated at low pH and reduce the overall ANC of a lake, and the ANC contributed by weak organic anions (i.e., organic buffering) in a lake relative to its pH and DOC.

The proportion of the total ANC attributable to weak organic acids (i.e., $ANC_{org)}$ ranged from 7.5% to 84.9% (median: 38.7). Generally, the importance of organic buffering was small in an absolute sense in low pH lakes, where ANC_{org} was low, and small in a relative sense in high pH lakes, where contribution to ANC was high for both organic acids and bicarbonate. Regardless of organic acid concentration, regional water bodies with both low ANC and low pH remain those most sensitive to acidification.

SYNTHESIS

To assist integrated assessment of environmental quality in the RAMP study area, results of all RAMP study components were evaluated together on a watershed-by-watershed basis, through the implementation of a simple scoring system based on effects-based criteria, against which data from each component was judged. These criteria included the following:

- *Climate and hydrology:* Streamflow relative to historical values;
- *Water and sediment quality:* Number (and magnitude) of variables exceeding water or sediment quality guidelines at each station, and degree of toxicity observed at stations where chronic toxicity testing was undertaken;
- *Benthic invertebrates:* Magnitude of difference between upstream and downstream community composition variables, and proportion of pollution-sensitive taxa;
- *Fish tissue quality:* Chemical concentrations in fish tissues exceeding guidelines for consumption of fish by humans or wildlife, thresholds for sublethal effects on fish health, and criteria for tainting of fish flesh.

Stations were identified as baseline (i.e., pre-development or reference), and operational (i.e., downstream of existing developments), for purposes of assessing potential effects of oil sands development and other human activities on aquatic environmental quality in the RAMP study area. Acid-sensitive lakes were excluded from this integrated assessment as different waterbodies were sampled. Aquatic vegetation also was excluded given lack of reference stations and methodological changes between years that limited interpretation.

Integrated assessment of waterbodies was complicated by inconsistencies between components with regard to sampling locations and scope. However, several general conclusions were drawn, including:

- Environmental quality in the Athabasca River mainstem and delta in 2003 was generally similar to previous years and not suggestive of effects of development;
- At stations in the Athabasca River mainstem, there generally was not concordance among components in any negative environmental quality indicators (i.e., poor water quality was not associated with poor sediment quality, etc.)

- Concentrations of mercury in fish tissues in the Athabasca River mainstem, which exceeded safe consumption guidelines, were not related to observed concentrations of mercury in sediments or water;

- Environmental quality in tributaries to the Athabasca River was highly variable, with some tributaries exhibiting poor environmental quality for multiple components concordantly, including the Tar and Ells rivers (which exceeded criteria for water and sediment chemistry and toxicity) and the Christina River (which exceeded water chemistry, sediment toxicity and benthos criteria);

- All component measurements undertaken in lower reaches of the Muskeg River indicate that upstream activities in this watershed are not affecting downstream environmental quality;

- Concentrations of mercury in fish tissues that exceeded consumption guidelines in regional lakes surveyed (i.e., Christina Lake and Lake Claire); could not be related to other environmental quality measures, given other RAMP components were not sampled in these watersheds (fish tissues were sampled in Christina Lake by Alberta Sustainable Resource Management, samples from Lake Claire were provided by a community member of Fort Chipewyan);

- Generally, environmental quality in waterbodies sampled by RAMP did not appear to be related to whether stations were defined as baseline or operational, given numerous stations in undeveloped watersheds exhibited poor environmental quality in one or several monitoring components.

Detailed assessment and discussion regarding the efficacy of RAMP in meeting its objectives was presented in the RAMP Five Year Report, and will be assessed further in the soon-to-be-released Peer Review of the Five Year Report. Therefore, this topic was not revisited in this report. However, some general comments and recommendations regarding the effectiveness of the RAMP program are presented in the 2003 annual report.

These recommendations generally pertain to:

- The need to understand and create an inventory of activities and releases related to oil sands developments that may affect aquatic environments, and the associated predictions of environmental impact assessments for these developments;

- Development of a decision-making framework and potentially watershed-specific criteria to guide design and interpretation of RAMP as it develops; and

- How to maintain consistency and continuity in RAMP sampling design and methods while continuing to adaptively manage the program in the face of changing scope, industry participation and technical considerations.

1.0 INTRODUCTION

1.1 BACKGROUND

The Alberta oil sands deposits originated over one hundred million years ago when much of western Canada was covered by a vast inland sea. As the local plants and animals died, they settled to the sea floor. As these deposits accumulated, surface pressure and temperature increased, eventually converting the organic remains into liquid hydrocarbons, sulphur compounds, carbon dioxide and water. The resulting oil-bearing sand deposits (e.g., the McMurray Formation) in northern Alberta represent one third of all known world oil reserves, estimated at 1.7 to 2.5 trillion barrels of bitumen.

In 1967, Great Canadian Oil Sands Ltd. (now Suncor Energy Inc.) initiated the region's first commercially successful bitumen extraction and upgrading facility. Since that time, investment and development in the Athabasca oil sands region near Fort McMurray has increased substantially, with 17 companies currently planning, or already undergoing, resource extraction of the Athabasca deposit (surface mining and *in situ* operations) (Figure 1.1, Table 1.1).

In addition to the oil sands operations, other development has also increased within the Regional Municipality of Wood Buffalo (RMWB), such as pipeline construction, forestry operations (sawmill, logging), drilling activities, and municipal growth/infrastructure development. Upstream of the RMWB, developments such as pulp and paper operations (five mills), agriculture and municipal wastewater facilities may also influence downstream water quality of the Athabasca River within the oil sands region.

In response to the rapid growth in mining and regional development, several organizations were initiated to address issues related to environmental integrity of the Athabasca oil sands region of northern Alberta, including:

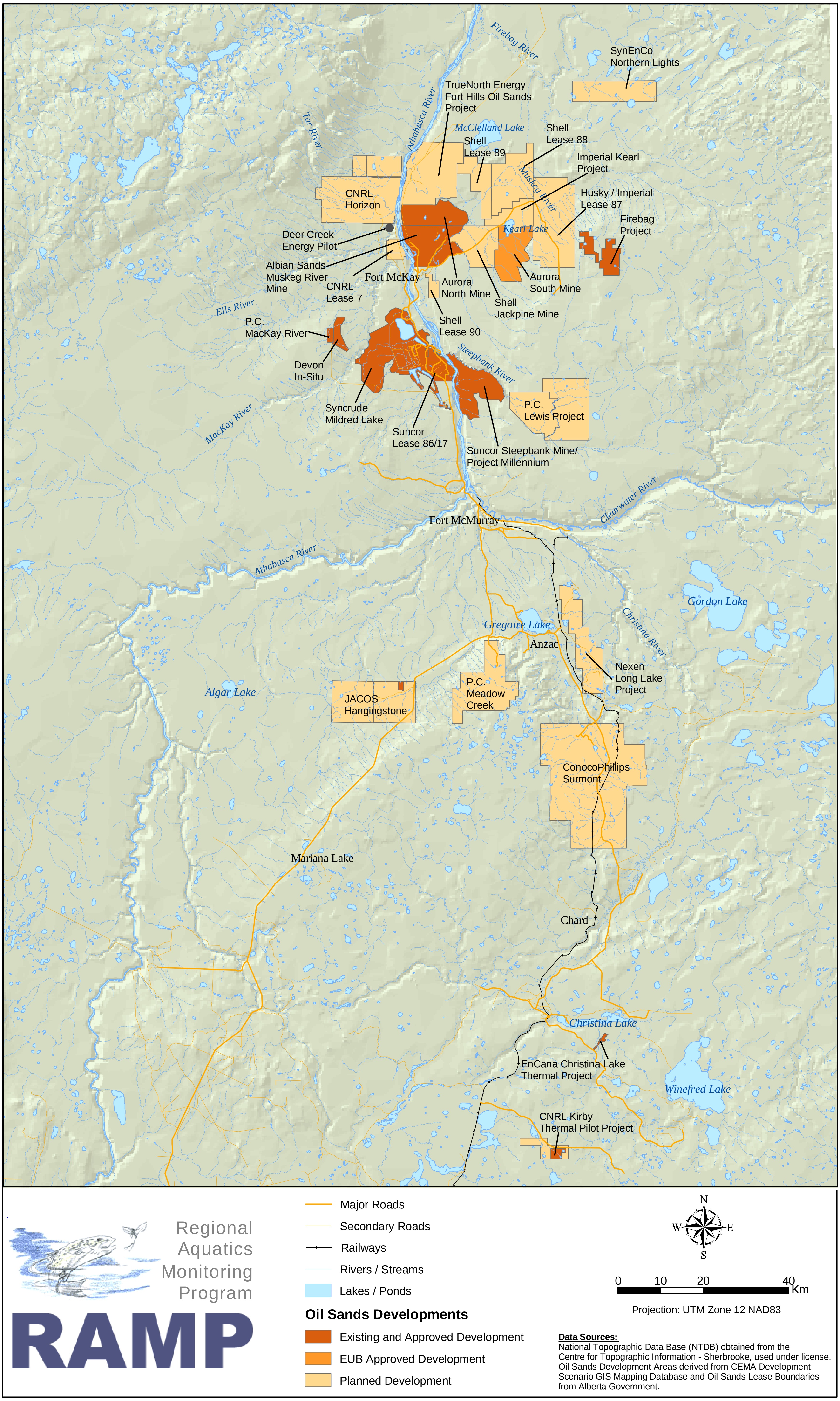
- Cumulative Environmental Management Association (CEMA) – established to develop management recommendations on how best to reduce potential long-term environmental impacts due to industrial development;

- Wood Buffalo Environmental Association (WBEA) – established to monitor and provide information on air quality and air related environmental impacts in the Wood Buffalo Region;

- Terrestrial Environmental Effects Monitoring (TEEM) – a program under WBEA designed to detect, characterize and quantify the extent to which air emissions affect terrestrial and aquatic ecosystems and hence traditional resource use in the Athabasca oil sands region; and

- Regional Aquatics Monitoring Program (RAMP) – established to integrate aquatic monitoring activities in the Athabasca oil sands region so that long term trends and potential cumulative effects can be evaluated and communicated.

Figure 1.1 Oil Sands Development Areas.



G:\Data\Projects\RAMP1069\GIS\Fig1-1_OilSandsDev.mxd
12 February 2004

Table 1.1 Athabasca oil sands production for existing, approved and planned developments.

Development	Location	Capacity (bpd)	Extraction Process	Status
Suncor Energy Inc.				
Upgrader Complex	30 km north of Fort McMurray	220,000 S	Processing	Approved
Lease 86/17, Steepbank and Millenium Mines	30 km north of Fort McMurray	280,000 B	Open pit	Approved
Firebag Pilot	40 km northeast of Mildred Lake	1,200 B	In situ	Approved
Firebag Project	40 km northeast of Mildred Lake	140,000 B	In situ	Approved
Voyageur	25 km north of Fort McMurray	550,000 B	Processing	Planned
Syncrude Canada Ltd.				
Mildred Lake Upgrader	45 km north of Fort McMurray	480,000 S	Processing	Approved
North Mine	60 km north of Fort McMurray	160,000 B	Open pit	Approved
Aurora North	east side of Athabasca River	200,000 B	Open pit	Approved
Aurora South	east side of Athabasca River	200,000 B	Open pit	EUB Approved
Albian Sands Energy Inc.				
Muskeg River Mine	75 km north of Fort McMurray	155,000 B	Open pit	Approved
Shell Canada Limited				
Jackpine Mine (Phase 1)	East portion of lease 13	200,000 B	Open pit	Under review
Muskeg River Mine Expansion (Phase 2)	North of Jackpine Mine	70,000 B	Open pit	Planned
Conoco Phillips (formerly Gulf)				
Surmont Pilot	60 km southeast of Fort McMurray	2,000 B	In situ	Approved pilot
Surmont	60 km southeast of Fort McMurray	100,000 B	In situ	Approved
Devon Canada Corp. (formerly Northstar Dover)				
Underground Test Facility (UTF)	90 km north of Fort McMurray	2,600 B	In situ	Approved
Jackfish	15 km southeast of Conklin	35,000 B	In situ	Planned
Devon SAGD Project (AENV)	55 km northwest of Fort McMurray	9,000 B	In situ	Approved
Japan Canada Oil Sands Limited (JACOS)				
Hangingstone Pilot	50 km southeast of Fort McMurray	10,000 B	In situ	Approved pilot
Hangingstone	50 km southeast of Fort McMurray	50,000 B	In situ	Planned

Table 1.1 (cont'd).

Development	Location	Capacity (bpd)	Extraction Process	Status
Petro-Canada Oil and Gas				
MacKay River	60 km northwest of Fort McMurray	30,000 B	In situ	Approved
Meadow Creek	45 km south of Fort McMurray	80,000 B	In situ	Planned
Lewis Project	30 km northeast of Fort McMurray	50,000 B	In situ	Planned
OPTI Canada Inc./Nexen Canada Ltd.				
Long Lake Pilot Project	40 km southeast of Fort McMurray	3,800 B	In situ	Approved
Long Lake Project	40 km southeast of Fort McMurray	140,000 S	In situ	Approved
		70,000 B	In situ	Approved
Imperial Oil/ExxonMobil Canada Ltd.				
Kearl Mine	70 km north of Fort McMurray	165,000 B	Open pit	Planned
Upgrader	70 km north of Fort McMurray	185,000 B	Processing	Planned
TrueNorth Energy L.P.				
Fort Hills	90 km north of Fort McMurray	190,000 B	Open pit	Approved
Canadian Natural Resources Limited (CNRL)				
Horizon Project	80 km north of Fort McMurray	270,000 B	Open pit	Under review
		233,000 S	In situ	Under review
Horizon In situ	80 km north of Fort McMurray	270,000 B	Open pit	Under review
Kirby Pilot	85 km northeast of Lac la Biche	1,600 B	In situ	Approved
Kirby Project	85 km northeast of Lac la Biche	30,000 B	In situ	Planned
SynEnCo				
Northern Lights Project	100 km northeast of Fort McMurray (on the Firebag River)	80,000 S	Open pit	Planned
Husky Energy Inc.				
Kearl Lease 187	70 km north of Fort McMurray	120,000 B	In situ	Planned
Deer Creek Energy				
Joslyn SAGD Pilot	60 km southeast of Fort McMurray	2,000 B	In situ	Approved
Joslyn Creek SAGD	60 km southeast of Fort McMurray	10,000 B	In situ	Approved
EnCana Corporation (formerly PanCanadian Petroleum Ltd.)				
Christina Lake Phase 1	170 km south of Fort McMurray	10,000 B	In situ	Approved
Christina Lake Phase 2 and 3	170 km south of Fort McMurray	70,000 B	In situ	Planned

Table 1.1 (cont'd).

Development	Location	Capacity (bpd)	Extraction Process	Status
Petrobank Energy & Resources Ltd. Pilot Plant	10 km northwest of Conklin	Exploration	In situ (Toe-to-Heel air injection)	Planned

bpd, barrels per day; B, Bitumen; S, Synthetic or pipelineable crude

Source: RAMP 2002 Annual Report; Oil Sands Discovery Centre Fact Sheet – Alberta Community Development.

The following annual RAMP report presents the general background of RAMP, describes the monitoring framework and approach and summarizes field surveys conducted during the 2003 program (Chapters 2-10).

1.1.1 What is RAMP?

The Regional Aquatics Monitoring Program (RAMP) is an industry funded, multi-stakeholder environmental monitoring program initiated in 1997. The intent of RAMP is to integrate aquatic monitoring activities so that long-term trends, regional issues and potential cumulative effects related to oil sands development can be identified and addressed. The coordination of monitoring efforts results in the development of a more comprehensive and cost-effective regional database that may be used by oil sands operators for their environmental management programs and assessments of proposed oil sands developments, as well as other stakeholders interested in the aquatic health of the oil sands region near Fort McMurray.

Several objectives of RAMP have been developed to guide the scope, management and implementation of the program over time. Specifically, the objectives of RAMP are to:

- Monitor aquatic environments in the oil sands region to detect and assess cumulative effects and regional trends;
- Collect scientifically defensible baseline and historical data to characterize variability in the oil sands area;
- Collect data against which predictions contained in Environmental Impact Assessments (EIAs) can be verified;
- Collect data that may be used to satisfy the monitoring required by regulatory approvals of developments in the oil sands area;

- Recognize and incorporate traditional knowledge (including Traditional Ecological Knowledge and Traditional Land Use studies) into the monitoring and assessment activities;

- Communicate monitoring and assessment activities, results and recommendations to communities in the Regional Municipality of Wood Buffalo, regulatory agencies, environmental committees/organizations and other interested parties;

- 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

- 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.

RAMP is governed by a multi-stakeholder decision body referred to as the Steering Committee. This committee consists of membership from oil sands industries, government agencies (municipal, provincial and federal), First Nations representatives, environmental non-government organizations (ENGO's) and other independent stakeholders (Figure 1.2). The program also includes a Technical Subcommittee responsible for the development and review of the RAMP technical program from year to year. The Technical Subcommittee is divided into discipline-specific sub-groups (e.g., fisheries, water quality, etc.) that develop and review their component for integration into the overall monitoring program. Investigators (Hatfield RAMP Team [Hatfield Consultants Ltd, Jacques Whitford Environment Ltd., Mack, Slack & Associates Inc., Western Resource Solutions], Alberta Environment, Syncrude Canada Ltd., First Nations, other consultants) primarily carry out the fieldwork, data analysis and reporting, as defined by the program. A Finance Subcommittee and a Communications Subcommittee have also been established to focus on issues related to funding and dissemination of RAMP information.

Figure 1.2 RAMP organizational structure.

STEERING COMMITTEE		
Industry	**Stakeholders**	**Government**
Alberta Pacific Forest Industries Inc.	Athabasca Chipewyan First Nations	Alberta Environment
Albian Sands Energy Inc.	Athabasca Tribal Council	Fisheries and Oceans Canada
Canadian Natural Resources Limited	Chipewyan Prairie First Nations	Environment Canada
Devon Energy Corporation	Fort Chipewyan Metis Local #124	
ExxonMobil Canada Ltd.	Fort McKay First Nations	
OPTI Canada Inc.	Fort McKay Metis Local #122	
Nexen Canada Inc.	Fort McMurray First Nations	
Petro-Canada Oil and Gas	Mikisew Cree First Nations	
Shell Canada Limited.	Oil Sands Environmental Coalition	
Suncor Energy Inc.		
Syncrude Canada Ltd.		
(Secretary: Hatfield Consultants Ltd.)		

Finance Subcommittee	Technical Subcommittee	Communication Subcommittee	Investigators
All funding participants, and any interested Steering Committee members.	Representatives from industry, communities, government, and investigators.	Representatives from industry, communities, government, and investigators.	Consultants, Aboriginal community representatives, and Alberta Environment

Technical Program Implementation	Communication Plan Implementation
Preparation of technical program for review by Steering Committee; Technical workshops	Newsletters; Annual Report; Community meetings

In 2003, RAMP was funded by Syncrude Canada Ltd. (Syncrude), Suncor Energy Inc. Oil Sands (Suncor), Albian Sands Energy Inc. (Albian), Shell Canada Limited (Shell), Canadian Natural Resources Limited (CNRL), ExxonMobil Canada Ltd. (Exxon), Petro-Canada Oil and Gas (Petro-Canada), Opti Canada Inc. (Opti)/Nexen Canada Ltd. (Nexen) and Devon Canada Corporation (Devon). TrueNorth Energy L.P. was originally part of the 2003 program, but left RAMP when the Fort Hills Oil Sands Project was deferred.

1.1.2 RAMP Study Area

The Regional Municipality of Wood Buffalo in northeastern Alberta defines the RAMP Regional Study Area. Within this area, a Focus Study Area (FSA) has been defined and includes watersheds were oil sands development is occurring or planned (Figure 1.3). Accordingly, much of the intensive monitoring activity is conducted within the FSA.

The dominant waterbody within the FSA is the Athabasca River. The Athabasca River flows from its headwaters in the Columbia Ice Fields near Banff to its delta at Lake Athabasca over 1,200 km downstream. The Athabasca is one of two major tributaries of the Mackenzie River, which is the longest river in Canada and the fifth longest in the world after the Nile, Mississippi, Amazon and Yangtze rivers.

The lower Athabasca River from Fort McMurray to the Peace-Athabasca Delta flows through mixed boreal forest interspersed with peat land formations. The regional topography is relatively flat, but partially bordered to the west by the Birch Mountains and to the east by intermittent slopes including the Muskeg Mountains, which extend northward from the Clearwater River valley. Upon reaching the Peace-Athabasca Delta, the Athabasca River becomes a vast, interconnected series of braided channels and wetlands flowing into Lake Mamawi and Lake Athabasca.

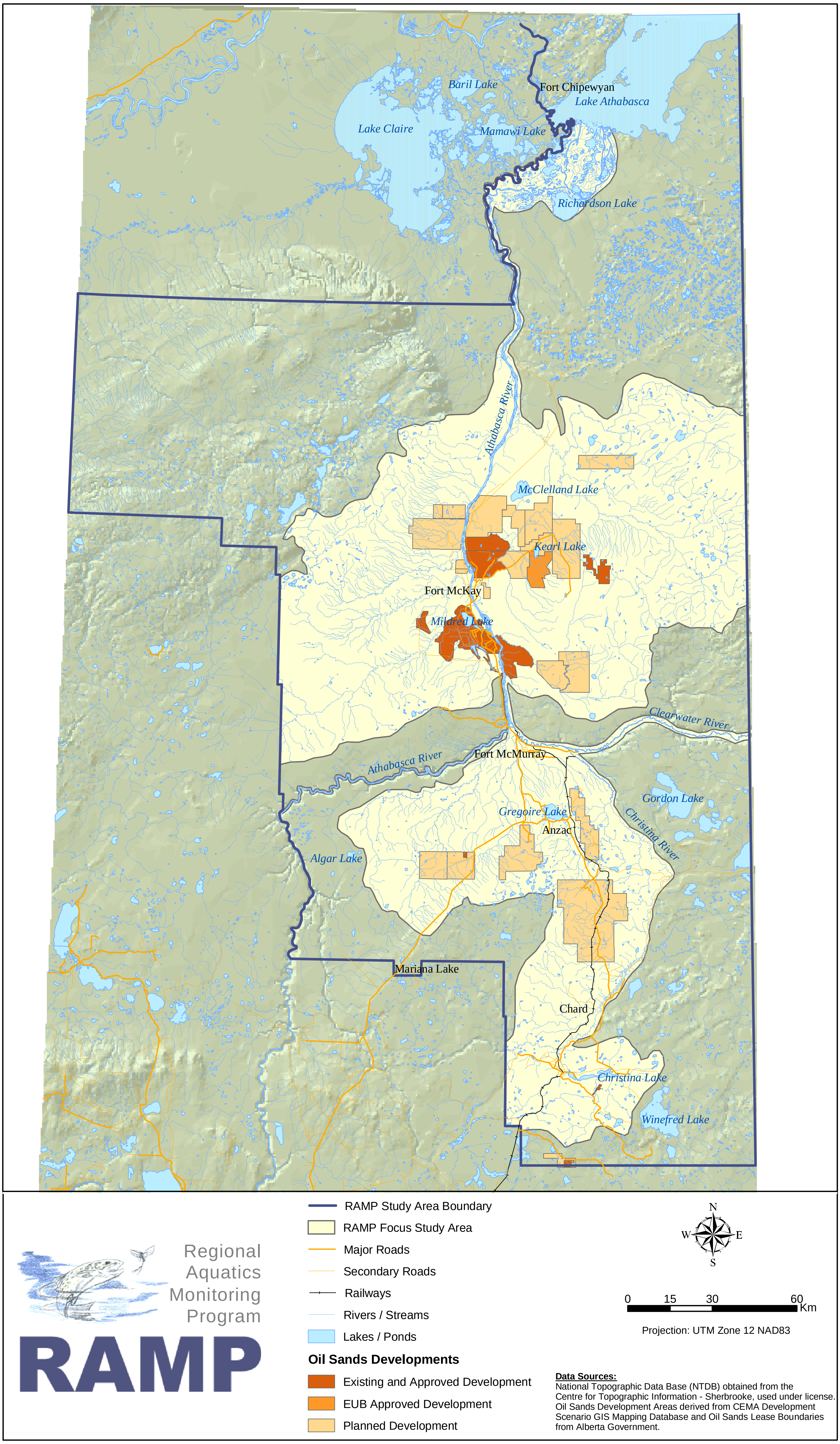
As the Athabasca River flows northward through the RAMP study area, several smaller tributary streams and rivers join and contribute to the overall flow (Figure 1.4). Some of the larger of these tributaries include (in upstream to downstream order):

- Clearwater River - a large river which originates in Saskatchewan, joins the Athabasca River at Fort McMurray, and includes the contribution of a large tributary to the Clearwater River, the Christina River, whose drainage includes several existing and planned *in situ* oil sands developments to the south of Fort McMurray;

- Steepbank River - joins the Athabasca River from the east and whose watershed includes the Suncor Steepbank/Project Millennium mines and Petro-Canada's planned Lewis project;

- Muskeg River - also flows from the east and drains several oil sands development areas, including Albian Sands' Muskeg River mine, Syncrude's Aurora North mine and planned Aurora South mine, Shell's planned Jackpine mine and the Imperial Oil/ExxonMobil proposed Kearl Project;

Figure 1.3 RAMP Regional and Focus Study Areas.



G:\Data\Projects\RAMP1069\GIS\Fig1-3_RAMP_StudyArea.mxd
12 February 2004

- MacKay River - flows from the west and whose watershed includes the Petro-Canada's MacKay River development, Devon's In Situ project, and portions of Syncrude's Mildred Lake lease;

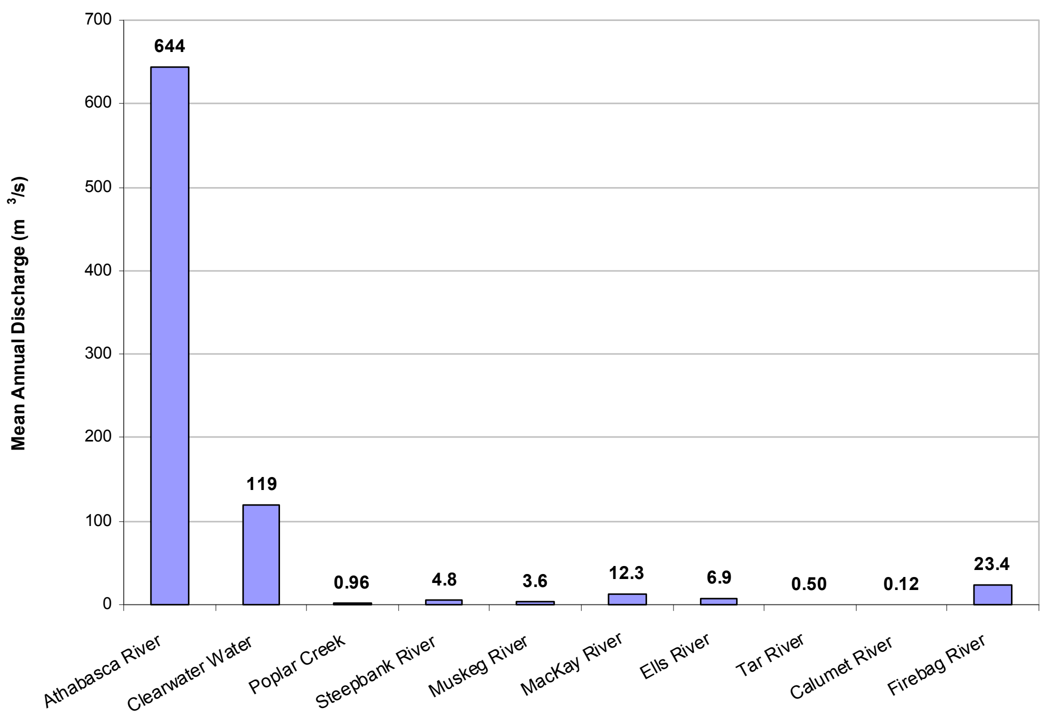
- Ells River - flows from the west and whose watershed is immediately adjacent to CNRL's planned Horizon Project;

- Tar and Calumet rivers - also flowing from the west, whose drainages are largely within the disturbance area of the planned CNRL Horizon Project;

- Fort Creek – small stream flowing from the east whose drainage may be influenced by Syncrude's Aurora North Project and TrueNorth's Fort Hills Project (currently deferred); and

- Firebag River - a large river flowing from Saskatchewan, whose watershed may include potential future developments such as SynEnCo's Northern Lights Project.

Figure 1.4 Mean annual discharge of the Athabasca River and major tributaries in the Athabasca oil sands region, Alberta.



Other waterbodies monitored under RAMP include smaller river tributaries of the Athabasca River (e.g., McLean Creek, Beaver Creek, etc.), tributaries within watersheds described above (e.g., Muskeg Creek, Wapasu Creek, Gregoire River, etc.), specific wetlands such as Isadore's Lake, Shipyard Lake and Kearl Lake, and regional lakes important from a fisheries perspective, or known to be sensitive to acidifying emissions.

1.2 MONITORING APPROACH

For each oil sands development, an Environmental Impact Assessment (EIA) is undertaken to evaluate the potential impact a proposed mining operation, alone or in combination with other developments, could have on the local/regional environment. To date, EIA's conducted for projects in the oil sands region have used a stressor-based approach. A potential stressor can be any factor (e.g., chemicals, temperature, water flow, nutrients, food availability, biological competition, etc.) that currently exists, or will be influenced/introduced by the proposed mining operation. Using this approach, the impact of a development is evaluated by predicting the potential impact of each identified stressor on valued components of the environment (e.g., key indicator resources, resource use by humans, water quality, etc.) (Munkittrick *et. al*. 2000).

Although the stressor-based impact assessment has been successful, the inherent risk of the approach is that it assumes that all potential stressors can be identified and evaluated. More recently, an effects-based approach has been advocated for impact assessments and subsequent monitoring efforts (Munkittrick *et. al.* 2000). This approach focuses on evaluating the performance of biological components of the environment (e.g., fish, benthic invertebrates, vegetation) because they integrate the potential effects of complex and varied stressors over time. This approach is independent of stressor identification, and focuses on understanding the accumulated environmental state resulting from the summation of all stressors. It is important to select appropriate biological components and measurement end-points for this approach to be successful. The current federal Environmental Effects Monitoring (EEM) program for the pulp and paper industry and the metal mining industry incorporates an effects-based monitoring approach (Environment Canada 1992, 2003).

RAMP incorporates a combination of both stressor- and effects-based approaches. Using impact predictions from the various EIA's, specific potential stressors have been identified that are monitored to document baseline conditions, as well as potential changes related to development. Examples include specific water quality parameters and changes in water quantity. In addition, there is a strong emphasis on monitoring sensitive biological indicators that reflect and integrate the overall condition of the aquatic environment. By combining both impact assessment approaches, RAMP strives to achieve a more holistic understanding of potential effects related to oil sands development.

The scope of RAMP focuses on key components of boreal aquatic ecosystems, including:

- Climate and hydrology - monitors changes in the quantity of water flowing through rivers and creeks in the oil sands region;
- Water and sediment quality in rivers, lakes and some wetlands – reflects habitat quality and potential exposure of fish and invertebrates to organic and inorganic chemicals;
- Benthic invertebrate community in rivers/streams and wetlands - serves as a biological indicator and is an important component of fish habitat;
- Fish populations in rivers and lakes - biological indicators of ecosystem integrity and a highly valued resource in the region;
- Water quality in regional lakes sensitive to acidification - early warning indicator of potential effects related to acid deposition; and
- Wetland aquatic vegetation – an ecological indicator of the health of regional wetlands.

The following sub-sections briefly describe the general approach followed by each monitoring component. Details on study design, sampling locations and methods are described in Chapters 2 to 8 for each individual RAMP component. In addition, details on the monitoring design and rationale are described in the following document: "Oil Sands Regional Aquatic Monitoring Program (RAMP) - Program Design and Rationale" developed by the RAMP Technical Subcommittee (Version 2, Golder 2002a).

1.2.1 Climate and Hydrology

The quantity of water in a system affects the capacity to support aquatic and terrestrial biota. Changes in the amount or timing of water flow may be due to natural fluctuations (e.g., related to climate), or due to human activities such as discharges, withdrawals or diversions. Accordingly, climate and hydrologic data are collected as part of RAMP to:

- Facilitate the interpretation of water and sediment quality, fisheries, benthic and aquatic vegetation surveys by placing in context current hydrologic conditions relative to historical mean or extreme conditions;
- Document stream-specific baseline climatic and hydrologic conditions to support regulatory applications and to meet requirements of regulatory approvals; and

- Calibrate and verify regional hydrologic models that form the basis of environmental impact assessments, operational water management plans and closure reclamation drainage designs.

The RAMP climate and hydrology component focuses on key elements of the hydrologic cycle, including rainfall, snowfall, streamflow, lake water levels, evaporation and evapotranspiration. Climate, streamflow and lake levels are monitored to develop an understanding of the hydrologic system, including natural variability, short and long-term trends, and potential impacts related to development.

Streams in the same region may have different hydrological characteristics related to differences in topography, vegetation, surficial geology, lake storage, groundwater-surface interaction and geographic effects on precipitation. Accordingly, the scope of the RAMP climate and hydrology program has gradually expanded geographically to include catchments affected, or expected to be affected, by oil sands mining in the area around of Fort McMurray. Some natural catchments (i.e., undisturbed) are also monitored to provide baseline data. The monitoring program includes the Athabasca River, numerous smaller rivers and streams, and some mine water releases to receiving streams. Data from long-term Environment Canada climatic and hydrologic monitoring stations in the region are also integrated into the RAMP database to provide greater spatial and temporal context.

Some streams are monitored year-round, while others, particularly smaller streams that tend to freeze completely in winter, are monitored only during the open-water season. RAMP also monitors winter (November to March) flows on some streams that Environment Canada monitors during the open-water season.

Historical development of the streamflow and lake level monitoring network, and plans for future monitoring, are presented in Table 1.2. Information in the table is based on information presented in the document "RAMP Program Design and Rationale – Version 2" (Golder 2002a), with some modifications. Plans for 2004 and onward have not been finalized. Historical streamflow monitoring by the Water Survey of Canada has been added to the table.

Table 1.2 RAMP climate and hydrology monitoring program (1995 to 2009).

see symbol key at bottom

WATERBODY AND LOCATION	STATION	1995				1996				1997				1998				1999			
		W	S	S	F	W	S	S	F	W	S	S	F	W	S	S	F	W	S	S	F
Wide-Area Snowcourse Survey																					
Athabasca River Tributaries																					
Mills Creek at Highway 63	S6										2	2	2		2	2	2		2	2	2
Poplar Creek at Highway 63 (07DA007)	S11		2	2	2		2	2	2			2	2		2	2	2		2	2	2
Fort Creek at Highway 63	S12																				
Ells River above Joslyn Creek	S14																				
Tar River near the Mouth	S15																				
Calumet River near the Mouth	S16																				
Tar River Upland Tributary	S17																				
Calumet River Upland Tributary	S18																				
Tar River Lowland Tributary near the Mouth	S19																				
Susan Lake Outlet	S25																				
McKay River near Fort MacKay (07DB001)	S26		4	4	4		4	4	4		4	4	4		4	4	4	2	4	4	4
Firebag River near the Mouth (07DC001)	S27		4	4	4		4	4	4		4	4	4		4	4	4		4	4	4
Joslyn Creek near Fort MacKay (07DA016)																					
Fort Creek Basin Snowcourse Survey																					
CNRL Area Snowcourse Survey																					
Athabasca River Mainstem																					
Athabasca River below Eymundson Creek	S24																				
Muskeg River Basin																					
Alsands Drain	S1			2	2		2	2	2		2	2			2	2	2		2	2	2
Jackpine Creek at Canterra Road	S2			2	2		2	2	2		2	2	2		2	2			2	2	
Iyinimin Creek above Kearl Lake	S3		2	2	2		2	2	2		2	2	2		2a	2a	2a		2a	2a	2a
Blackfly Creek near the Mouth	S4		2	2	2		2	2	2		2	2	2		2	2	2				
Muskeg River above Stanley Creek	S5																				
Muskeg River above Muskeg Creek	S5A			2	2		2	2	2		2	2	2		2	2	2	2	2	2	2
Muskeg River near Fort MacKay (07DA008)	S7		4	4	4		4	4	4		4	4	4		4	4	4	4	4	4	4
Stanley Creek near the Mouth	S8																			1	1
Kearl Lake Outlet	S9														2	2	2		2e	2e	2e
Wapasu Creek at Canterra Road	S10																		2	2	2
Albian Pond 3 Outlet	S13																				
Muskeg River Upland	S20																				
Shelley Creek near the Mouth	S21																				
Muskeg Creek near the Mouth	S22																				
Aurora Boundary Weir	S23																				
Khahago Creek below Black Fly Creek	S28																				
Muskeg River at the Aurora/Albian Boundary	S33																				
Aurora Climate Station	C1		f	f	f	f	f	f	f	f	f	f	f	f	f	f	f	f	f	f	f
Muskeg River Basin Snowcourse Survey											d				d				d		
Muskeg River High Water Gauging												3				3				3	
Jackpine Creek High Water Gauging												3				3					
Clearwater River Mainstem																					
Clearwater River above Christina River ((07CD005)		4	4	4	4	4	4	4	4		4	4	4		4	4	4		4	4	4
Clearwater River at Draper (07CD001)		4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4
Clearwater River Tributaries																					
Christina River near Chard (07CE002)	S29																				
Hangingstone River at Highway 63	S30																				
Hangingstone Creek near the Mouth	S31																				
Surmont Creek at Highway 881	S32																				
Wetlands																					
McClelland Lake	L1											2	2		2	2	2		2	2	2
Kearl Lake	L2																		1	1	1
Isadore's Lake	L3																				
Regional Data																					
Compilation of Environment Canada data																					

WATERBODY AND LOCATION	STATION	2000				2001				2002				2003				2004			
		W	S	S	F	W	S	S	F	W	S	S	F	W	S	S	F	W	S	S	F
Wide-Area Snowcourse Survey																		d			
Athabasca River Tributaries																					
Mills Creek at Highway 63	S6		2e	2e	2e		2	2	2		2	2	2		2	2	2	2	2	2	2
Poplar Creek at Highway 63 (07DA007)	S11		2	2	2		2	2	2		2	2	2		2	2	2	2	2	2	2
Fort Creek at Highway 63	S12		2	2	2		2	2	2		2g	2g	2g								
Ells River above Joslyn Creek	S14						2	2	2		2	2	2		2	2	2		2	2	2
Tar River near the Mouth	S15						2	2	2		2	2	2		2	2	2				
Calumet River near the Mouth	S16						2	2	2	h	2h	2h	2h		2h	2h	2h		2h	2h	2h
Tar River Upland Tributary	S17						2	2	2		2	2	2		2	2	2		2	2	2
Calumet River Upland Tributary	S18						2	2	2		2	2	2		2	2	2		2	2	2
Tar River Lowland Tributary near the Mouth	S19						2	2	2		2a	2a	2a		2a	2a	2a		2a	2a	2a
Susan Lake Outlet	S25										2	2	2								
McKay River near Fort MacKay (07DB001)	S26	2	4	4	4	2	4	4	4	2	4	4	4	2	4	4	4	2			
Firebag River near the Mouth (07DC001)	S27		4	4	4		4	4	4	2	4	4	4		4	4	4				
Joslyn Creek near Fort MacKay (07DA016)																			2	2	2
Fort Creek Basin Snowcourse Survey			d																		
CNRL Area Snowcourse Survey							d				d				d						
Athabasca River Mainstem																					
Athabasca River below Eymundson Creek	S24						2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
Muskeg River Basin																					
Alsands Drain	S1	2					2	2	2	2	2	2	2								
Jackpine Creek at Canterra Road	S2		2	2	2		2	2	2		2	2	2		2	2	2	2	2	2	2
Iyinimin Creek above Kearl Lake	S3						2a	2a	2a		2a	2a	2a		2a	2a	2a		2a	2a	2a
Blackfly Creek near the Mouth	S4																				
Muskeg River above Stanley Creek	S5														2	2	2	2	2	2	2
Muskeg River above Muskeg Creek	S5A	2	2	2	2	2	2	2	2	2e	2e	2e	2e	2e	2e	2e	2e	2e	2e	2e	2e
Muskeg River near Fort MacKay (07DA008)	S7		4	4	4		4	4	4	2	4	4	4	2	2	2	2	2	2	2	2
Stanley Creek near the Mouth	S8		1	1	1		1	1	1		1	1	1		1	1	1		1	1	1
Kearl Lake Outlet	S9						2	2	2		2	2	2		2	2	2	2	2	2	2
Wapasu Creek at Canterra Road	S10						2	2	2		2	2	2		2	2	2	2	2	2	2
Albian Pond 3 Outlet	S13		2	2	2		2	2	2		2	2	2								
Muskeg River Upland	S20						2	2	2		2	2	2		2	2	2		2	2	2
Shelley Creek near the Mouth	S21						2	2	2		2	2	2		2	2	2		2	2	2
Muskeg Creek near the Mouth	S22						2	2	2		2	2	2		2	2	2		2	2	2
Aurora Boundary Weir	S23					2	2	2	2	2	2	2	2								
Khahago Creek below Black Fly Creek	S28						2	2	2		2	2	2		2	2	2		2	2	2
Muskeg River at the Aurora/Albian Boundary	S33														2	2	2	2	2	2	2
Aurora Climate Station	C1	f	f	f	f	f	f	f	f	f	f	f	f	f	f	f	f	f	f	f	f
Muskeg River Basin Snowcourse Survey			d				d														
Muskeg River High Water Gauging				3				3													
Jackpine Creek High Water Gauging								3													
Clearwater River Mainstem																					
Clearwater River above Christina River ((07CD005)			4	4	4		4	4	4		4	4	4		4	4	4		4	4	4
Clearwater River at Draper (07CD001)		4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4
Clearwater River Tributaries																					
Christina River near Chard (07CE002)	S29									2	4a	4a	4a	2	4a	4a	4a	2	4a	4a	4a
Hangingstone River at Highway 63	S30										2	2	2								
Hangingstone Creek near the Mouth	S31										2	2	2						2	2	2
Surmont Creek at Highway 881	S32						2	2	2		2	2	2								
Wetlands																					
McClelland Lake	L1		2	2	2		2	2	2	2a	2a	2a	2a	2a	2a	2a	2a	2a	2a	2a	2a
Kearl Lake	L2	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Isadore's Lake	L3	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Regional Data																					
Compilation of Environment Canada data																					

WATERBODY AND LOCATION	STATION	2005				2006				2007				2008				2009			
		W	S	S	F	W	S	S	F	W	S	S	F	W	S	S	F	W	S	S	F
Wide-Area Snowcourse Survey																					
Athabasca River Tributaries																					
Mills Creek at Highway 63	S6		2	2	2		2	2	2		2	2	2		2	2	2		2	2	2
Poplar Creek at Highway 63 (07DA007)	S11		2	2	2		2	2	2		2	2	2		2	2	2		2	2	2
Fort Creek at Highway 63	S12																				
Ells River above Joslyn Creek	S14		2	2	2		2	2	2		2	2	2		2	2	2		2	2	2
Tar River near the Mouth	S15		2	2	2		2	2	2		2	2	2		2	2	2		2	2	2
Calumet River near the Mouth	S16		2	2	2		2	2	2		2	2	2		2	2	2		2	2	2
Tar River Upland Tributary	S17		2	2	2		2	2	2		2	2	2		2	2	2		2	2	2
Calumet River Upland Tributary	S18		2	2	2		2	2	2		2	2	2		2	2	2		2	2	2
Tar River Lowland Tributary near the Mouth	S19		2	2	2		2	2	2		2	2	2		2	2	2		2	2	2
Susan Lake Outlet	S25		2	2	2		2	2	2		2	2	2		2	2	2		2	2	2
McKay River near Fort MacKay (07DB001)	S26	2				2				2				2				2			
Firebag River near the Mouth (07DC001)	S27	2				2				2				2				2			
Joslyn Creek near Fort MacKay (07DA016)																					
Fort Creek Basin Snowcourse Survey																					
CNRL Area Snowcourse Survey																					
Athabasca River Mainstem																					
Athabasca River below Eymundson Creek	S24	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
Muskeg River Basin																					
Alsands Drain	S1																				
Jackpine Creek at Canterra Road	S2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
Iyinimin Creek above Kearl Lake	S3		2a	2a	2a		2a	2a	2a		2a	2a	2a		2a	2a	2a		2a	2a	2a
Blackfly Creek near the Mouth	S4																				
Muskeg River above Stanley Creek	S5	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
Muskeg River above Muskeg Creek	S5A	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
Muskeg River near Fort MacKay (07DA008)	S7	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
Stanley Creek near the Mouth	S8		1	1	1		1	1	1		1	1	1		1	1	1		1	1	1
Kearl Lake Outlet	S9		2	2	2		2	2	2		2	2	2		2	2	2		2	2	2
Wapasu Creek at Canterra Road	S10		2	2	2		2	2	2		2	2	2		2	2	2		2	2	2
Albian Pond 3 Outlet	S13																				
Muskeg River Upland	S20		2	2	2		2	2	2		2	2	2		2	2	2		2	2	2
Shelley Creek near the Mouth	S21		2	2	2		2	2	2		2	2	2		2	2	2		2	2	2
Muskeg Creek near the Mouth	S22		2	2	2		2	2	2		2	2	2		2	2	2		2	2	2
Aurora Boundary Weir	S23																				
Khahago Creek below Black Fly Creek	S28		2	2	2		2	2	2		2	2	2		2	2	2		2	2	2
Muskeg River at the Aurora/Albian Boundary	S33																				
Aurora Climate Station	C1	f	f	f	f	f	f	f	f	f	f	f	f	f	f	f	f	f	f	f	f
Muskeg River Basin Snowcourse Survey																					
Muskeg River High Water Gauging																					
Jackpine Creek High Water Gauging																					
Clearwater River Mainstem																					
Clearwater River above Christina River ((07CD005)																					
Clearwater River at Draper (07CD001)																					
Clearwater River Tributaries																					
Christina River near Chard (07CE002)	S29	2	a	a	a	2	a	a	a	2	c	c	c	2	c	c	c	2	c	c	c
Hangingstone River at Highway 63	S30																				
Hangingstone Creek near the Mouth	S31																				
Surmont Creek at Highway 881	S32																				
Wetlands																					
McClelland Lake	L1	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
Kearl Lake	L2	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Isadore's Lake	L3	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Regional Data																					
Compilation of Environment Canada data																					

Legend

1 = water levels
2 = water levels and discharge
3 = high water gauging
4 = hydrometric data collected by Environment Canada

a = rainfall
b = snowfall
c = rainfall and snowfall
d = snowcourse survey
e = barometric pressure
f = air temperature, relative humidity, rainfall, snowfall, wind speed and direction, solar radiation, snow on the ground
g = water temperature
h = rainfall, snowfall and air temperature

1.2.2 Water and Sediment Quality

RAMP monitors water and sediment chemistry in order to identify human and natural factors affecting the quality of streams and lakes in the oil sands region. Monitoring the chemical signatures of water provides point-in-time measurements, while sediment analyses provide information on the rate of chemical accumulations over time. Together, these data help identify potential chemical exposure pathways between the physical environment and biotic communities relying on aquatic resources.

Specific objectives of the water and sediment quality program include:

- Develop a water and sediment quality database to verify EIA predictions, support regulatory applications and to meet requirements of regulatory approvals;
- Monitor potential changes in water and sediment quality that may identify chemical inputs from point and non-point sources;
- Assess the suitability of waterbodies to support aquatic life; and
- Provide supporting data to facilitate the interpretation of biological surveys.

In order to determine if and how a development may be affecting water and sediment quality, stations potentially influenced by the development are compared to upstream reference stations (where possible) located beyond the influence of the development. Stations are monitored over time to characterize natural temporal variability in baseline conditions, and to identify potential trends in water and sediment quality related to increasing anthropogenic activity, including oil sands development.

A range of compounds are measured in water and sediment, including:

Water Quality	Sediment Quality
Conventional variables	Particle size
Major ions	Carbon content
Nutrients	Target and alkylated PAHs
Biological Oxygen Demand	Organics
Target and alkylated PAHs	Metals
Other organics	

Water Quality	Sediment Quality
Conventional variables	Particle size
Total and dissolved metals	

Bioassay testing is also conducted to assess toxicity related to chronic exposure of different aquatic organisms to ambient river water or sediment from selected stations.

RAMP water quality stations are located throughout the RAMP study area, from the upper Christina River to the Peace-Athabasca Delta. Water quality stations are monitored annually each fall when water flows are generally low, and the resulting assimilative capacity of a receiving waterbody is limited. New water quality stations located in waterbodies already monitored by RAMP, are sampled four times in the first year to determine seasonal variations in water quality (Table 1.3). Three years of seasonal baseline data are collected at stations established in new waterbodies added to RAMP (Table 1.3).

In the lower Athabasca River, bottom sediments are very transient and are almost completely flushed by high flows related to spring freshet. Existing RAMP sediment quality stations in the Athabasca River are monitored annually in the fall to take advantage of the accumulation of fine sediments that occurs from late spring to late fall. In addition, sediment sampling is conducted in the Peace-Athabasca Delta where upstream sediments transported during high flows accumulate over time. Other waterbodies (e.g., tributaries of the Athabasca River, wetlands) are sampled less frequently, because they are generally exposed to less cumulative development and sedimentation rates are lower than in the Athabasca River (Table 1.4). New sediment stations are monitored every fall for the first three years, with toxicity testing being conducted for the first two years to establish baseline conditions (Table 1.4).

Table 1.3 RAMP water quality monitoring program (1997 to 2009).

see symbol key at bottom

		1997				1998				1999				2000				2001				2002				2003				2004				2005				2006				2007				2008				2009			
WATERBODY AND LOCATION	**STATION**	W	S	S	F	W	S	S	F	W	S	S	F	W	S	S	F	W	S	S	F	W	S	S	F	W	S	S	F	W	S	S	F	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]	ATR-UFM	13	11	13	11	13	11	13	11	13	11	13	11	13	11	13	11	13	11	13	11	13	11	13	11	13	11	13	11	13	11	13	11	13	11	13	11	13	11	13	11	13	11	13	11	13	11	13	11	13	11	13	11
Upstream Donald Creek (cross channel)	ATR-DC-CC		1	1	1																				1				3				1				1				1				1				1				1
(west bank) [b]	ATR-DC-W								1								1				3				1				1				1				1				1				1				1				1
(east bank) [b]	ATR-DC-E								1								1				3				1				1				1				1				1				1				1				1
(middle)	ATR-DC-M																1																																				
Upstream of the Steepbank River (middle)	ATR-SR-M																1																																				
(west bank)	ATR-SR-W																1				1				1				1				1				1				1				1				1				1
(east bank)	ATR-SR-E																1				1				1				1				1				1				1				1				1				1
Upstream of the Muskeg River (middle)	ATR-MR-M																1																																				
(west bank) [b c]	ATR-MR-W								1								1				1				1				1				1				1				1				1				1				1
(east bank) [b c]	ATR-MR-E								1								1				1				1				1				1				1				1				1				1				1
Upstream Fort Creek (cross channel)	ATR-1		1	1	1																																																
(west bank) [b c]	ATR-FC-W								1								1				3				1				1				1				1				1				1				1				1
(east bank) [b c]	ATR-FC-E								1								1				3				1				1				1				1				1				1				1				1
(middle)	ATR-FC-M																1																																				
Downstream of all development (cross channel)	ATR-DD																					1,1	1	1	3	1,1	1	1	3	1,1	1	1	3	1,1	1	1	3	1,1	1	1	3	1,1	1	1	3	1,1	1	1	3	1,1	1	1	3
Upstream of mouth of Firebag River	ATR-FR																								1				1				1				1				1				1				1				1
Upstream of the Embarras River (cross channel)	ATR-ER																1				3																																
At Old Fort (grab) [d]	ATR-OF													11	11	11	11	11	11	11	11	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12
Athabasca River Delta																																																					
Big Point Channel [e]	ARD-1											1					1				1								1																								
Athabasca River Tributaries (South of Fort McMurray)																																																					
Clearwater River (upstream of Fort McMurray)	CLR-1																	3	8	8	8	1	7	7	8	1	7	7	8	1	7	7	7	1	7	7	7	1	7	7	7	1	7	7	7	1	7	7	7	1	7	7	7
(upstream of Christina River)	CLR-2																	3	8	8	8	1	7	7	8	1	7	7	8		6	6	7	1	6	6	7		6	6	7		6	6	7	1	6	6	7		6	6	7
Christina River (upstream of Fort McMurray)	CHR-1																					1	1	1	3	1	1	1	3	1	1	1	3	1			1				1				1	1			1				1
(upstream of Janvier)	CHR-2																					1	1	1	3	1	1	1	3	1	1	1	3	1			1				1				1	1			1				1
Hangingstone River (upstream of Ft. McMurray)	HAR-1																													1	1	1	3	1	1	1	3	1	1	1	3				1	1			1				1
Athabasca River Tributaries (North of Fort McMurray)																																																					
McLean Creek (mouth)	MCC-1											6	7		6	6	9		6	6	9	1	6	6	7		6	6	7		6	6	9	1	6	6	7		6	6	7		6	6	9	1	6	6	7		6	6	7
(100 m upstream)	MCC-2											6	6																																								
Poplar Creek (mouth)	POC-1																1				1	1			1				1				1	1			1				1				1	1			1				1
Steepbank River (mouth)	STR-1		1	1	1		1	1	1	1							1				1	1			1				1				1	1			1				1				1	1			1				1
(upstream of Project Millennium)	STR-2																					1			1				1				1	1			1				1				1	1			1				1
(upstream of Nt. Steepbank)	STR-3																													1	1	1	1	1			1				1				1	1			1				1
North Steepbank River (upstream of P.C. Lewis)	NSR-1																					1	1	1	1	1	1	1	1	1	1	1	1																				
MacKay River (mouth)	MAR-1								1								1				1	1			1				1				1	1			1				1				1	1			1				1
(upstream of P.C. MacKay)	MAR-2																					1			1	1	1	1	1				1	1			1				1				1	1			1				1
Ells River (mouth)	ELR-1						1	1	1						11	11	11	11				1	1	1	2	1	1	1	2	Dependant on CNRL application																							
(upstream of CNRL Lease 7)	ELR-2														11	11	11	14												Dependant on CNRL application																							
Tar River (mouth)	TAR-1						1	1	1													1	1	1	2	1	1	1	2	1	1	1	1	1			1				1				1	1			1				1
(upstream of CNRL Horizon)	TAR-2																													1	1	1	1	1			1				1				1	1			1				1
Fort Creek (mouth)	FOC-1														7	7	9		6	6	7	1	6	6	7		6	6	7		6	6	9	1	6	6	7		6	6	7		6	6	9	1	6	6	7		6	6	7
Firebag River (mouth)	FIR-1																					1	1	1	1	1	1	1	1	1	1	1	1	1			1				1				1	1			1				1
(upstream of Suncor Firebag)	FIR-2																					1	1	1	1	1	1	1	1	1	1	1	1	1			1				1				1	1			1				1
Embarras River	EMR-1																												1																								
Muskeg River																																																					
Mouth [f]	MUR-1		1	1	1	13	13,1	13,1	11,1	13	13,6	13,6	11,7				1				1				1				1				1				1				1				1				1				1
Upstream of Canterra Road Crossing [g]	MUR-2									2	9	9	9	10	10	10	10	10	10	10	10	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4
AENV sampling [f]						13	13	13	11	13	13	13	11	15	15	15	14	15	15	15	14	15	15	15	14	15	15	15	14	15	15	15	14	15	15	15	14	15	15	15	14	15	15	15	14	15	15	15	14	15	15	15	14
Downstream of Alsands Drain	MUR-3																																																				
Upstream of Jackpine Creek [f g h]	MUR-4					13	13	13	11	13	13,6	13,6	11,7	4	10	10	10	4	10	10	10	4	10	10	10	4	10	10	10	4	10	10	10	4	10	10	10	4	10	10	10	4	10	10	10	4	10	10	10	4	10	10	10
Upstream of Muskeg Creek [f g]	MUR-5					13	13	13	11	13,2	13,9	13,9	11,9	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10
Upstream of Wapasu Creek	MUR-6					2			2	2	9	9	9		6	6	9		6	6	9		6	6	9		6	6	7		6	6	9		6	6	7		6	6	7		6	6	9		6	6	7		6	6	7

Table 1.3 (cont'd).

see symbol key at bottom

WATERBODY AND LOCATION	STATION	1997				1998				1999				2000			
		W	S	S	F	W	S	S	F	W	S	S	F	W	S	S	F
Muskeg River Tributaries																	
Alsands Drain (mouth) [f g h]	ALD-1					13	13	13	11	13	13,6	13,6	11,7	4	10	10	10
Jackpine Creek (mouth) [f]	JAC-1					13	13	13	11	13	13	13	11,1				1
Shelley Creek (mouth)	SHC-1								11				11,1				
Muskeg Creek (mouth)	MUC-1								11,2				11,1				1
Stanley Creek (mouth)	STC-1								11				11,1				
Wapasu Creek (Canterra Road Crossing)	WAC-1					2			11	2			11,1				
Wetlands																	
Kearl Lake (composite)	KEL-1							1									1
Isadore's Lake (composite)	ISL-1							1									1
Shipyard Lake (composite)	SHL-1							1			1	1	1			1	1
McClelland Lake (composite)	MCL-1																1
Additional Sampling (Non-Core Programs)																	
Un-nammed Creek - north of Ft. Creek (mouth)	UNC-1															1	1
Calumet River (mouth)	CAR-1																
OPTI Lakes	-																
Potential TIE	-																
QA/QC																	
Field and trip blanks, plus one split sample	-														1	1	1

WATERBODY AND LOCATION	STATION	2001				2002				2003				2004				2005			
		W	S	S	F	W	S	S	F	W	S	S	F	W	S	S	F	W	S	S	F
Muskeg River Tributaries																					
Alsands Drain (mouth) [f g h]	ALD-1	4	10	10	10	4	10	10	10	4	10	10	10	4	10	10	10	4	10	10	10
Jackpine Creek (mouth) [f]	JAC-1				1				1				1				1				1
Shelley Creek (mouth)	SHC-1																				
Muskeg Creek (mouth)	MUC-1				1				1				1				1	1	1	1	1
Stanley Creek (mouth)	STC-1				1	1	1	1	1	1	1	1	1				1	1	1	1	1
Wapasu Creek (Canterra Road Crossing)	WAC-1																				
Wetlands																					
Kearl Lake (composite)	KEL-1			1	1				1	1			1			1	1				1
Isadore's Lake (composite)	ISL-1			1	1																
Shipyard Lake (composite)	SHL-1			1	1			1	1			1	1			1	1			1	1
McClelland Lake (composite)	MCL-1			1	1				1							1	1				1
Additional Sampling (Non-Core Programs)																					
Un-nammed Creek - north of Ft. Creek (mouth)	UNC-1																				
Calumet River (mouth)	CAR-1					1	1	1	2	1	1	1	2								
OPTI Lakes	-		5		5		5		5												
Potential TIE	-								√				√				√				√
QA/QC																					
Field and trip blanks, plus one split sample	-			1	1	1	1	1	1,1	1	1	1	1,1	1	1	1	1,1	1	1	1	1,1

WATERBODY AND LOCATION	STATION	2006				2007				2008				2009			
		W	S	S	F	W	S	S	F	W	S	S	F	W	S	S	F
Muskeg River Tributaries																	
Alsands Drain (mouth) [f g h]	ALD-1	4	10	10	10	4	10	10	10	4	10	10	10	4	10	10	10
Jackpine Creek (mouth) [f]	JAC-1				1				1				1				1
Shelley Creek (mouth)	SHC-1				1												1
Muskeg Creek (mouth)	MUC-1				1				1	1	1	1	1				1
Stanley Creek (mouth)	STC-1				1				1	1	1	1	1				1
Wapasu Creek (Canterra Road Crossing)	WAC-1				1				1				1				1
Wetlands																	
Kearl Lake (composite)	KEL-1				1			1	1				1				1
Isadore's Lake (composite)	ISL-1																
Shipyard Lake (composite)	SHL-1			1	1			1	1			1	1			1	1
McClelland Lake (composite)	MCL-1				1			1	1				1				1
Additional Sampling (Non-Core Programs)																	
Un-nammed Creek - north of Ft. Creek (mouth)	UNC-1																
Calumet River (mouth)	CAR-1																
OPTI Lakes	-																
Potential TIE	-				√				√				√				√
QA/QC																	
Field and trip blanks, plus one split sample	-	1	1	1	1,1	1	1	1	1,1	1	1	1	1,1	1	1	1	1,1

Legend

1 = standard water quality parameters (conventionals, major ions, nutrients, t. & d. metals, recoverable hydrocarb. and naph. acids)
2 = standard w.q. + chronic toxicity testing (*Selenastrum capricornutum, Ceriodaphnia dubia,* fathead minnow)
3 = standard w.q. + PAHs
4 = standard w.q. + chronic tox testing + PAHs
5 = standard w.q. for OPTI lakes (routine paramters and arsenic)
6 = thermograph
7 = thermograph + standard w.q.
8 = thermograph + standard w.q. + PAHs
9 = thermograph + standard w.q. + chronic tox. testing
10 = thermograph + standard w.q. + chronic tox testing + PAHs
11 = AENV routine parameters (conventional parameters, major ions, nutrients and total metals)
12 = AENV routine parameters + RAMP standard parameters
13 = AENV routine parameters + PAHs
14 = AENV routine parameters + DataSonde
15 = AENV routine parameters + PAHs + DataSonde
Note: Beginning in 2003, volatile hydrocarbons (VOCs) will be measured at some locations on the Muskeg, Tar, Ells and Steepbank Rivers

Footnotes

[a] Two samples collected in winter, but PAHs and several other parameters only measured once
[b] Sample sites were previously labeled ATR-1, 2 and 3 (moving upstream from the Delta)
[c] Samples were collected downstream of tributary in 1998
[d] Monthly sampling for nutrients and conventional parameters; quarterly sampling for total and dissolved metals
[e] In 1999, one composite samples was prepared with water from Big Point, Goose Island, Embarras and an unnamed side channel
[f] AENV collects/collected nine samples throughout the year, although only three are/were analyzed for PAHs
[g] All testing, with the exception of thermographs, is conducted by individual industry
[h] In 1999, MUR-4 was located upstream of Shelley Creek
√ = allowance made for potential TIE

Table 1.4 RAMP sediment quality monitoring program (1997 to 2009).

see symbol key at bottom

WATERBODY AND LOCATION	STATION	1997				1998				1999				2000				2001				2002				2003				2004				2005				2006				2007				2008				2009			
		W	S	S	F	W	S	S	F	W	S	S	F	W	S	S	F	W	S	S	F	W	S	S	F	W	S	S	F	W	S	S	F	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 (cross channel)	ATR-UFM																								1				3				1				1				3				1				1				3
Upstream of Donald Creek (west bank)[a]	ATR-DC-W				3				3								1				3				1				3				1				1				3				1				1				3
(east bank)[a]	ATR-DC-E				3				3								1				3				1				3				1				1				3				1				1				3
Upstream of Steepbank River (west bank)	ATR-SR-W																1				3				1				3				1				1				3				1				1				3
(east bank)	ATR-SR-E																1				3				1				3				1				1				3				1				1				3
Upstream of the Muskeg River (west bank)[a b]	ATR-MR-W								3								1				3				1				3				1				1				3				1				1				3
(east bank)[a b]	ATR-MR-E								3								1				3				1				3				1				1				3				1				1				3
Upstream of Fort Creek (west bank)[a b]	ATR-FC-W				3				3								1				3				1				3				1				1				3				1				1				3
(east bank)[a b]	ATR-FC-E				3				3								1				3				1				3				1				1				3				1				1				3
Testing inter-site variability (3 comp. samples)	-																1																																				
Downstream of all development (west bank)	ATR-DD-W																								1				3				1				1				3				1				1				3
(east bank)	ATR-DD-E																								1				3				1				1				3				1				1				3
Upstream of mouth of Firebag River (west bank)	ATR-FR-W																								1				3				1				1				3				1				1				3
(east bank)	ATR-FR-E																								1				3				1				1				3				1				1				3
Upstream of the Embarras River	ATR-ER																3				1				1				3				1				1				3				1				1				3
Athabasca Delta / Lake Athabasca																																																					
Delta composite[c]	ARD-1											3					3																																				
Big Point Channel	BPC																				3				3				3												3												3
Goose Island Channel	GIC																				3				3				3												3												3
Fletcher Channel	FLC																				3				3				3												3												3
Flour Bay	FLB-1																3																																				
Athabasca River Tributaries (South of Fort McMurray)																																																					
Clearwater River (upstream of Fort McMurray)	CLR-1																				1				3				3												3												3
(upstream of Christina River)	CLR-2																				1				3				3												3												3
Christina River (upstream of Fort McMurray)	CHR-1																								1				3				3								3												3
(upstream of Janvier)	CHR-2																								1				3				3								3												3
Hangingstone River (upstream of Ft. McMurray)	HAR-1																																3				3				1												3
Athabasca River Tributaries (North of Fort McMurray)																																																					
McLean Creek (mouth)	MCC-1												3				3				1				3												3												3				
Poplar Creek (mouth)	POC-1				1																				3								3												3								
Steepbank River (mouth)	STR-1				1				1																3												3												3				
(upstream of Project Millennium)	STR-2				1																				3												3												3				
(upstream of Nt. Steepbank)	STR-3																																				3												3				
North Steepbank River (upstream of P.C. Lewis)	NSR-1																								3				3				1				3												3				
MacKay River (mouth)	MAR-1				1				1												3				3								3												3								
(upstream of P.C. MacKay)	MAR-2																				1				3								3												3								
Ellis River (mouth)	ELR-1								1																3				3	Dependant on CNRL application																							
(upstream of CNRL Lease 7)	ELR-2																													Dependant on CNRL application																							
Tar River (mouth)	TAR-1								1																3				3				1												3								
(upstream of CNRL Horizon)	TAR-2																																1												3								
Fort Creek (mouth)	FOC-1																1				1				3								3				3				3								3				
Firebag River (mouth)	FIR-1																								3				3				1				1												3				
(upstream of Suncor Firebag)	FIR-2																								3				3				1				1												3				
Muskeg River																																																					
Mouth	MUR-1				1				1				3				1				1				3				3				3				3				3				3				3				3
1 km upstream of mouth	MUR-1b																1												1												1												1
Upstream of Canterra Road Crossing	MUR-2																1								3				3				3				3				3				3				3				3
Upstream of Jackpine Creek	MUR-4				1												1												1												1												1
Upstream of Muskeg Creek	MUR-5																1												1												1												1

Table 1.4 (cont'd).

see symbol key at bottom

WATERBODY AND LOCATION	STATION	1997				1998				1999				2000				2001				2002				2003			
		W	S	S	F	W	S	S	F	W	S	S	F	W	S	S	F	W	S	S	F	W	S	S	F	W	S	S	F
Upstream of Stanley Creek	MUR-D2																								3				3
Upstream of Wapasu Creek	MUR-6																1												1
Muskeg River Tributaries																													
Jackpine Creek (mouth)	JAC-1				1																								
Shelley Creek (mouth)	SHC-1																												
Muskeg Creek (mouth)	MUC-1																												
Stanley Creek (mouth)	STC-1																												1
Wapasu Creek (Canterra Road Crossing)	WAC-1																												
Wetlands																													
Kearl Lake (composite)	KEL-1																				1								
Isadore's Lake (composite)	ISL-1																				1								
Shipyard Lake (composite)	SHL-1																				1				3				1
McClelland Lake (composite)	MCL-1																								1				
Additional Sampling (Non-Core Programs)																													
Un-nammed Creek - north of Ft. Creek (mouth)	UNC-1																												
Calumet River (mouth)	CAR-1																								3				3
Potential TIE	-																				√								
QA/QC																													
One split and one duplicate sample	-																1				1				1				1

WATERBODY AND LOCATION	STATION	2004				2005				2006				2007				2008				2009			
		W	S	S	F	W	S	S	F	W	S	S	F	W	S	S	F	W	S	S	F	W	S	S	F
Upstream of Stanley Creek	MUR-D2				3				3				3				3				3				3
Upstream of Wapasu Creek	MUR-6												1												1
Muskeg River Tributaries																									
Jackpine Creek (mouth)	JAC-1																								
Shelley Creek (mouth)	SHC-1																								
Muskeg Creek (mouth)	MUC-1																								
Stanley Creek (mouth)	STC-1												1												1
Wapasu Creek (Canterra Road Crossing)	WAC-1																								
Wetlands																									
Kearl Lake (composite)	KEL-1				1												1								
Isadore's Lake (composite)	ISL-1																								
Shipyard Lake (composite)	SHL-1				3												3								
McClelland Lake (composite)	MCL-1				1												1								
Additional Sampling (Non-Core Programs)																									
Un-nammed Creek - north of Ft. Creek (mouth)	UNC-1																								
Calumet River (mouth)	CAR-1																								
Potential TIE	-																								
QA/QC																									
One split and one duplicate sample	-				1				1				1				1				1				1

Legend

1 = standard sediment quality parameters (carbon content, particle size, recoverable hydrocarbons, TEH and TVH, total metals, PAHs and alkylated PAHs)
2 = sediment toxicity testing (*Chironomus tentans, Lumbriculus variegatus, Hyalella azteca*)
3 = standard s.q. + toxicity testing

Footnotes

[a] Sample sites were previously labeled ATR-1, 2 and 3 (moving upstream from the Delta)
[b] Samples were collected downstream of tributary in 1998
[c] In 1999, one composite sample was collected from Big Point, Goose Island, Embarras and an unnamed side channel
√ = allowance made for potential TIE

1.2.3 Benthic Invertebrate Community

Benthic macroinvertebrates are a commonly used indicator of aquatic environmental conditions. Benthic invertebrates are included as a component of the RAMP for a variety of reasons. First, they integrate biologically relevant variations in water and habitat quality. Second, they are limited in their mobility and, therefore, reflect local conditions; thus, they can be used to identify point sources of inputs or disturbance. The short invertebrate life span (typically about one year) allows them to integrate the physical and chemical aspects of water quality over annual time periods and provide early warning of impending effects on fish communities (Kilgour and Barton 1999). Finally, based on known tolerances of benthic taxa, it is possible to re-create the environmental conditions determining what animals are present (Rooke and Mackie 1982a, b).

The RAMP benthic invertebrate community component has three general objectives:

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

The benthic invertebrate component of RAMP focuses on tributaries of the Athabasca River and regional wetlands. Historically, sampling was also conducted on the mainstem Athabasca River, but was discontinued in 1998 because of problems related to the transient/shifting nature of bottom sediments in the river. With recent expansion of oil sands operations, the program has correspondingly expanded to include new tributaries and additional stations on tributaries near active oil sand extraction sites (Table 1.5).

Benthic sampling is conducted in the fall of each year to limit potential season-associated variability in composition of the benthic community. Where available, historical data (collected in previous years through the RAMP program) are used to place current results in context with historical trends in community structure that may be occurring.

Table 1.5 RAMP benthic invertebrate community monitoring program (1997 to 2009).

WATERBODY AND LOCATION	HABITAT	STATION	1997				1998				1999				2000				2001				2002				2003				2004				2005				2006				2007				2008				2009			
			W	S	S	F	W	S	S	F	W	S	S	F	W	S	S	F	W	S	S	F	W	S	S	F	W	S	S	F	W	S	S	F	W	S	S	F	W	S	S	F	W	S	S	F	W	S	S	F	W	S	S	F
Athabasca River																																																						
Near Donald Creek (west bank)	depositional	ATR-B-B4 to B6				1																																															
Near Donald Creek (east bank)	depositional	ATR-B-B1 to B3				1																																															
Near Fort Creek (west bank)	depositional	ATR-B-A4 to A6				1																																															
Near Fort Creek (east bank)	depositional	ATR-B-A1 to A3				1																																															
Suncor near-field monitoring	depositional	-																				2																															
Athabasca Delta	depositional	(3 sites)																								1				1																							
Calumet River																																																						
Lower reach near mouth	erosional?	CAL-E																				2				1				1				1				1								1								1
Upper reach	erosional?	CAL-E2																												1																								
Clearwater River																																																						
Downstream of Christina River	depositional	CWR-D1																				1				1				1				1				1								1								1
Upstream of Christina River	depositional	CWR-D2																				1				1				1				1				1								1								1
Christina River																																																						
Lower reach near mouth	erosional?	CHR-E1																								1				1				1				1				1								1				
Upper reach at Janvier	erosional?	CHR-E2																								1				1				1				1				1								1				
Ells River																																																						
Lower reach near mouth	erosional?	ELR-E1																								1				1				1				1				1								1				
Upper Reach	erosional?	ELR-E2																												1																								
Firebag River																																																						
Lower reach near mouth	erosional?	FBR-E1																												1																								
Upper reach	erosional?	FBR-E2																												1																								
Fort Creek																																																						
Lower reach near mouth	erosional	FOC-E												2								1				1				1				1								1								1				
Hangingstone River																																																					
Lower reach near mouth	erosional	HSR-E																																																			
Jackpine Creek																																																						
Lower reach near mouth	erosional	JAC-E1																								1				1				1				1				1								1				
Upper reach	erosional	JAC-E2																												1																								
Mackay River																																																						
200 m upstream of mouth	erosional	MAR-1								1																																											
500 m upstream of mouth	erosional	MAR-2								1																																											
1.2 km upstream of mouth	erosional	MAR-3								1																																											
Lower reach near mouth	erosional	MAR-E1																1				1				1				1				1								1								1				
Upper reach	erosional	MAR-E3																								1				1				1				1				1								1				
Muskeg River																																																						
50 m upstream of mouth	erosional	MUR-1								1																																											
200 m upstream of mouth	erosional	MUR-2								1																																											
450 m upstream of mouth	erosional	MUR-3								1																																											
Lower reach near mouth	erosional	MUR-E1																1				1				1				1				1								1								1				
Lower to middle reach	depositional	MUR-D1																1				1				1				1				1								1								1				
Upstream of Stanley Creek	depositional	MUR-D2																								1				1				1				1				1								1				
Steepbank River																																																						
50 m upstream of mouth	erosional	STR-1								1																																											
150 m upstream of mouth	erosional	STR-2								1																																											
300 m upstream of mouth	erosional	STR-3								1																																											
Lower reach near mouth	erosional	STR-E1																1				1				1				1				1								1								1				
Upper reach	erosional	STR-E2																												1																								
Tar River																																																						
Lower reach near mouth	erosional?	TAR-E1																				2				1				1				1				1								1								1
Upper reach	erosional?	TAR-E2																												1																								
Kearl Lake																																																						
Kearl Lake	lake	KEL																				1				1				1				1				1								1								1
McClelland Lake																																																						
McClelland Lake	lake	MCL																								1				1				1				1				1								1				
Shipyard Lake																																																						
Shipyard Lake	lake	SHL																1				1				1				1				1								1								1				

Table 1.5 (cont'd).

WATERBODY AND LOCATION	HABITAT	STATION	1997				1998				1999				2000				2001				2002				2003				2004				2005				2006				2007				2008				2009			
			W	S	S	F	W	S	S	F	W	S	S	F	W	S	S	F	W	S	S	F	W	S	S	F	W	S	S	F	W	S	S	F	W	S	S	F	W	S	S	F	W	S	S	F	W	S	S	F	W	S	S	F
Historical Data																																																						
Historical Data Review															1	1	1	1					1	1	1	1																												
5-Year Summary Report																																																						
Summary Report																							1	1																														

NOTES:
1 = RAMP site
2 = Sampled outside of RAMP (data available to RAMP)
15 samples will be collected in each river/stream reach and 10 in each lake (random sample locations within one habitat type or depth, respectively), during the fall.
5 consecutive years' worth of data will be accumulated at each river/stream site and lake (except in Athabasca R.) and then frequency will be dropped to once every 2 years.
3 individual sites will be sampled at the Athabasca delta in 2002; samples from 2 sites will be analyzed (least and most toxic sediments)
Suncor near-field monitoring in 2001 is funded outside of RAMP. Athabasca River work after 2001 is conditional upon 2001 findings.

The tributary monitoring approach adopted by RAMP focuses on characterizing benthic communities (total abundance, taxonomic richness, relative dominance, etc.) within the lower reach of each river (i.e., downstream of development) relative to communities found in an upper reference reach. This approach allows for detection of the cumulative effects of all developments within a basin. A reach consists of relatively homogeneous stretches of river ranging from 2 to 5 km in length, depending on habitat availability. Within reaches, samples are collected from either erosional or depositional habitats, depending on which is the most dominant habitat type within a tributary. To monitor wetlands, sampling effort is distributed over the entire open-water area of the wetland, but restricted to a narrow range in water depth to minimize natural variations in communities.

1.2.4 Fisheries

The RAMP Fisheries Program was established to monitor the health and sustainability of fish populations within the oil sands region. The monitoring activities focus on the Athabasca River, as well as tributaries potentially influenced by current or future development. Fish populations are monitored because they are key components of the aquatic ecosystem and important ecological indicators that integrate effects from natural and anthropogenic influences. Fish also represent a highly valued recreational and subsistence resource. In this regard, there are expectations from regulators, First Nations and the general public with respect to comprehensive ongoing monitoring of fish populations in the oil sands region.

Specific objectives of the fisheries component are to:

- Appraise the ecological integrity of fish populations in the oil sands region by assessing attributes such as growth, reproduction and survival;
- Assess the suitability of fisheries resources in the oil sands region for human consumption; and
- Generate high quality data on fish populations for use in environmental impact predictions.

To meet the specific fisheries program objectives, RAMP conducts a range of core monitoring activities that are intended to assess and document ecological characteristics of fish populations, chemical burdens, and migration patterns in the oil sands region. Specific elements of the core fish program include: fish inventories and spawning surveys; tissue sampling for organic and inorganic chemicals; monitoring of fish health through evaluation of performance indicators (e.g., physical condition, population age, length/weight comparisons etc.) in sentinel fish species; and fish fence monitoring.

In the oil sands region of Alberta, specific key indicator fish species (or key indicator resources, KIRs) have been identified for the Athabasca River and select tributaries. The key indicator species were selected through consultation with First Nations, government and industry representatives, and include goldeye, lake whitefish, longnose sucker, northern pike, trout-perch, and walleye (CEMA 2001). Although the fisheries program evaluates the integrity of the total fish community, particular emphasis is placed on the selected key fish species based on their ecological importance and value to local communities of the region.

Fish tissue assessments are conducted by RAMP to quantify and monitor contaminant levels in relation to the suitability of the fish resource for human consumption and to identify potential direct or indirect toxicity effects on fish. As part of the ongoing program, muscle tissues are collected from lake whitefish and walleye from the Athabasca River and northern pike from the Muskeg River. Tissues are analyzed for metals, including mercury, and specific organic compounds known to cause tainting of fish flesh. Historically, polycyclic aromatic hydrocarbons (PAHs) have been measured, but the analysis was discontinued in 2002 because these compounds are easily metabolized in fish and unlikely to accumulate in fish muscle. In 2002, analysis of fishes from regionally important lakes was initiated to provide a mechanism to analyze fish captured during opportunistic sampling, or in conjunction with fisheries investigations mandated separately from RAMP. Regionally important lakes sampled to date consist of Gregoire Lake (2002), Lake Claire (2003) and Christina Lake (2003).

General fish inventories are conducted to monitor and assess temporal and spatial changes in species presence, relative abundance and population parameters in selected watercourses. In the Athabasca River, the inventory is conducted annually in the spring and fall and is designed to assess populations of large-bodied key indicator species in the vicinity of oil sands development. The Clearwater River was added to the inventory program in 2003, and other watercourses such as Muskeg River, MacKay River, Christina River and the Firebag River have been surveyed in the past as part of the RAMP fisheries program.

Sentinel fish species monitoring is part of the RAMP fisheries program to assess the potential effects of stressors (e.g., industrial development) on wild fish populations. The approach evaluates the performance (e.g., growth, survival, condition, reproduction) of a specific sentinel species potentially influenced by development relative to reference and/or historical performance data. The underlying premise of the approach is that the health of the selected sentinel species reflects the overall condition of the aquatic environment in which the fish resides. The approach has also been included as part of the federal government's Environmental Effects Monitoring (EEM) programs under the pulp and paper

(Environment Canada 1992) and metal mining (Environment Canada 2002) effluent regulations. Sentinel species monitoring is conducted at regular intervals at several sites in the Athabasca River (trout-perch, longnose sucker), as well as several Athabasca tributaries (slimy sculpin), including the Muskeg River and the Steepbank River. Sentinel species monitoring is conducted on a three year cycle.

To date, fish fence monitoring has been limited to the Muskeg River, and is used to generate data on the biology and movement of spawning populations of large bodied fish species that use the Muskeg River drainage. These data assist in the identification and quantification of local and regional environmental impacts/effects in the Muskeg watershed.

In addition to the core activities, the Fish Program also includes a variety of other studies designed to address specific data gaps that may arise concerning fish populations in the oil sands region. In particular, these studies have included radiotelemetry studies on the Athabasca and Muskeg Rivers, spawning/egg surveys, winter fish habitat surveys and an experimental program looking at the possible application of the fish community-based Index of Biotic Integrity (IBI).

The long-term monitoring plan for core elements of the RAMP fisheries component is shown in Table 1.6.

Table 1.6 RAMP fisheries monitoring program (1997 to 2009).

see symbol key at bottom

WATERBODY AND LOCATION	REACH	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																					
Poplar Area	0/1[a]		1	1,5	1,5		1,6	1,5	1,3,6												
Steepbank Area	4/5/6		1	1,5	1,5		1,6	1,5	1,3,6									7			6
Muskeg Area	10/11/2012		1	1,5	1,5		1,6	1,5	1,3,6									7			6
Tar-Ells Area	16/17		1	1,5	1,5		1,6	1	1,3,6									7			
CNRL/TrueNorth Area (Fort/Asphalt reaches)																					
Reference Area - about 200 km upstream[b]	5/6							1,5	1,3,6												
Reference Area - upstream of Fort McMurray[c]			1																		
Radiotelemetry study region[d]					2		2		2						2	2	2	2	2		
Downstream of Suncor's Discharge	AR-SD												1,3								
Below Muskeg River	AR-MR												1,3								
Reference site upstream of Ft. McMurray STP																					
Reference site between STP and Suncor	AR-R												1,3								
Downstream of Developments (near Firebag R.)																					
Athabasca River Delta																					
Athabasca River Tributaries																					
Fort Creek (mouth)															1,8,5,9	1					
Historical Review of Tributary Fish Data																					
Clearwater and Christina Rivers																					
Muskeg River																					
Lower 35 km below Jackpine Creek confluence				1			4						1,3		2,8	2	2	2	2	1	6
Mouth (within 1 km of confl. with Athabasca R.)	MR-MT												1,3						4		3
Reference sites (Steepbank, Horse and Dunkirk R.)																	3				3
Upper Muskeg River (near Wapasu Ck. Confluence)																					
Muskeg River Tributaries																					
Alands Drain																					
Jackpine Creek (accessable areas of lower creek)															8					1	
Shelley Creek																					
Muskeg Creek (Canterra road crossing)[e]																					
Stanley Creek																					
Wapasu Creek (mouth or Canterra road)[e]																					
Regionally Important Lakes																					
Various lakes in water/air emissions pathway																					
Kearl Lake																					
Isadore's Lake																					
Steepbank River																					
Steepbank Mine baseline fisheries reach (1995)[f]	AF014			1																	
Vicinity of Steepbank Mine	SR-MN												1,3								3
Reference site in vicinity of Bitumin Heights	SR-R												1,3								
Setinel reference site[g]	SR-EC												1,3				3				3
Sentinel reference sites (Horse and Dunkirk R.)																	3				3
Shipyard Lake																					
McLean Creek																					
Mouth																					
Upstream of mouth (100 m)																					
Mackay River																					
Lower reach (85 km section from bridge to mouth)	MAR-1		1																		
Tar River																					
Mouth																					

WATERBODY AND LOCATION	REACH	2002				2003				2004				2005			
		W	S	S	F	W	S	S	F	W	S	S	F	W	S	S	F
Athabasca River																	
Poplar Area	0/1[a]		1												1		
Steepbank Area	4/5/6		1		10,6				6						1		3,6
Muskeg Area	10/11/2012		1		10,6				6						1		3,6
Tar-Ells Area	16/17		1												1		3
CNRL/TrueNorth Area (Fort/Asphalt reaches)			1												1		
Reference Area - about 200 km upstream[b]	5/6																3
Reference Area - upstream of Fort McMurray[c]																	
Radiotelemetry study region[d]																	
Downstream of Suncor's Discharge	AR-SD				10,3				10								3
Below Muskeg River	AR-MR				10,3				10								3
Reference site upstream of Ft. McMurray STP					3				10								3
Reference site between STP and Suncor	AR-R				3				10								3
Downstream of Developments (near Firebag R.)									10,6								
Athabasca River Delta																	
Athabasca River Tributaries																	
Fort Creek (mouth)																	
Historical Review of Tributary Fish Data																	
Clearwater and Christina Rivers								10									
Muskeg River																	
Lower 35 km below Jackpine Creek confluence				1	6							1	6				
Mouth (within 1 km of confl. with Athabasca R.)	MR-MT		4		4		4						3		4		
Reference sites (Steepbank, Horse and Dunkirk R.)													3				
Upper Muskeg River (near Wapasu Ck. Confluence)			1,4		1,4												
Muskeg River Tributaries																	
Alands Drain																	
Jackpine Creek (accessable areas of lower creek)				1								1					
Shelley Creek																	
Muskeg Creek (Canterra road crossing)[e]			1,4		1,4												
Stanley Creek																	
Wapasu Creek (mouth or Canterra road)[e]			1,4		1,4												
Regionally Important Lakes																	
Various lakes in water/air emissions pathway									6								
Kearl Lake																	
Isadore's Lake																	
Steepbank River																	
Steepbank Mine baseline fisheries reach (1995)[f]	AF014																
Vicinity of Steepbank Mine	SR-MN												3				
Reference site in vicinity of Bitumin Heights	SR-R																
Setinel reference site[g]	SR-EC												3				
Sentinel reference sites (Horse and Dunkirk R.)													3				
Shipyard Lake																	
McLean Creek																	
Mouth																	
Upstream of mouth (100 m)																	
Mackay River																	
Lower reach (85 km section from bridge to mouth)	MAR-1		1					10							1		
Tar River																	
Mouth																	

WATERBODY AND LOCATION	REACH	2006				2007				2008				2009			
		W	S	S	F	W	S	S	F	W	S	S	F	W	S	S	F
Athabasca River																	
Poplar Area	0/1[a]										1						
Steepbank Area	4/5/6										1		3,6				
Muskeg Area	10/11/2012										1		3,6				
Tar-Ells Area	16/17										1		3				
CNRL/TrueNorth Area (Fort/Asphalt reaches)											1						
Reference Area - about 200 km upstream[b]	5/6																
Reference Area - upstream of Fort McMurray[c]																	
Radiotelemetry study region[d]																	
Downstream of Suncor's Discharge	AR-SD												3				
Below Muskeg River	AR-MR												3				
Reference site upstream of Ft. McMurray STP													3				
Reference site between STP and Suncor	AR-R												3				
Downstream of Developments (near Firebag R.)																	
Athabasca River Delta																	
Athabasca River Tributaries																	
Fort Creek (mouth)																	
Historical Review of Tributary Fish Data																	
Clearwater and Christina Rivers																	
Muskeg River																	
Lower 35 km below Jackpine Creek confluence							2,8	2,1	2,6	2	2						
Mouth (within 1 km of confl. with Athabasca R.)	MR-MT						4		3								
Reference sites (Steepbank, Horse and Dunkirk R.)									3								
Upper Muskeg River (near Wapasu Ck. Confluence)																	
Muskeg River Tributaries																	
Alands Drain																	
Jackpine Creek (accessable areas of lower creek)							8	1									
Shelley Creek																	
Muskeg Creek (Canterra road crossing)[e]																	
Stanley Creek																	
Wapasu Creek (mouth or Canterra road)[e]																	
Regionally Important Lakes																	
Various lakes in water/air emissions pathway																	
Kearl Lake																	
Isadore's Lake																	
Steepbank River																	
Steepbank Mine baseline fisheries reach (1995)[f]	AF014																
Vicinity of Steepbank Mine	SR-MN								3								
Reference site in vicinity of Bitumin Heights	SR-R																
Setinel reference site[g]	SR-EC								3								
Sentinel reference sites (Horse and Dunkirk R.)									3								
Shipyard Lake																	
McLean Creek																	
Mouth																	
Upstream of mouth (100 m)																	
Mackay River																	
Lower reach (85 km section from bridge to mouth)	MAR-1										1						
Tar River																	
Mouth																	

Table 1.6 (cont'd).

see symbol key at bottom

		1997				1998				1999				2000				2001				2002				2003				2004				2005				2006				2007				2008				2009			
WATERBODY AND LOCATION	**REACH**	W	S	S	F	W	S	S	F	W	S	S	F	W	S	S	F	W	S	S	F	W	S	S	F	W	S	S	F	W	S	S	F	W	S	S	F	W	S	S	F	W	S	S	F	W	S	S	F	W	S	S	F
Ells River																																																					
Upper and lower Ells River[h]													1,3																																						
Poplar Creek																																																					
Gregoire River - OPTI (non core program)																																																					

Legend

1 = fish inventory
2 = radiotelemetry; 1997-1998 walleye, lake whitefish (Athabasca River)
2000-2001 longnose sucker, northern pike, Arctic grayling (Athabasca River and Muskeg River)
3 = sentinel fish monitoring; 1998: longnose sucker (Athabasca River)
1999-2009: trout-perch, longnose sucker (Atha. River); slimy sculpin (Muskeg, Steepbank)
4 = fish fence: aluminum counting fence (large bodied fish); small-mesh fyke nets (small bodied fish)
5 = fish habitat association
6 = fish tissue: walleye and lake whitefish (Athabasca River); northern pike and Arctic grayling (Muskeg River)
7 = winter fish habitat sampling
8 = spawning survey
9 = benthic drift survey
10 = IBI Assessment - Test program
N/A = site unnamed

Footnotes

(a) Reaches include east and west banks
(b) Reference area upstream of Fort McMurray; includes a 22 km section extending 1 km upstream of the Duncan Creek Confluence downstream to Iron Point
(c) Reference area upstream of Fort McMurray. It was investigated as a potential reference area for longnose sucker sentinel species monitoring but found to be inadequate due to habitat differences and concerns about longnose sucker mobility.
(d) Radiotelemetry region includes the area 60 km upstream of Fort McMurray to 250 km downstream of Fort McMurray.
(e) small bodied fish inventory done by fish fence (fyke net) to record fish movements in and out of watercourse. Needs to be done prior to Kearl Project.
(f) Located from 3 to 11 km upstream of the confluence with the Athabasca River.
(g) Reference site located approximately 21 km upstream of confluence with Athabasca River; sampling done by Environment Canada, NWRI, Burlington, Ontario
(h) The Ells River was evaluated as a potential reference site for sentinel species (slimy sculpin) monitoring on the Muskeg and Steepbank Rivers.
Several sites were sampled but no slimy sculpin were captured. Hence, the site was determined not to be suitable as a reference site for this species.

1.2.5 Wetlands Aquatic Vegetation

Wetlands are an important component of the boreal aquatic ecosystem because they filter out sediment and pollutants from water, recharge the water table, reduce soil erosion of downstream waterbodies and provide food and important habitat for aquatic and terrestrial biota. Accordingly, RAMP monitors select wetlands, such as Shipyard Lake, Isadore's Lake and Kearl Lake, located in close proximity to existing and planned oil sands developments, to assess the health of these systems over time. These wetlands are also representative of the aquatic vegetation communities found within the RAMP study area

The monitoring approach focuses on evaluating the integrity of aquatic vegetation communities and supporting water quality parameters. The objectives of the program are to detect and measure the temporal and spatial change in health and distribution of the various types of aquatic vegetation communities. Changes in aquatic vegetation reflect the overall health of a wetland, as well as influences the use of a wetland by benthic invertebrates, fishes, birds and wildlife.

Monitoring includes field surveys every three years to characterize the variability in wetland community types (e.g., submergent/emergent macrophyte species occurrence, percent cover, vigour) represented in the selected wetlands (Table 1.7). In years when field sampling is not scheduled, aerial photographs are used to document changes vegetation distribution from year to year.

Originally, comparable reference wetlands were to be identified to facilitate the evaluation of Kearl, Shipyard and Isadore's lakes. However, few reference lakes are available in the study area and those identified as possible candidates were in areas potentially affected by industry in the near future. It was concluded that the successful selection of reference lakes was unlikely.

1.2.6 Acid Sensitive Lakes

The Regional Sustainable Development Strategy (RSDS) for the Athabasca oil sands area (AENV 1999) identified the importance of protecting the quality of water, air and land within the region. The effects of acid deposition on sensitive receptors were identified in the RSDS as a regional issue and actions taken were designed to support the goal of conserving acid-sensitive soils, rivers, lakes, wetlands and associated vegetation complexes under the cumulative impact of deposition of acidifying materials. The RSDS called for the collection of information on this issue through the continued, long-term monitoring of regional receptors of acidifying emissions under TEEM (Terrestrial Environmental Effects Monitoring Committee) for terrestrial receptors and RAMP for aquatic receptors.

Table 1.7 RAMP wetland aquatic vegetation monitoring program (1997 to 2009).

see symbol key at bottom

WATERBODY AND LOCATION	STATION	1997 W S S F	1998 W S S F	1999 W S S F	2000 W S S F	2001 W S S F	2002 W S S F	2003 W S S F	2004 W S S F	2005 W S S F	2006 W S S F	2007 W S S F	2008 W S S F	2009 W S S F
Kearl Lake														
Vegetation	KEL-1	1,2	1,2		1	2	1	1,2	2	1	1	2	1	1
Isadore's Lake														
Vegetation	ISL-1	1,2	1,2		1	2	1	1,2	2	1	1	2	1	1
Shipyard Lake														
Vegetation	SHL-1	1,2	1,2		1	2	1	1,2	2	1	1	2	1	1
McClelland Lake														
Vegetation	MCL-1				1		1		2	1	1	2	1	1
Reference Wetlands														
Lease 25 Wetlands[(a)]	L25W-1	1,2												
Spruce Pond[(a)]	SPP-1		1,2											
Reference Wetlands (to be determined)	REF-1						1	X 1,2	2	1	1	2	1	1
Reference Wetlands (to be determined)	REF-2						1	X 1,2	2	1	1	2	1	1

Legend

1 = vegetation (air photograph interpretation)

2 = vegetation (field sampling)

X = determination of reference wetlands

N/A = site unnamed

Footnotes

[(a)] Lease 25 Wetland is located within the Athabasca River floodplain north of the Steepbank River. It was evaluated as a potential reference wetland and found to be unsuitable.

[(b)] Spruce Pond is a wetland located 20 km northwest of Fort McMurray that was evaluated as a potential reference wetland. It was found to be unsuitable as a reference wetland.
for RAMP as it has neither the community types found in riparian wetlands (Isadore's and Shipyard Lakes) or the upland wetland (Kearl Lake).

Table 1.8 RAMP acid sensitive lakes monitoring program (1997 to 2009).

see symbol key at bottom

WATERBODY AND LOCATION	STATION	1997 W S S F	1998 W S S F	1999 W S S F	2000 W S S F	2001 W S S F	2002 W S S F	2003 W S S F	2004 W S S F	2005 W S S F	2006 W S S F	2007 W S S F	2008 W S S F	2009 W S S F
Acid Sensitive Lakes														
Acid Sensitive Lakes	NA			1	1	1	1	1	1	1	1	1	1	1
ESTIMATED ANNUAL COST														

Legend

1 = water quality parameters

N/A = site unnamed

Consistent with the goals of the RSDS, the acid sensitive lake program (ASL) under RAMP was initiated in 1999 in partnership with Alberta Environment to conduct annual monitoring of water chemistry in regional lakes to determine the long-term effects of acid deposition on these lakes and their catchment basins. The lakes were to be monitored for various chemical and biological parameters that would be capable of indicating long-term trends in acidification including acidity-related parameters, carbon parameters, major ions, nutrients and chlorophyll. In the 2003 ASL program, a total of 50 lakes and ponds were sampled. Selection of lakes was based on the following considerations:

- The locations of the lakes were selected to represent a gradient in acid deposition from both current and anticipated oil sands development;
- For scientific validity, the lake selection included reference lakes in the Caribou Mountains and Canadian Shield that were distant from the sources of acidifying emissions;
- Certain regional lakes, which have been the subject of long-term monitoring by AENV, were included to maintain the continuity of their data and additional information on potential trends;
- The lakes selected for monitoring were to exhibit moderate to high sensitivity to acidification as defined by a total alkalinity less than 400 ueq/L;
- A fall sampling program was implemented to capture a picture of lake water chemistry after conditions have stabilized; and,
- In recent surveys (2002 and 2003), small water bodies (ponds), previously ignored, were included in the program because of their proximity to oil sands development and belief that they might be low in alkalinity and hence highly sensitive to acid deposition.

The assessment includes the calculation of a critical load of acidity for each lake and comparing it to levels of predicted Potential Acidic Input (PAI) from developments such as oil sands operations (e.g., emissions of sulphur dioxide, oxides of nitrogen). The critical load is defined as the highest load of acid deposition that will not cause long-term changes in lake chemistry and biology. Exceedances of the critical load by the PAI in a lake imply a potential for acidification.

Lakes in the RAMP study area are generally highly coloured due to concentrations of organic acids. These acids may play a significant role in the acid-base dynamics of the lakes. In 2003, detailed analyses were conducted to establish the buffering or acid neutralizing capacity attributable to weak organic acids and the role of strong organic acids in lowering the acid neutralizing capacity in the RAMP lakes.

The long-term monitoring plan for ASL component calls for continued monitoring of the lakes within the oil sands region for the routine water quality parameters (Table 1.8). Refinement of the program is ongoing and issues related to seasonality in water quality, effects of spring acid pulse, identifying appropriate measurement end-points and understanding cause-effect relationships may induce changes in the ASL program, although some may be addressed by other organizations such as CONRAD or CEMA.

1.2.7 Defining Baseline vs. Operational Monitoring Stations

As RAMP continues over time, the definition of specific monitoring stations will change from baseline to operational monitoring status. An effort has been made to collect at least 3 years of baseline data at stations prior to land disturbance related to mine development. Although it is recognized that many potential impacts related to oil sands developments will occur in the future, stations near existing operations or where land disturbance has occurred, have been designated as operational monitoring stations (i.e., conservative approach).

Table 1.9 summarizes the date of first disturbance (as of 2003) at oil sands projects within the RAMP Focus Study Area. In addition, Figure 1.5 shows the extent of mine development for projects in operation as of 2002. Based on this information, as well project-specific information from individual operators, Table 1.10 identifies which monitoring stations are considered baseline versus operational for the 2003 program. This information is most relevant for components such as climate and hydrology, water and sediment quality and benthic invertebrates that incorporate a large number of sampling stations upstream and downstream of individual oil sands operations. For the acid sensitive lakes component, lakes were selected a priori to represent a gradient in acid deposition from both current and anticipated oil sands developments. Lake selection included reference lakes in the Caribou Mountains and Canadian Shield that were distant from the sources of acidifying emissions.

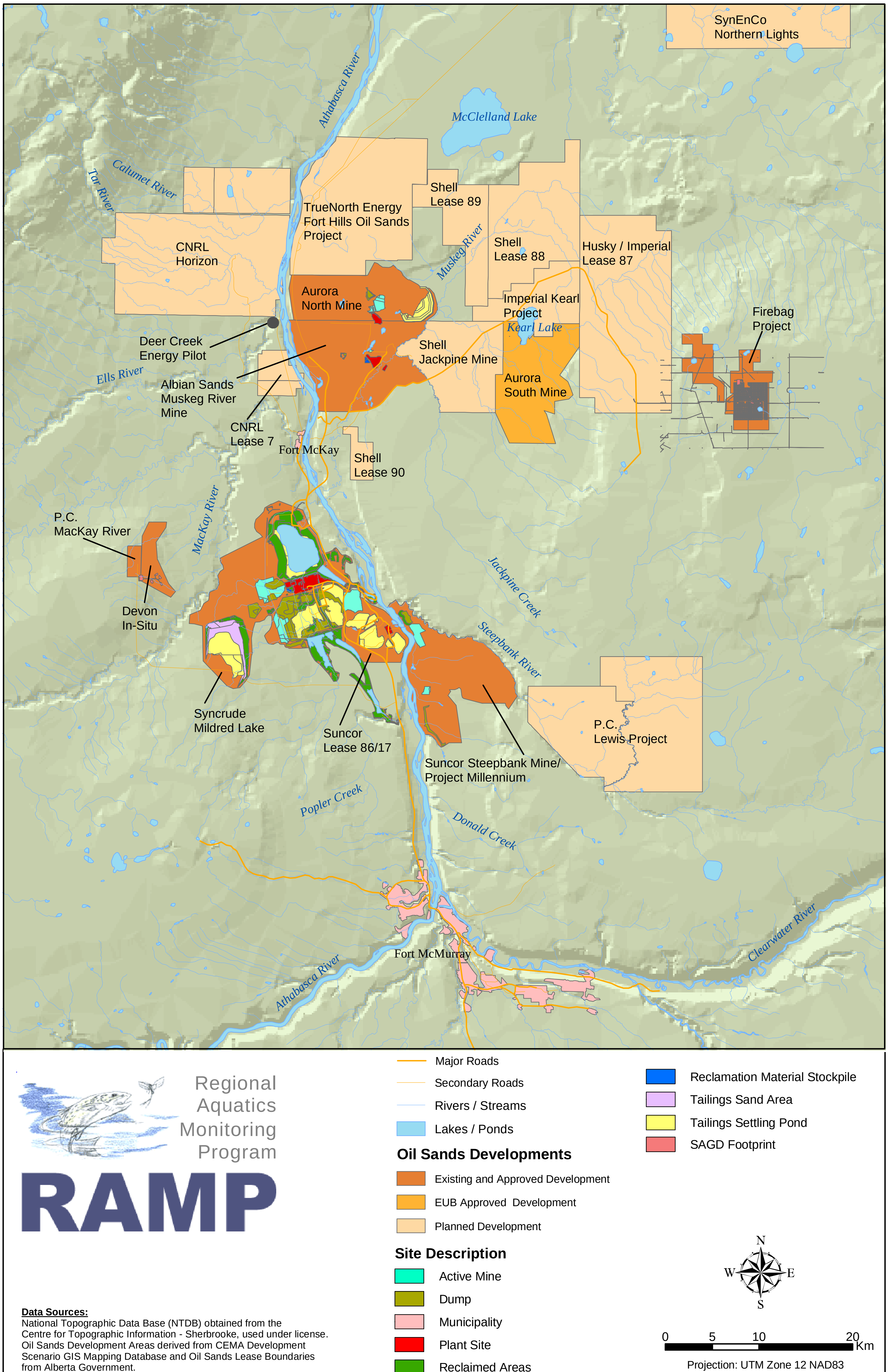
1.3 SUMMARY

The Regional Aquatics Monitoring Program (RAMP) is a long-term, multi-disciplinary environmental monitoring program initiated in 1997. During this time, the scale and scope of the program has expanded significantly in response to increasing development (existing and planned) in the Athabasca oil sands region of northern Alberta. The program incorporates stressor-based and effects-based monitoring approaches to: 1) document natural variability in chemical, physical and biological characteristics of waterbodies in the region; and 2) identify long-term trends, regional issues and potential cumulative effects related to oil sands development. To facilitate this process, RAMP focuses on key components of the regional aquatic ecosystem including climate and hydrology, water/sediment quality, benthic invertebrate communities, fish populations, wetland vegetation and acid sensitive lakes.

In 2003, most monitoring stations were surveyed to increase our understanding of baseline conditions of specific waterbodies in the region. However, some stations were located near existing mining operations and provided initial data required to evaluate the potential for these developments to influence aquatic receiving environments over time. As development progresses in the region, the focus of RAMP will naturally shift from a baseline to an operational/impact monitoring program.

The following chapters provide the results of the 2003 technical monitoring program developed by the RAMP Technical Subcommittee and implemented by the Hatfield RAMP Team.

Figure 1.5 Extent of Mine Development for Oil Sands Projects in Operation as of 2002.



Data Sources:
National Topographic Data Base (NTDB) obtained from the Centre for Topographic Information - Sherbrooke, used under license.
Oil Sands Development Areas derived from CEMA Development Scenario GIS Mapping Database and Oil Sands Lease Boundaries from Alberta Government.

G:\Data\Projects\RAMP1069\GIS\Fig1-5_ExtentMineDev.mxd
12 February 2004

Table 1.9 Current status of oil sands developments within RAMP study area (as of 2003).

Oil Sands Development	Type of Operation	Date of Application	Date of First Disturbance
Suncor Energy Inc.			
Lease 86/17	open-pit	1964	1967
Fixed Plant Expansion	processing	1996	existing area
Steepbank Mine	open-pit	1996	1997
Millennium Mine	open-pit	1998	2000
Firebag Pilot Project	in-situ	2000	2000
Firebag Project	in-situ	2000	2002
South Tailings Pond	tailings pond	2003	2005
NorthSteepbank Mine	open-pit	2004	2007
Syncrude Canada Ltd.			
Mildred Lake	open-pit	1973	1973
Upgrader/Expansion	processing	1998	existing area
North Mine	open-pit	1995	1996
Aurora North	open-pit	1996	1996
Aurora South	open-pit	1995	2007-2008
Albian Sands Energy Inc.			
Muskeg River Mine	open-pit	1997	2000
Shell Canada Limited			
Jackpine Mine	open-pit	2002	Winter 2004/2005
Muskeg River Mine Expansion	open-pit	2004	Unknown
Lease 88/89	open-pit	Unknown	Unknown
Canadian Natural Resources Ltd. (CNRL)			
Horizon Project	open-pit	2002	2004
Imperial Oil/ExxonMobil Ltd.			
Kearl Mine Project	open-pit	2004	Unknown
Petro-Canada Oil and Gas			
MacKay River	in-situ	1998	2002
Meadow Creek	in-situ	2001	Unknown
Lewis Project	in-situ	unknown	Unknown

Table 1.9 (cont'd).

Oil Sands Development	Type of Operation	Date of Application	Date of First Disturbance
Opti Canada Ltd. /Nexen Canada Ltd.			
Long Lake Project	in-situ	2000	Unknown
Devon Energy Canada Ltd.			
Dover	in-situ	Unknown	Unknown
Non-RAMP Members:			
EnCana			
Christina Lake	in-situ	1998	2000
TrueNorth Energy			
Fort Hills	open-pit	2001	Unknown
Conoco			
Surmont Pilot	in-situ	1996	1996
Surmont	in-situ	2001	Unknown
JACOS			
Hangingstone Pilot	in-situ	1997	1998
Hangingstone	in-situ	Unknown	Unknown
Deer Creek Energy			
Deer Creek Pilot	in-situ	2000	Unknown
Phase II	in-situ	Unknown	Unknown

Table 1.10 Baseline versus operational monitoring stations for the 2003 RAMP.

Waterbody and Location	Water/ Sediment Quality Code	Benthos Code	Hydrology Code	Fisheries Code	Vegetation Code	Monitoring Status
Athabasca River						
Upstream of Fort McMurray	ATR-UFM			Site 1		baseline
Upstream Donald Creek	ATR-DC			0/1		baseline
Upstream of the Steepbank River	ATR-SR			Site 2, 4/5/6		baseline
Downstream of Suncor/Syncrude				Site 3		operational
Upstream of the Muskeg River	ATR-MR			10/11/12		operational
Downstream of Muskeg River				Site 4		operational
Tar-Ells River area				16/17		operational
Upstream Fort Creek	ATR-FC					operational
Downstream of all development	ATR-DD		S24			operational
Upstream of mouth of Firebag River	ATR-FR					operational
Downstream of Firebag River				Site 5		operational
Upstream of the Embarras River	ATR-ER					operational
At Old Fort	ATR-OF					operational
Athabasca River Delta						
Big Point Channel	ARD-1	BPC-1 to 10				operational
Goose Island Channel	GIC	GIC-1 to 10				operational
Fletcher Channel	FLC	FLC-1 to 10				operational
Flour Bay	FLB-1					operational
Athabasca River Tributaries (South of Fort McMurray)						
Clearwater River (upstream of Fort McMurray)	CLR-1					baseline
(upstream of Christina River)	CLR-2					baseline
Christina River (upstream of Fort McMurray)	CHR-1	CHR-D-1 to 15				baseline
(upstream of Janvier)	CHR-2	CHR-D-16 to 30	S29			baseline
Horse River				HR-R		baseline
Hangingstone River (upstream of Ft. McMurray)	HAR-1	HSR-E	S30			baseline
Hangingstone Creek			S31			NS
Surmont Creek			S32			NS

Table 1.10 (cont'd).

Waterbody and Location	Water/ Sediment Quality Code	Benthos Code	Hydrology Code	Fisheries Code	Vegetation Code	Monitoring Status
Athabasca River Tributaries (North of Fort McMurray)						
McLean Creek (mouth)	MCC-1					operational
(100 m upstream)	MCC-2					operational
Poplar Creek (mouth)	POC-1					baseline
(at Hwy 63)			S11			baseline
Steepbank River (mouth)	STR-1	STR-E1		SR-E		operational
(upstream of Project Millennium)	STR-2			SR-R		baseline
(upstream of Nt. Steepbank)	STR-3	STR-E2				baseline
North Steepbank River (upstream of P.C. Lewis)	NSR-1					baseline
Beaver River (mouth)	BER-1					operational
MacKay River (mouth)	MAR-1	MAC-E-1 to 15		MAR-1		operational
(upstream of P.C. MacKay)	MAR-2	MAC-E-16 to 30				baseline
(WSC station)			S26			baseline
Dunkirk River (fish)				DR-R		baseline
Ells River (mouth)	ELR-1	ELR-D-1 to 15				baseline
(upstream of Joslyn Ck)			S14			baseline
(upstream of CNRL Lease 7)	ELR-2	ELR-E-1 to 15				baseline
Tar River (mouth)	TAR-1	TAR-D-1 to 15	S15			baseline
(lowland Tar)			S19			baseline
(upstream of CNRL Horizon)	TAR-2	TAR-E-1 to 15	S17			baseline
Mills Creek at Hwy 63			S6			baseline
Fort Creek (mouth)	FOC-1	FOC-D-1 to 5				baseline
(at Hwy 63)			S12			NS
Susan Lake Outlet			S25			NS
Firebag River (mouth)	FIR-1	FIR-D-1 to 15				baseline
(upstream of Suncor Firebag)	FIR-2	FIR-E-1 to 15				baseline
(WSC station)			S27			NS
Calumet River (mouth)	CAR-1	CAL-D-1 to 15	S16			baseline
(upper reach)		CAL-D-16 to 20	S18			baseline
Embarras River	EMR-1					operational

Table 1.10 (cont'd).

Waterbody and Location	Water/ Sediment Quality Code	Benthos Code	Hydrology Code	Fisheries Code	Vegetation Code	Monitoring Status
Muskeg River						
Mouth	MUR-1	MUR-E-1 to 15				operational
1 km upstream of mouth	MUR-1b			MR-E		operational
At WSC station			S7			operational
Upstream of Canterra Road Crossing	MUR-2	MUR-D-1 to 15				operational
Downstream of Alsands Drain	MUR-3					operational
Upstream of Jackpine Creek	MUR-4					operational
Upstream of Muskeg Creek	MUR-5		S5a			baseline
Upstream of Stanley Creek	MUR-D2	MUR-D-16 to 30	S5			baseline
Upstream of Wapasu Creek	MUR-6		S20			baseline
Muskeg River Tributaries						
Alsands Drain (mouth)	ALD-1		S1			NS
Albian Polishing Pond #3			S13			NS
Aurora Boundary Weir			S23			NS
Jackpine Creek (mouth)	JAC-1	JAC-D-1 to 15	S2			baseline
(upper reach)		JAC-D-16 to 30				baseline
Shelley Creek (mouth)	SHC-1		S21			baseline
Muskeg Creek (mouth)	MUC-1		S22			baseline
Blackfly Creek above Muskeg Creek			S4			NS
Khahago Creek below Blackfly Creek			S28			baseline
Stanley Creek (mouth)	STC-1		S8			operational
Wapasu Creek (Canterra Road Crossing)	WAC-1		S10			baseline
Kearl Lake Outlet			S9			baseline
Iyinimin Creek above Kearl Lake			S3			baseline
Wetlands						
Kearl Lake	KEL-1	KEL-1 to 10	L2		KEL-1	baseline
Isadore's Lake	ISL-1		L3		ISL-1	operational
Shipyard Lake	SHL-1	SHL-1 to 10			SHL-1	operational
McClelland Lake	MCL-1	MCL-1 to 10	L1		MCL-1	baseline
Additional Sampling (Non-Core Programs)						
Un-named Creek - north of Ft. Creek (mouth)	UNC-1					baseline
OPTI Lakes	-					baseline

2.0 CLIMATE AND HYDROLOGY

2.1 OVERVIEW OF 2003 PROGRAM

The climate and hydrology monitoring program for 2003 included the following:

- monitoring climate at six stations, including temperature and precipitation at most stations, as well as several other climate parameters at the Aurora Climate Station;

- conducting snow course surveys on the Birch Mountains east slope and in the Fort Hills area;

- monitoring water levels and stream flows and collecting water samples for total suspended solids (TSS) analysis at:

  - 13 stations in the Muskeg River basin;

  - 9 stations on other Athabasca River tributaries;

  - one station on the Athabasca River itself; and

  - one station on the Christina River, south of Fort McMurray.

- monitoring water levels at three wetland stations;

- integrating regional Environment Canada climatic and hydrometric monitoring data into the RAMP database;

- making repairs at several stations, particularly at Ells River where the spring flood destroyed the station; and

- installing two new stations on the Muskeg River.

An overview of the locations of the climate and hydrometric stations and snowcourse survey sites monitored for the RAMP program in 2003 is shown on Figure 2.1.

2.2 METHODS

2.2.1 Monitoring Locations

2.2.1.1 RAMP Stations

Climatic and hydrometric stations operated in 2003 are shown on Figure 2.2 and Figure 2.3, respectively. The operating season and monitoring program at each station are summarized in Table 2.1. Locations of the 2003 snow course survey sites are shown on Figure 2.4.

Table 2.1 RAMP climate and hydrometric stations operating in 2003.

No.	Name	Operating Season	Parameters Measured
C1	Aurora Climate Station	All year	Air temperature, rainfall, humidity, solar radiation, snow on the ground, wind speed and direction
L1	McClelland Lake	All year	Water level
		Open-water	Rainfall
L2	Kearl Lake	All year	Water level
L3	Isadore's Lake	All year	Water level
S2	Jackpine Creek at Canterra Road	Open-water	Level, discharge
S3	Iyinimin Creek above Kearl Lake	Open-water	Level, discharge, rainfall
S5	Muskeg River above Stanley Creek	All year[1]	Level, discharge
S5A	Muskeg River above Muskeg Creek	All year	Level, discharge, barometric pressure
S6	Mills Creek at Highway 63	Open-water	Level, discharge
S7	Muskeg River near Fort McKay (07DA008)	Winter	Level, discharge
S8	Stanley Creek near the Mouth	Open-water	Level
S9	Kearl Lake Outlet	Open-water	Level, discharge
S10	Wapasu Creek at Canterra Road	All-year[2]	Level, discharge
S11	Poplar Creek at Highway 63 (07DA007)	Open-water	Level, discharge
S14	Ells River above Joslyn Creek	Open-water	Level, discharge
S15	Tar River near the Mouth	Open-water	Level, discharge
S16	Calumet River near the Mouth	Open-water	Level, discharge, rainfall, snowfall, air temperature
S17	Tar River Upland Tributary	Open-water	Level, discharge
S18A	Calumet River Upland Tributary	Open-water	Level, discharge

Table 2.1 (cont'd).

No.	Name	Operating Season	Parameters Measured
S19	Tar River Lowland Tributary near the Mouth	Open-water	Level, discharge, rainfall
S20	Muskeg River Upland	Open-water	Level, discharge
S21	Shelley Creek near the Mouth	Open-water	Level, discharge
S22	Muskeg Creek near the Mouth	Open-water	Level, discharge
S24	Athabasca River below Eymundson Creek	All year	Level, discharge
S26	MacKay River near Fort McKay (07DB001)	Winter	Level, discharge
S27	Firebag River near the Mouth (07D6C001)	Winter	Level, discharge
S28	Khahago Creek below Blackfly Creek	Open-water	Level, discharge
S29	Christina River near Chard (07CE002)	Winter	Level, discharge
		Open-water	Rainfall
S33	Muskeg River at the Aurora/Albian Boundary[1]	All year	Level, discharge

Notes: [1] – starting in April-May 2003; [2] – Winter operation began in fall 2003.

2.2.1.2 Environment Canada Stations

Data from regional hydrometric stations operated by the Water Survey of Canada (WSC), and meteorological stations operated by the Meteorological Service of Canada (MSC) were collected for the RAMP program and incorporated into the RAMP database. Locations of both active and discontinued regional climate stations operated by RAMP or MSC are shown on Figure 2.5 for the area north of Fort McMurray, and Figure 2.6 for the area south of Fort McMurray. Similar maps of hydrometric stations are provided on Figure 2.7 (North) and Figure 2.8 (South). Names of the stations are provided in Appendix A2.5.

2.2.1.3 Data Contributed by Oil Sands Operators

As discussed in Section 2.4, it is considered important to include water withdrawal and release information in the RAMP database. Locations of water withdrawal and release points are shown on the catchment status map presented in Section 2.3.4.

2.2.2 Field Methods

2.2.2.1 General

Field staff visited the hydrometric stations routinely to make manual streamflow measurements and to check and maintain automated sensing equipment. Manual streamflow measurements are necessary for the development of a stage-discharge relationship, which is used to convert the continuously recorded water levels to discharge.

Specific field activities at hydrometric stations included the following:

- measuring streamflows to develop stage-discharge rating curves;
- measuring water levels to confirm pressure transducer readings;
- collecting water samples at specified stations for analysis of total suspended solids;
- downloading dataloggers; and
- performing routine maintenance and any required repairs.

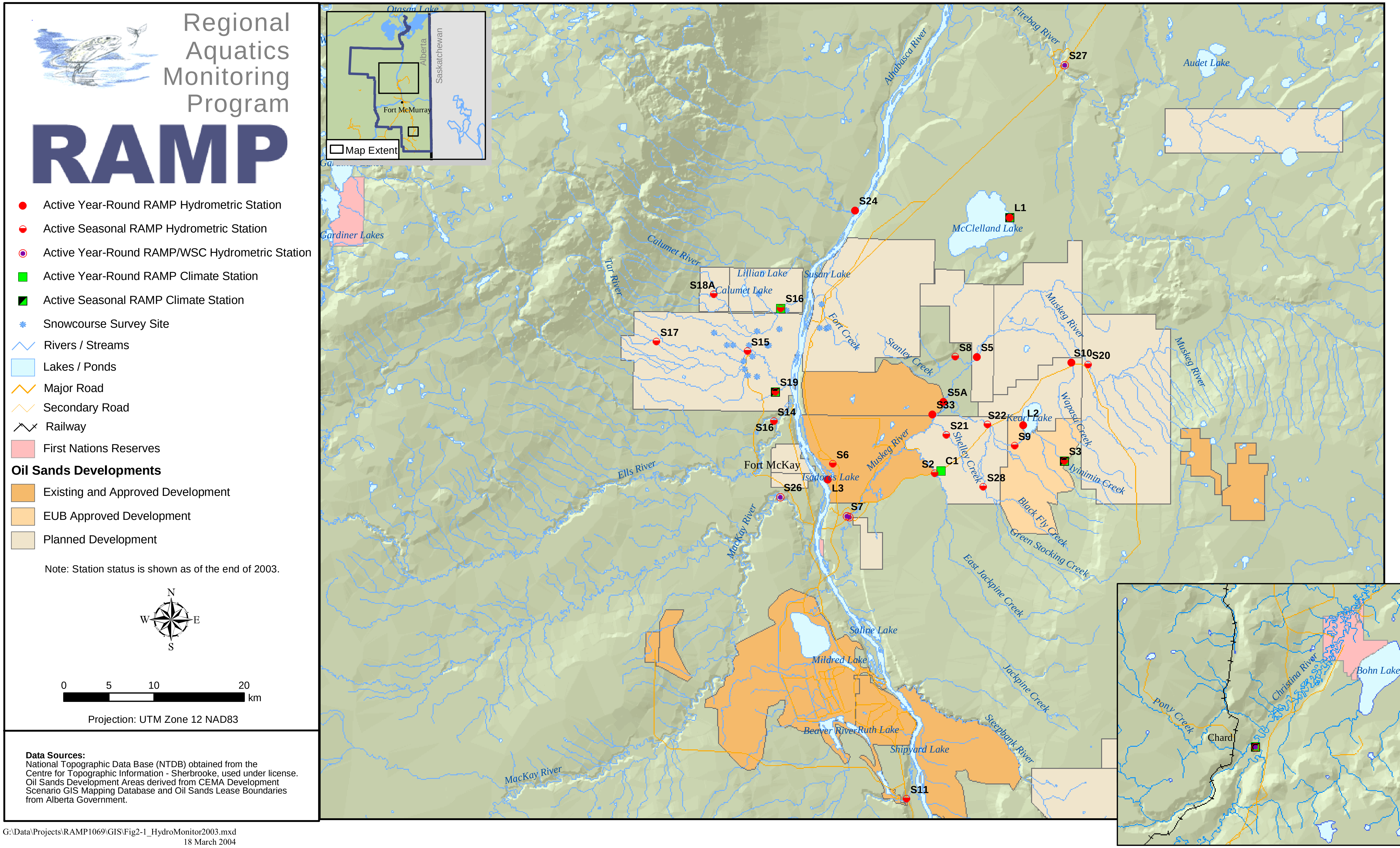
2.2.2.2 Streamflow Measurement

Streamflow measurement procedures and standards are based on recommendations by the Water Survey of Canada (Davis, pers. comm.), the United States Geological Survey (1982), the BC Ministry of Environment, Lands and Parks (1998), and the Water Survey of Canada (2001). Measurements were made by wading or from a bridge or a boat. Measurement standards are summarized briefly below.

- Number of verticals: 20, or at a spacing of 0.1 m in small streams.
- Number of readings in the vertical: one at 60% of the depth below the surface for depths of 1.1 m or less; otherwise one at 20% and one at 80% of the depth. For measurements under ice, two readings at 20% and 80% of the depth for water depths greater than 1 m.
- Velocity averaging: At least 20 seconds for electromagnetic meters; 45 seconds for mechanical meters.

Details of the measurement procedures used for the RAMP project are provided in Appendix A2.7.

Figure 2.1 2003 Hydrologic Monitoring.

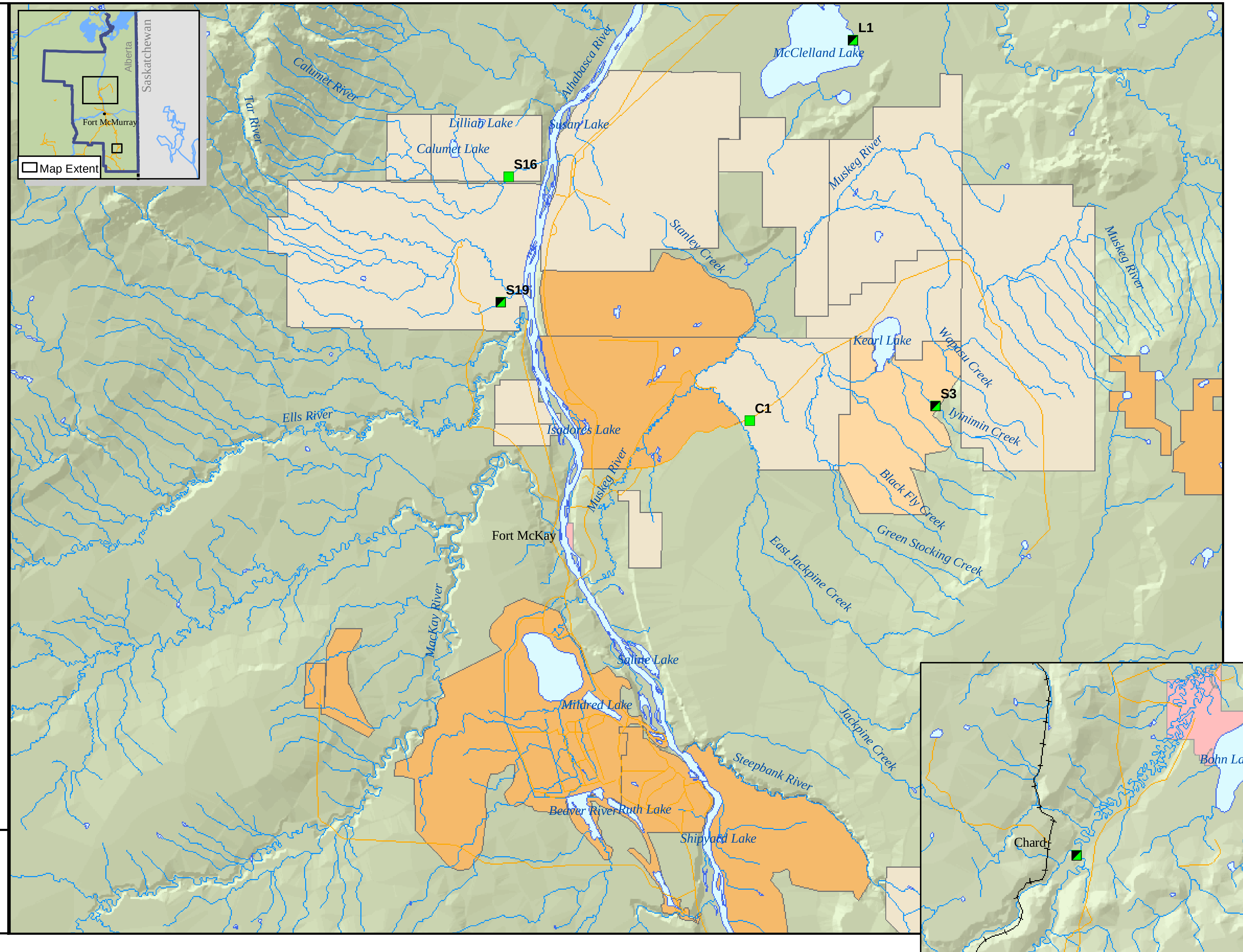


G:\Data\Projects\RAMP1069\GIS\Fig2-1_HydroMonitor2003.mxd
18 March 2004

Figure 2.2 RAMP Climate Monitoring 2003.

Regional Aquatics Monitoring Program

RAMP



Active Year-Round RAMP Climate Station

Active Seasonal RAMP Climate Station

Rivers / Streams

Lakes / Ponds

Major Road

Secondary Road

Railway

First Nations Reserves

Oil Sands Developments

Existing and Approved Development

EUB Approved Development

Planned Development

Note: Station status is shown as of the end of 2003.

N W E S

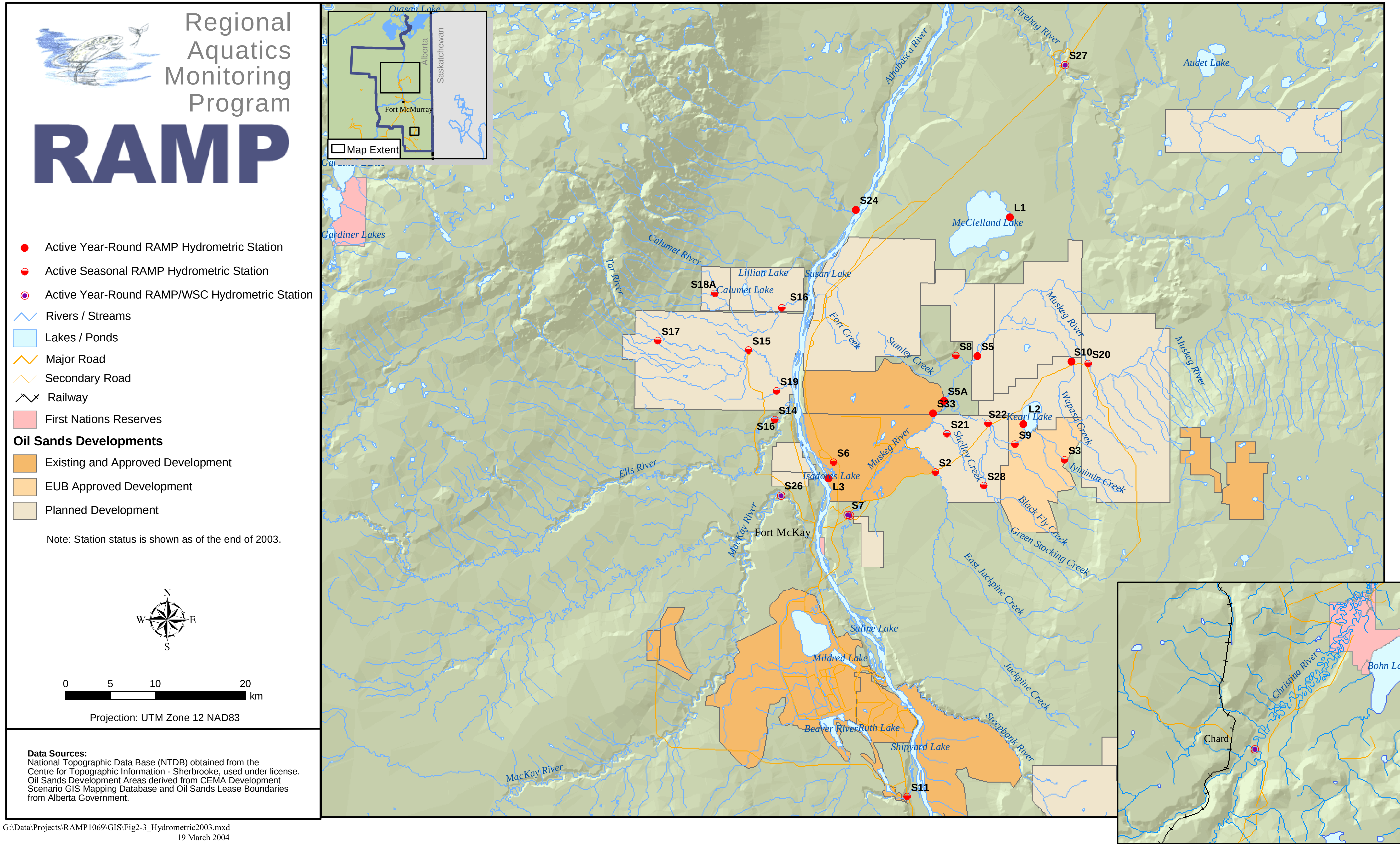
0 5 10 20 km

Projection: UTM Zone 12 NAD83

Data Sources:
National Topographic Data Base (NTDB) obtained from the Centre for Topographic Information - Sherbrooke, used under license. Oil Sands Development Areas derived from CEMA Development Scenario GIS Mapping Database and Oil Sands Lease Boundaries from Alberta Government.

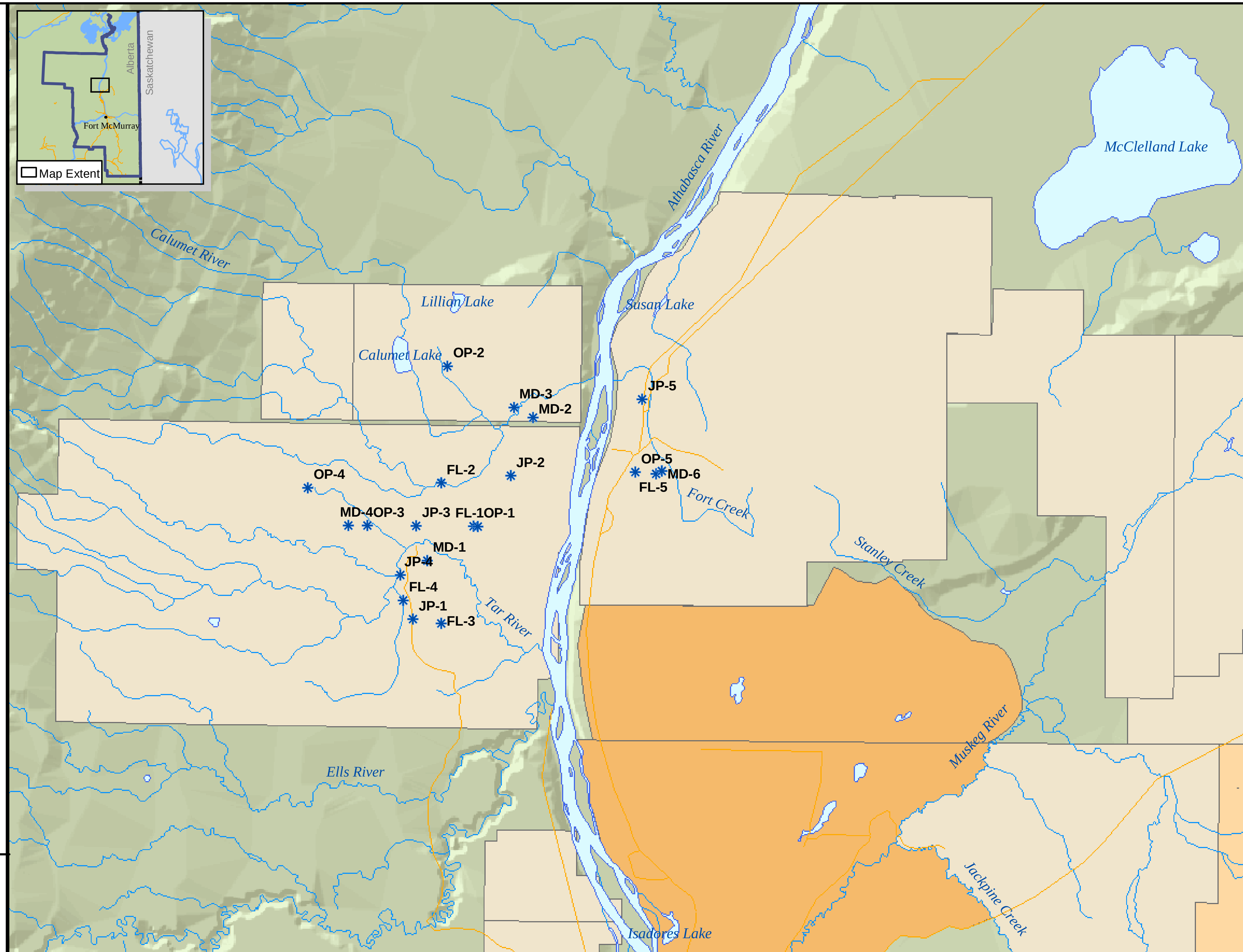
G:\Data\Projects\RAMP1069\GIS\Fig2-2_Climate2003.mxd
19 March 2004

Figure 2.3 RAMP Hydrometric Monitoring 2003.



G:\Data\Projects\RAMP1069\GIS\Fig2-3_Hydrometric2003.mxd
19 March 2004

Figure 2.4 Snowcourse Surveys 2003.



Regional Aquatics Monitoring Program

RAMP

Snowcourse Survey Site
Rivers / Streams
Lakes / Ponds
Major Road
Secondary Road

Oil Sands Developments

Existing and Approved Development
EUB Approved Development
Planned Development

N
W E
S

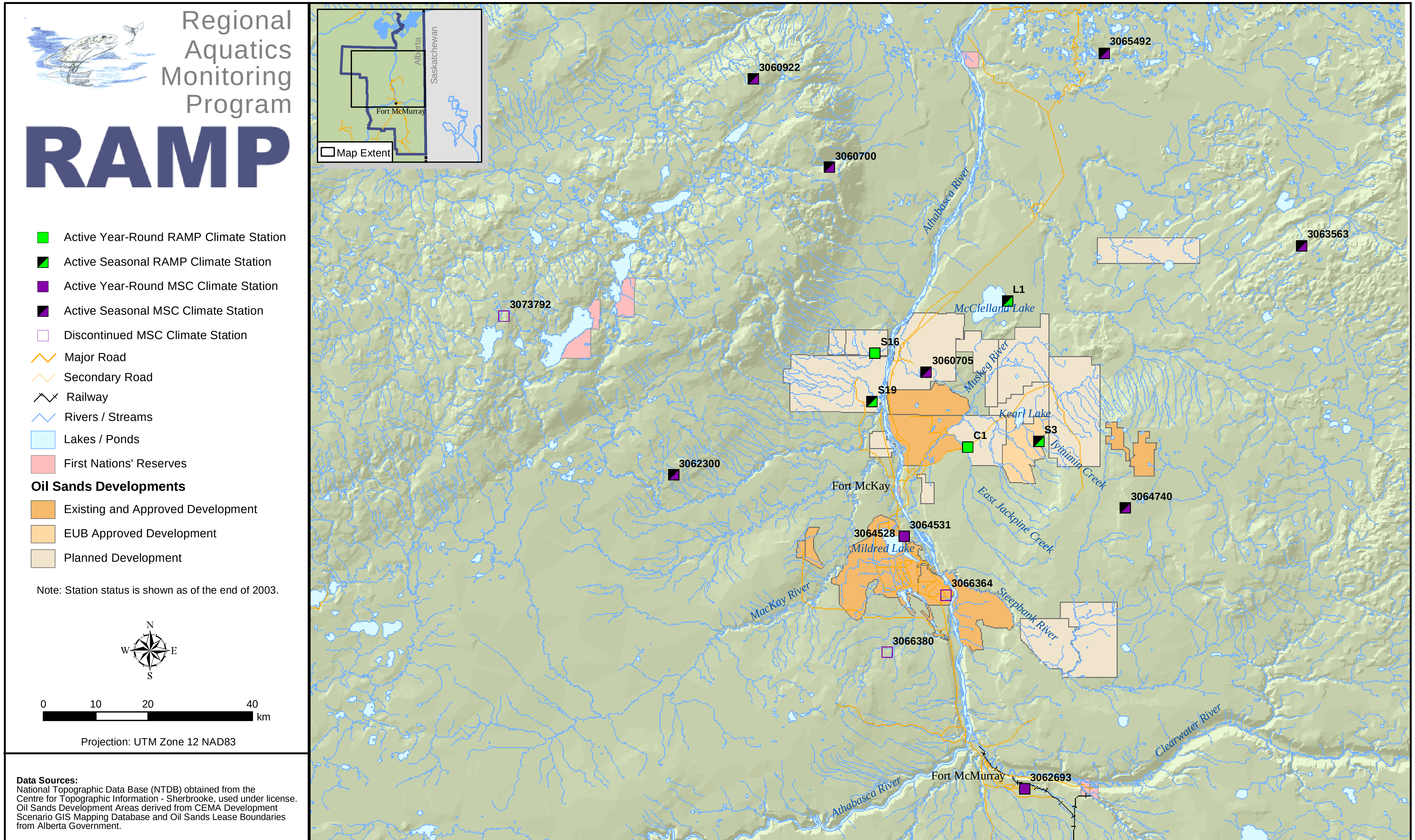
0 2.5 5 10
km

Projection: UTM Zone 12 NAD83

Data Sources:
National Topographic Data Base (NTDB) obtained from the Centre for Topographic Information - Sherbrooke, used under license. Oil Sands Development Areas derived from CEMA Development Scenario GIS Mapping Database and Oil Sands Lease Boundaries from Alberta Government.

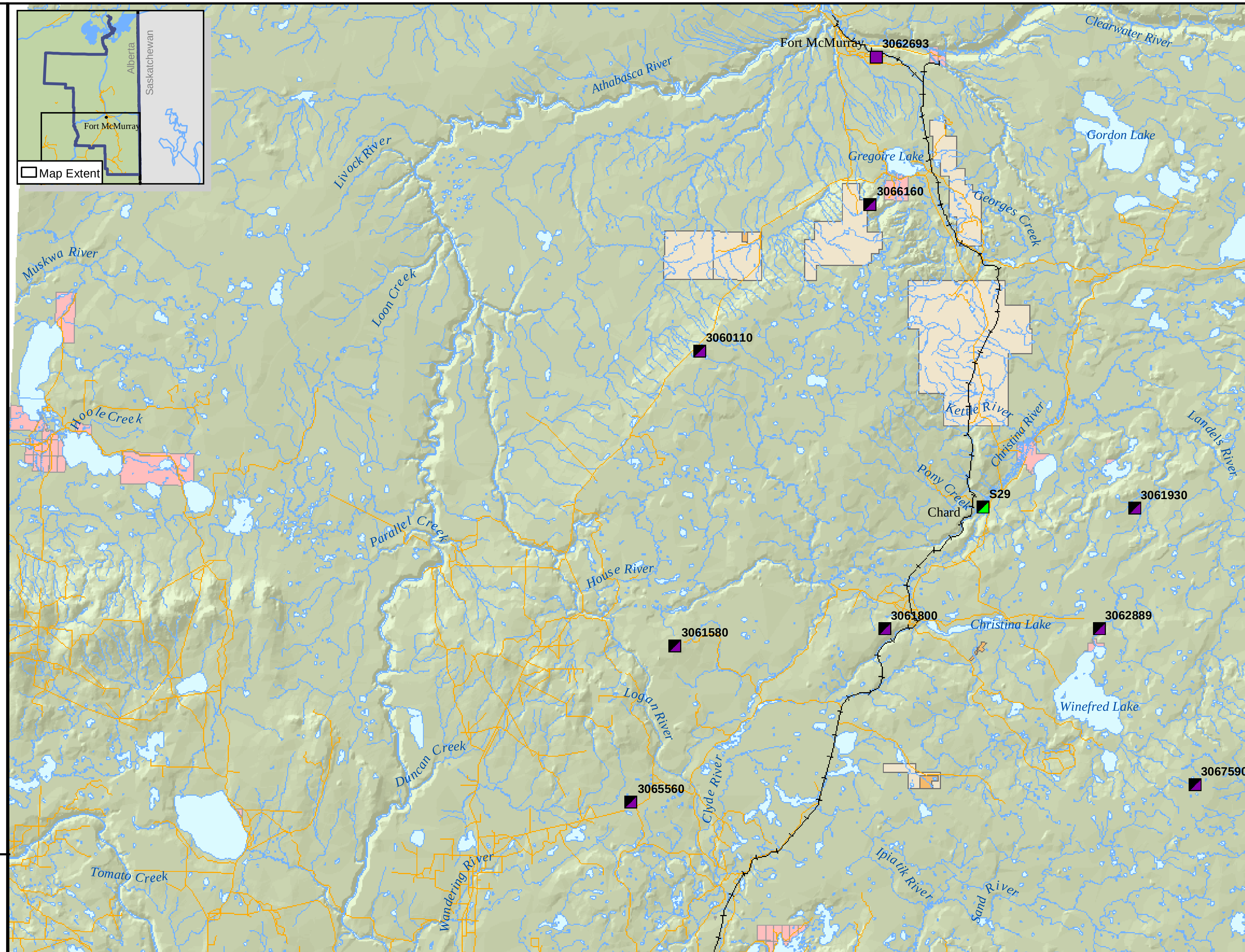
G:\Data\Projects\RAMP1069\GIS\Fig2-4_Snowcourse2003.mxd
18 March 2004

Figure 2.5 Regional Climate Monitoring North of Fort McMurray.



G:\Data\Projects\RAMP1069\GIS\Fig2-5_RegClimateMonitor-N.mxd
18 March 2004

Figure 2.6 Regional Climate Monitoring South of Fort McMurray.



Regional Aquatics Monitoring Program

RAMP

- Active Seasonal RAMP Climate Station
- Active Year-Round MSC Climate Station
- Active Seasonal MSC Climate Station
- Major Road
- Secondary Road
- Railway
- Rivers / Streams
- Lakes / Ponds
- First Nations' Reserves

Oil Sands Developments

- Existing and Approved Development
- EUB Approved Development
- Planned Development

Note: Station status is shown as of the end of 2003.

N W E S

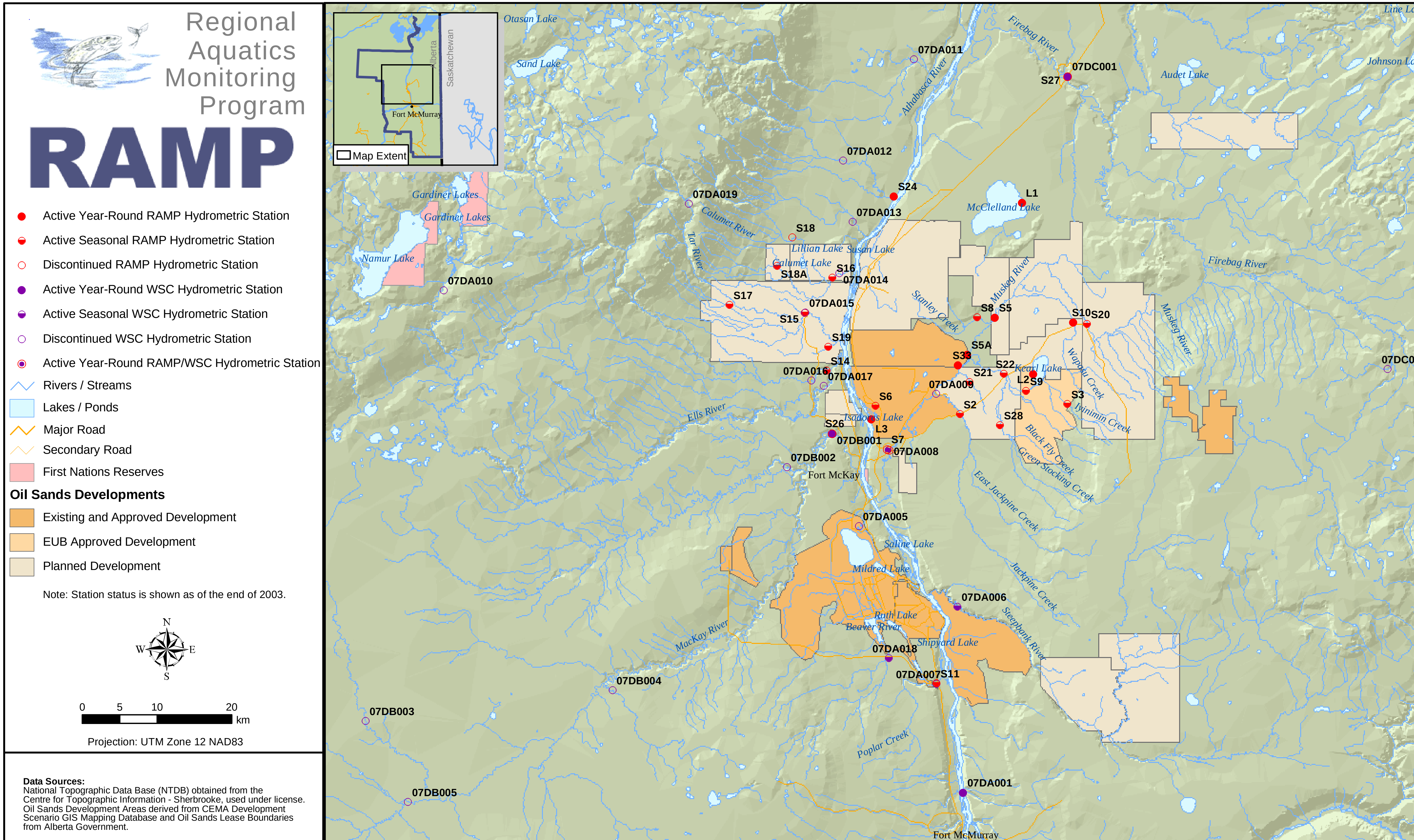
0 10 20 40 km

Projection: UTM Zone 12 NAD83

Data Sources:
National Topographic Data Base (NTDB) obtained from the Centre for Topographic Information - Sherbrooke, used under license. Oil Sands Development Areas derived from CEMA Development Scenario GIS Mapping Database and Oil Sands Lease Boundaries from Alberta Government.

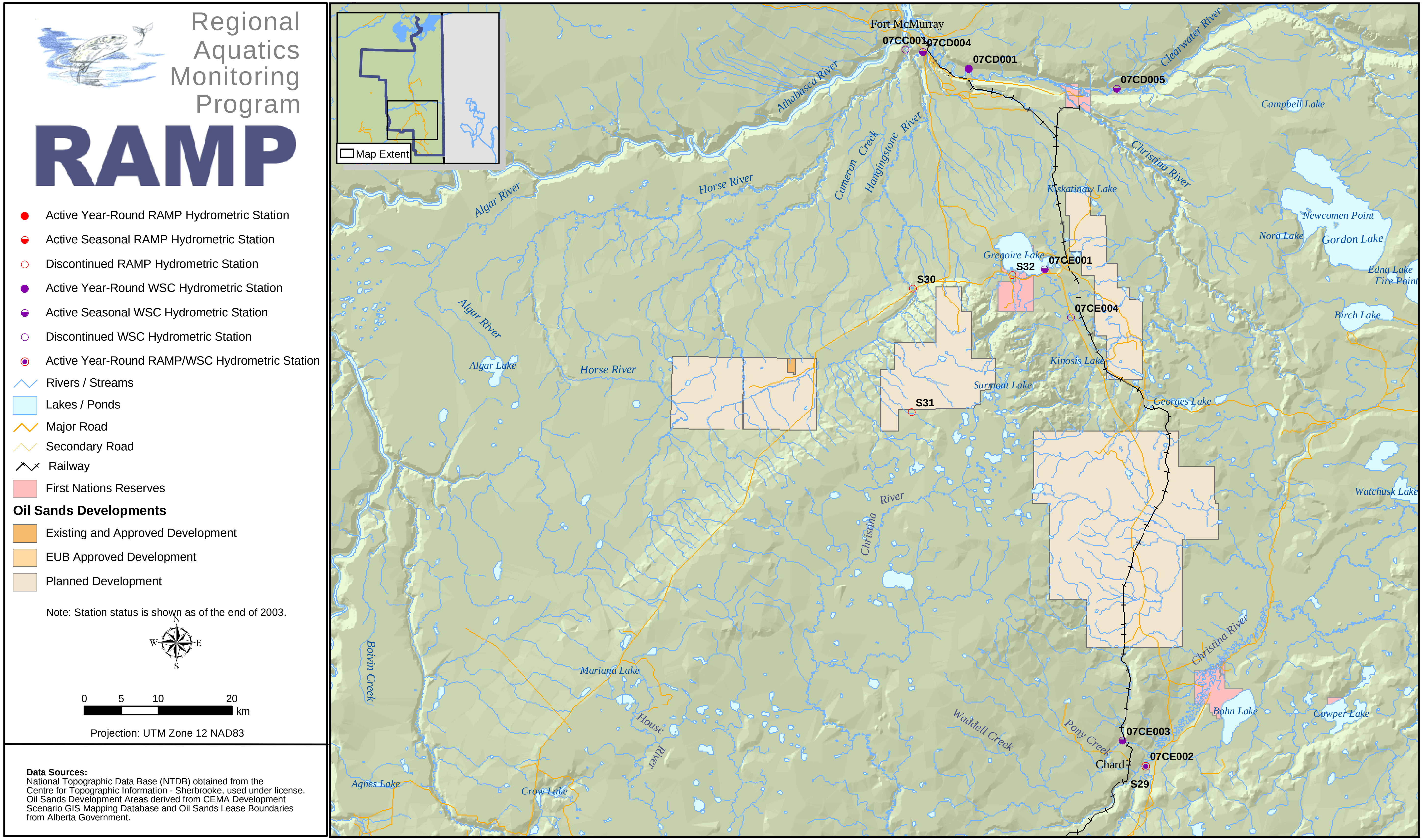
G:\Data\Projects\RAMP1069\GIS\Fig2-6_RegClimateMonitor-S.mxd
18 March 2004

Figure 2.7 Regional Hydrometric Monitoring North of Fort McMurray.



G:\Data\Projects\RAMP1069\GIS\Fig2-7_RegioHydroMonitor-N.mxd
17 March 2004

Figure 2.8 Regional Hydrometric Monitoring South of Fort McMurray.



G:\Data\Projects\RAMP1069\GIS\Fig2-8_RegioHydroMonitor-S.mxd
18 March 2004

2.2.2.3 Snow Course Surveys

Snow course surveys provide an indication of the variation in snow accumulation on various terrain types in the study area. This information can be used to estimate the total snow water available for melt in a given catchment, to provide an indication of spring runoff potential or for use in hydrologic modeling.

The 2003 program included snow surveys in the Fort Hills area and on the east slopes of the Birch Mountains. Snow surveys were conducted March 14 – 19, 2003, in an effort to measure the maximum snowpack before the spring melt began.

At each snow course site, a sampling site was established and snow depths were measured at 30 to 50 locations on a 10 m grid. At least four samples were taken for density measurements using an Adirondack snow density gauge. Snow depth and the sample mass were recorded for each density sample to allow calculation of the snow water equivalent and snow density.

2.2.3 Continuous Monitoring

Automated equipment is used to collect data at RAMP climate and hydrometric stations at intervals ranging from 15 minutes to one hour, essentially providing a continuous record. Water depths are measured using submerged pressure transducers.

The data are downloaded locally during each site visit, or in some cases remotely using a cell modem connection. Data were checked during or immediately after downloading to identify any problems at the site.

2.2.4 Data Analyses

2.2.4.1 Water Level Data

The results of the water level surveys carried out during each visit were used to plot the apparent pressure transducer elevation against time to detect any physical movement or sensor calibration drift. The elevation plot was used to convert the recorded water depths to assumed or geodetic elevations.

2.2.4.2 Streamflow Data

The results of the manual streamflow measurements were plotted to develop or refine the stage-discharge rating curve for each station, and to identify any shifts in the rating curve due to changes in the stream geometry or downstream obstructions such as beaver dams.

For each streamflow monitoring station, one or more rating curves were defined, along with the period of record over which each curve was applicable.

During each streamflow measurement, the water surface elevation was surveyed relative to a fixed benchmark. The survey results were used to compute the apparent transducer elevation as the water level minus the transducer reading. Transducer elevations were plotted against time to identify physical sensor movement or sensor drift.

The short time interval (15 minute to 1 hour) water levels collected at each streamflow monitoring station were converted to elevation considering any changes in transducer elevation.

During open-water periods, the short time interval elevations were converted to discharge by applying the appropriate stage-discharge rating curve. The water level and discharge data were then reduced to mean daily values for tabulation and plotting.

Winter discharges were computed from water levels using a simplified version of the backwater method, one of seven methods used by Water Survey of Canada. The backwater caused by the ice cover was computed for each manual streamflow measurement. It was assumed that the ice backwater depth varied linearly between measurements. The effective stage corresponding to each (15-minute) water level record was computed by deducting the backwater depth from the measured water level. The open-water rating curve was used to convert the effective stage to discharge, and the results were averaged to obtain mean daily discharge.

This method of handling winter discharges represents a change from the previous RAMP methodology, in which attempts were made to define a single ice-affected rating curve for each station as a function of an "effective stage" measured at the bottom of the ice cover. The backwater method is considered to reflect more accurately the time-varying nature of the effect of ice on the stage-discharge relationship.

2.2.5 Changes from the 2002 Program

2.2.5.1 Stations Removed

A number of stations that were part of the 2002 program were discontinued at the end of 2002. Three stations were discontinued due to the deferment of the TrueNorth Fort Hills Oil Sands Project:

- S12 – Fort Creek at Highway 63
- S25 – Susan Lake Outlet
- S27 – Firebag River near the Mouth

The Firebag River station (S27) was reactivated in December 2003 at the request of Imperial Oil.

Three stations were discontinued because progress in the mining and reclamation plans resulted in cessation of releases at the monitored locations:

- S1 – Alsands Drain
- S13 – Albian Pond 3 Outlet
- S23 – Aurora Boundary Weir

Three stations were discontinued because they had been established only in support of the Petro-Canada EIA, which has been completed:

- S30 – Hangingstone River at Highway 63
- S31 – Hangingstone Creek near the Mouth
- S32 – Surmont Creek at Highway 881

2.2.5.2 Stations Added

Two stations that were not part of the monitoring program in 2002 were added in 2003 at the request of Syncrude to comply with monitoring requirements. A new station, S33 – Muskeg River at the Aurora/Albian Boundary, was established on April 30, 2003 to monitor streamflows at the downstream boundary of the Aurora North lease. Station S5 – Muskeg River above Stanley Creek, which had been monitored for Syncrude in the past but had been inactive for several years, was re-established on May 4, 2003 to monitor streamflows above Stanley Creek, which is the receiving stream for a planned streamflow diversion.

2.2.5.3 Station Name Standardization

Some hydrometric station names were changed to make the name more descriptive and specific, or to be consistent with Water Survey of Canada naming conventions. A table comparing the names used previously with the names adopted for this report is provided in Table 2.2.

Table 2.2 Streamflow station name revisions.

No.	Previous Name	Recommended Name
S1	Alsands Drain; Alsands Drain Upstream of Muskeg River	Alsands Drain
S2	Jackpine Creek; Jackpine Creek at Canterra Road; Jackpine Creek upstream of Muskeg River	Jackpine Creek at Canterra Road
S3	Iyinimin Creek; Iyinimin Creek upstream of Kearl Lake	Iyinimin Creek above Kearl Lake
S4	Blackfly Creek; Blackfly / Khahago Creek upstream of Muskeg River; Blackfly Creek upstream of Muskeg River	Blackfly Creek near the Mouth
S5	Muskeg River	Muskeg River above Stanley Creek
S5A	Muskeg River Aurora; Muskeg River upstream of Aurora Mine Site	Muskeg River above Muskeg Creek
S6	Mills Creek; Mills Creek at Hwy 63	Mills Creek at Highway 63
S7	Muskeg River WSC; Muskeg River 7DA8; Muskeg River at Environment Canada; *Muskeg River near Fort McKay (07DA008)*	Muskeg River near Fort McKay (07DA008)
S8	Stanley Creek; Stanley Creek upstream of Muskeg River	Stanley Creek near the Mouth
S9	Kearl Lake Outlet	Kearl Lake Outlet
S10	Wapasu Creek; Wapasu Creek at Canterra Road	Wapasu Creek at Canterra Road
S11	Poplar Creek; Poplar Creek at Hwy 63; *Poplar Creek near Fort McMurray (07DA007)*	Poplar Creek at Highway 63 (07DA007)
S12	Fort Creek; Fort Creek at Hwy 63	Fort Creek at Highway 63
S13	Albian Pond #3 upstream of Muskeg River; Albian Polishing Pond #3; Albian Pond #3 Outlet	Albian Pond 3 Outlet
S14	Ells River; Ells River upstream of Joslyn Creek	Ells River above Joslyn Creek
S15	Tar River; Tar River near the Mouth; Tar River near Fort McKay (07DA015)	Tar River near the Mouth
S16	Calumet River; Calumet River near the Mouth	Calumet River near the Mouth
S17	Tar River Upland; Upland Tar River Tributary; Upland Tar River	Tar River Upland Tributary
S18	Calumet River Upland; Upland Calumet River; Upland Calumet River Tributary	Calumet River Upland
S18A	Upland Calumet River	Calumet River Upland Tributary
S19	Tar River Lowland; Lowland Tar River Tributary; Lowland Tar River	Tar River Lowland Tributary near the Mouth
S20	Muskeg River Upland; Upland Muskeg River	Muskeg River Upland

Table 2.2 (cont'd).

No.	Previous Name	Recommended Name
S21	Shelley Creek	Shelley Creek near the Mouth
S22	Muskeg Creek	Muskeg Creek near the Mouth
S23	Aurora Boundary Weir; Syncrude Aurora Boundary Weir upstream of Muskeg River	Aurora Boundary Weir
S24	Athabasca River; Athabasca River Downstream of Development	Athabasca River below Eymundson Creek
S25	Susan Lake Outlet; Susan Lake Outlet Creek	Susan Lake Outlet
S26	MacKay River 7DB1; MacKay River WSC; *MacKay River near Fort MacKay (07DB001)*	MacKay River near Fort McKay (07DB001)
S27	Firebag River 7DC1; Firebag River WSC; *Firebag River near the Mouth (07DC001)*	Firebag River near the Mouth (07DC001)
S28	Khahago Creek; Khahago Creek upstream of Muskeg River	Khahago Creek below Black Fly Creek
S29	Christina River; Christina River 7CE2; *Christina River near Chard (07CE002)*	Christina River near Chard (07CE002)
S30	Hangingstone River; Hangingstone River at Highway 63	Hangingstone River at Highway 63
S31	Hangingstone Creek	Hangingstone Creek near the Mouth
S32	Surmont Creek; Surmont Creek at Highway 881	Surmont Creek at Highway 881
S33	(new)	Muskeg River at the Aurora/Albian Boundary

* Previous RAMP designations in normal font; *WSC station names in italics*

2.3 RESULTS

2.3.1 Climate Monitoring

Climate is monitored in detail at the Aurora Climate Station (C1), and supplemental measurements of air temperature, precipitation and barometric pressure are made at some of the streamflow stations. A monthly summary of climate monitoring results for 2003 at the Aurora Climate Station is presented in Table 2.3, and results for the other climate monitoring stations are presented in Table 2.4.

Precipitation data collected at the Aurora Climate Station is illustrated on Figure 2.9. Note that daily precipitation values may reflect the melting of several days' accumulation of snow, as discussed in Appendix A2.1. Precipitation measured at all of the RAMP precipitation stations is compared on Figure 2.10. Data gaps are generally due to equipment damage by wildlife.

Figure 2.9 C1 – Aurora Climate Station precipitation 2003.

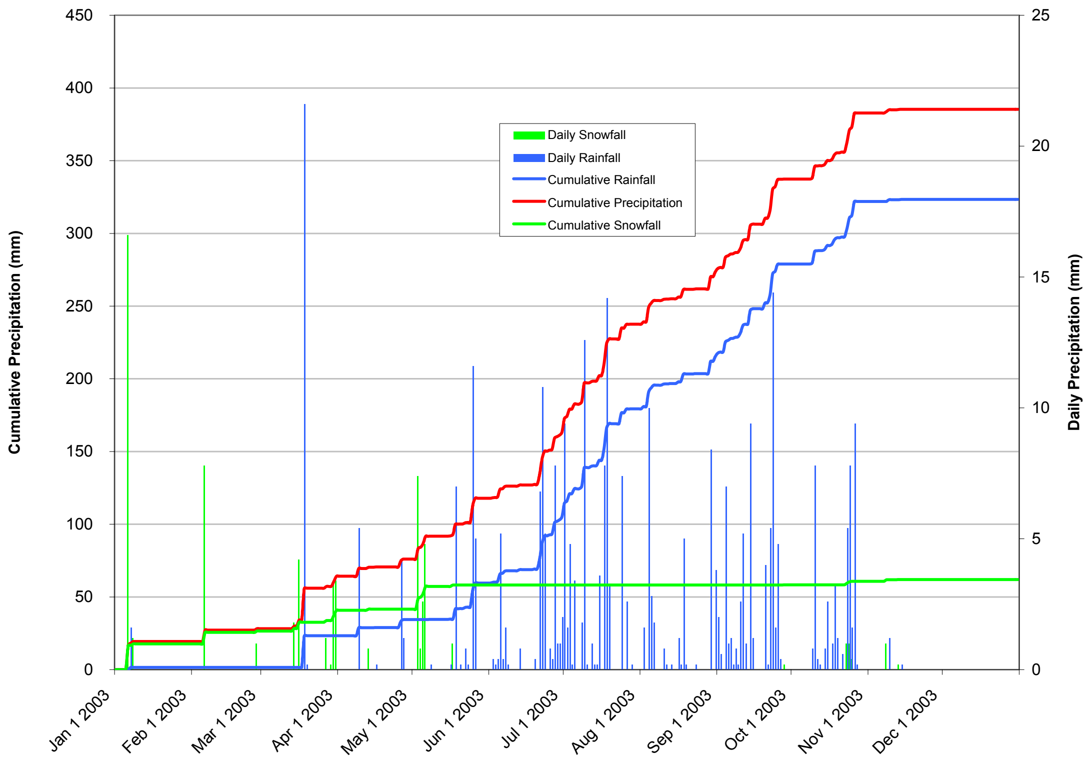


Table 2.3 Summary of 2003 monthly climate data collected at C1 Aurora Climate Station.

Month	Temperature			Total Precip.[1]	Snowfall Water Equivalent[2]	Rainfall Depth[2]	Depth of Snow on Ground	Mean Relative Humidity	Total Global Solar Radiation	Wind Speed and Direction				
										Mean Monthly Wind		Maximum Sustained Speeds		
	Min.	Mean	Max.							Speed[3]	Direction[3]	5 sec.	2 min.	10 min.
	(°C)	(°C)	(°C)	(mm)	(mm)	(mm)	(cm)	(%)	(kWh/m^2)	(km/h)	(degrees)	(km/h)	(km/h)	(km/h)
January	-39.8	-18.9	13.1	19.4	17.8	1.6	20	78.3	15.3	0.5	153	52.0	27.4	24.5
February	-39.8	-19.3	3.0	8.8	8.8	0.0	32	75.8	32.7	1.4	69	36.4	19.9	16.4
March	-39.9	-11.4	16.1	36.0	14.2	21.8	35	69.4	84.0	1.2	78	33.0	22.0	19.8
April	-17.0	3.3	24.4	11.8	0.8	11.0	9	58.2	137.9	1.9	124	38.5	22.9	19.5
May	-6.7	9.5	31.1	41.8	16.6	25.2	0	59.2	169.6	0.8	28	41.7	27.8	19.1
June	0.0	14.3	32.8	45.4	0.0	45.4	0	66.9	164.8	1.0	20	41.0	20.4	18.2
July	4.3	17.4	33.5	74.4	0.0	74.4	0	71.9	174.7	0.6	232	53.6	28.9	19.3
August	-2.7	15.6	34.1	36.4	0.0	36.4	0	73.0	141.2	0.7	228	50.0	28.5	21.2
September	-7.7	8.8	29.6	63.4	0.2	63.2	0	80.4	79.6	0.1	148	36.6	19.6	16.4
October	-18.7	4.0	27.4	45.4	2.4	43.0	0	82.4	45.7	0.8	187	39.4	22.5	20.5
November	-26.4	-9.8	10.0	2.6	1.2	1.4	n/a[4]	78.4	18.3	1.5	188	45.4	23.3	18.3
December	-31.4	-11.8	3.3	0.0	0.0	0.0	n/a[4]	82.4	12.0	2.0	185	42.4	22.7	19.8
Annual[5]	-39.9	0.1	34.1	385.4	62.0	323.4		73.0	1076	1.0	137	42.5	23.8	19.4

[1] Time distribution of snowfall is sometimes not measured correctly. See notes in Appendix 2, Section A2.1.3.
[2] Precipitation gauge measures total precipitation. Rainfall and snowfall are differentiated by examination of the precipitation, temperature and snow on the ground data.
[3] See notes in Appendix 2, Section A2.1.3 for explanations.
[4] Data not available pending further examination of apparent equipment malfunction.
[5] Annual values shown consist of extremes, averages or totals, depending on the parameter.

Table 2.4 Summary of 2003 climate data collected at other RAMP climate stations.

Month	S16 Calumet River Station						S3 Iyinimin Creek above Kearl Lake[1]	S5A Muskeg River Above Muskeg Creek	S19 Tar River Lowland Tributary near the Mouth	S29 Christina River near Chard (07CE002)	L1 McClelland Lake[2]
	Jan 1 - Dec 31, 2003						May 4-Jun 29	Jan 1-Dec 14	May 1-Oct 12	May 1-Oct 10	Jun 24-Jul 25 Aug 21-Sep 22
	Temperature			Snowfall Water Equivalent	Rainfall Depth	Total Precip.	Rainfall Depth	Barometric Pressure	Rainfall Depth	Rainfall Depth	Rainfall Depth
	Min. (°C)	Mean (°C)	Max. (°C)	(mm)	(mm)	(mm)	(mm)	(kPa)	(mm)	(mm)	(mm)
Jan	-43.1	-20.6	11.4	17.0	1.1	18.1		98.8			
Feb	-43.6	-19.9	0.7	28.2	0.1	28.3		98.6			
Mar	-44.1	-11.5	18.5	2.0	37.3	39.3		98.0			
Apr	-17.1	2.9	25.9	0.8	9.9	10.7		98.1			
May	-7.2	9.1	33.4	0.3	19.1	19.4	34.3 P[3]	97.9	23.1	30.3	
Jun	-2.1	14.0	35.6	0.0	38.2	38.2	95.0 P	97.7	28.2	116.2	37.1 P
Jul	0.7	16.9	34.6	0.0	63.0	63.0		97.8	59.1	87.1	40.0 P
Aug	-4.4	14.6	35.9	0.0	32.5	32.5		98.0	25.0	66.9	11.0 P
Sep	-9.8	8.1	31.7	0.0	37.8	37.8		98.0	54.3	51.9	21.7 P
Oct	-22.0	2.6	28.7	22.4	5.9	28.3		97.8	6.6 P	3.5 P	
Nov	-32.0	-12.4	7.8	0.0	0.0	0.0		97.6			
Dec	-32.9	-16.8	-0.7	39.1	0.0	39.1		97.8			
Annual[4]	-44.1	-1.1	35.9	109.7	244.9	354.6		98.0			

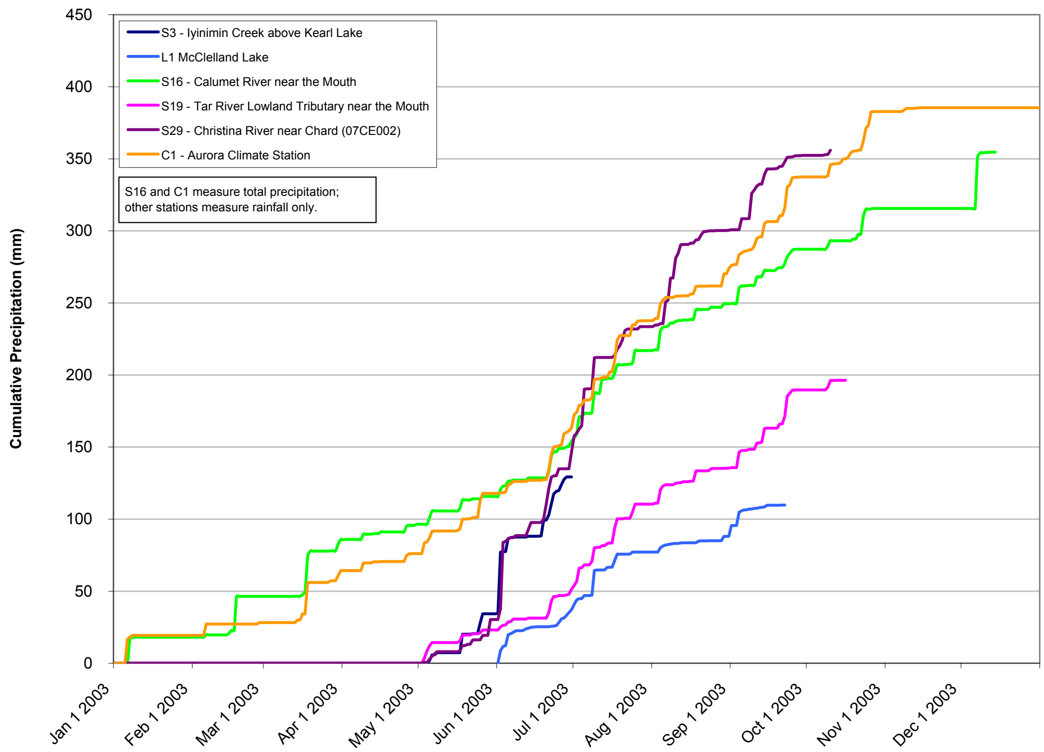
[1] Rain gauge funnel, wiring and/or support damaged by wildlife repeatedly. Gauge inoperable from July through October.

[2] Rain gauge funnel, wiring and/or support damaged by wildlife early in May, August and late in September.

[3] P = Partial month.

[4] Annual values shown consist of extremes, averages or totals, depending on the parameter.

Figure 2.10 Precipitation summary for RAMP climate stations 2003.



Temperature data measured at the Aurora Climate Station is illustrated on Figure 2.11. Unusually warm weather occurred in early January 2003, with highs of over 10°C for three successive days. However, over the following two months, lows close to -40°C were recorded several times. Temperatures rose unusually abruptly in mid-March, and fell unusually abruptly again in late October.

A wind rose illustrating hourly wind speeds and directions observed in 2003 is shown on Figure 2.12. Winds were predominantly from the south and northeast. Winds greater than 10 km/h were observed from the south, northeast and northwest.

2.3.2 Snow Course Survey

Snow course survey results are summarized in Table 2.5 and illustrated on Figure 2.13. Detailed results are provided in Appendix A2.2.

The snow survey, made between March 14 and 19, found that snow depths were generally greater in the Birch Mountains area than in the Fort Hills Creek area.

Snow water equivalents, averaged over the five terrain types, were 74 mm in the Birch Mountains area compared to 53 mm in the Fort Hills Creek area.

Snow densities ranged from 0.12 to 0.23 g/cm^3, with an overall average density of 0.17 g/cm^3.

Figure 2.11 Daily maximum, mean and minimum temperatures at C1 – Aurora Climate Station during 2003.

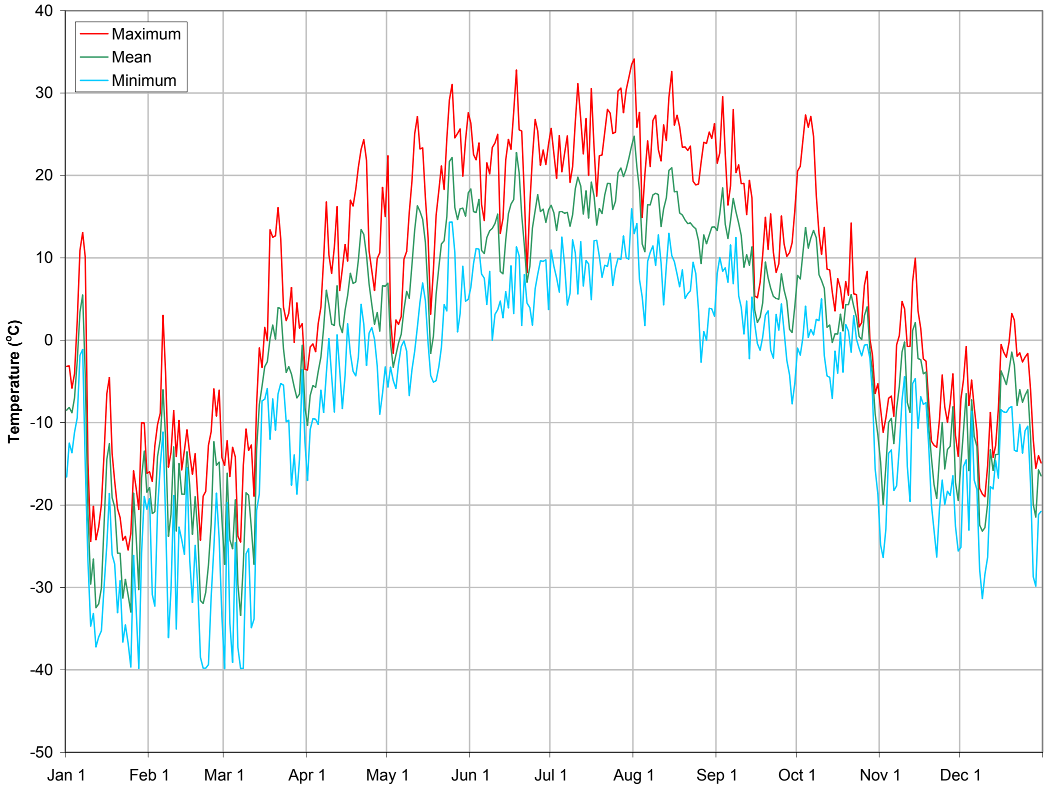


Figure 2.12 Frequency of winds by speed and direction measured at C1 – Aurora Climate Station in 2003.

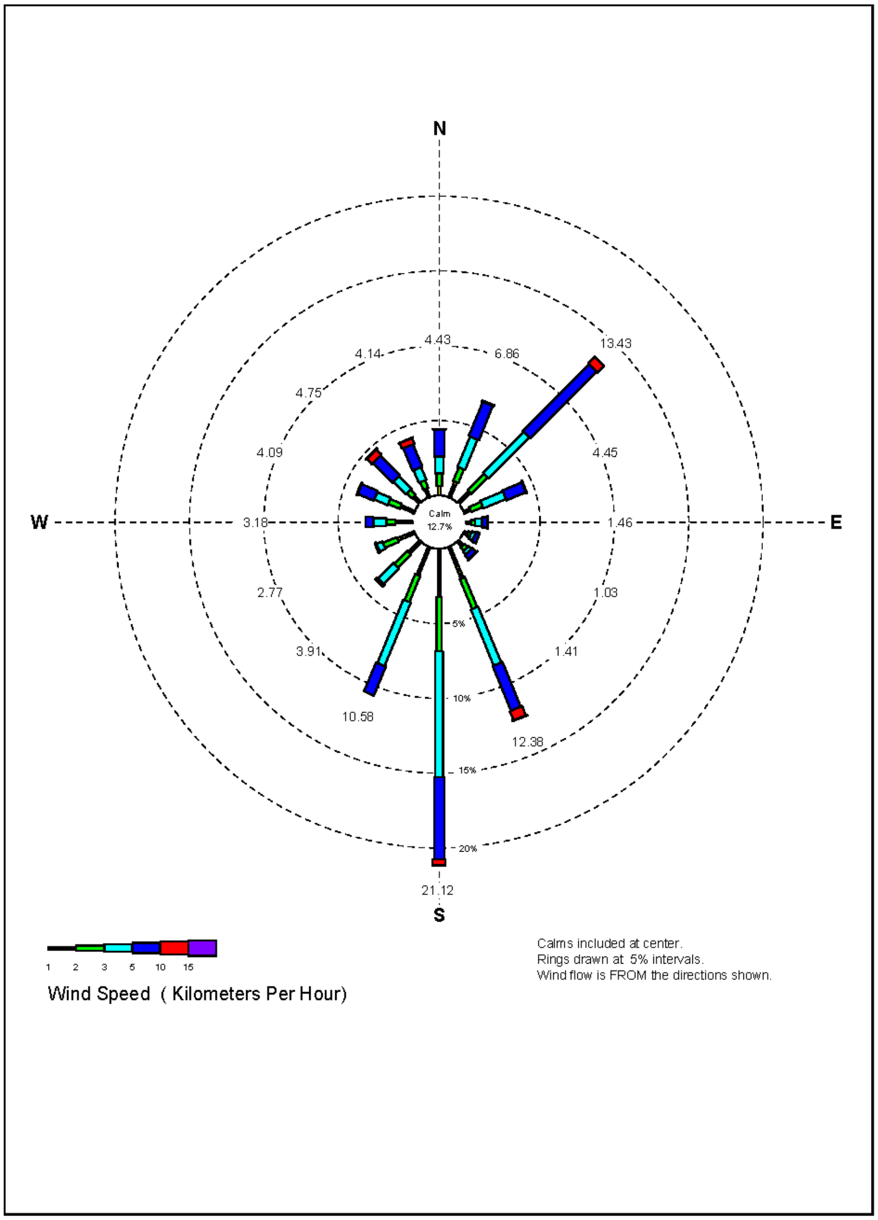


Figure 2.13 2003 snow survey results on the east slopes of the Birch Mountains and in the Fort Hills Creek area.

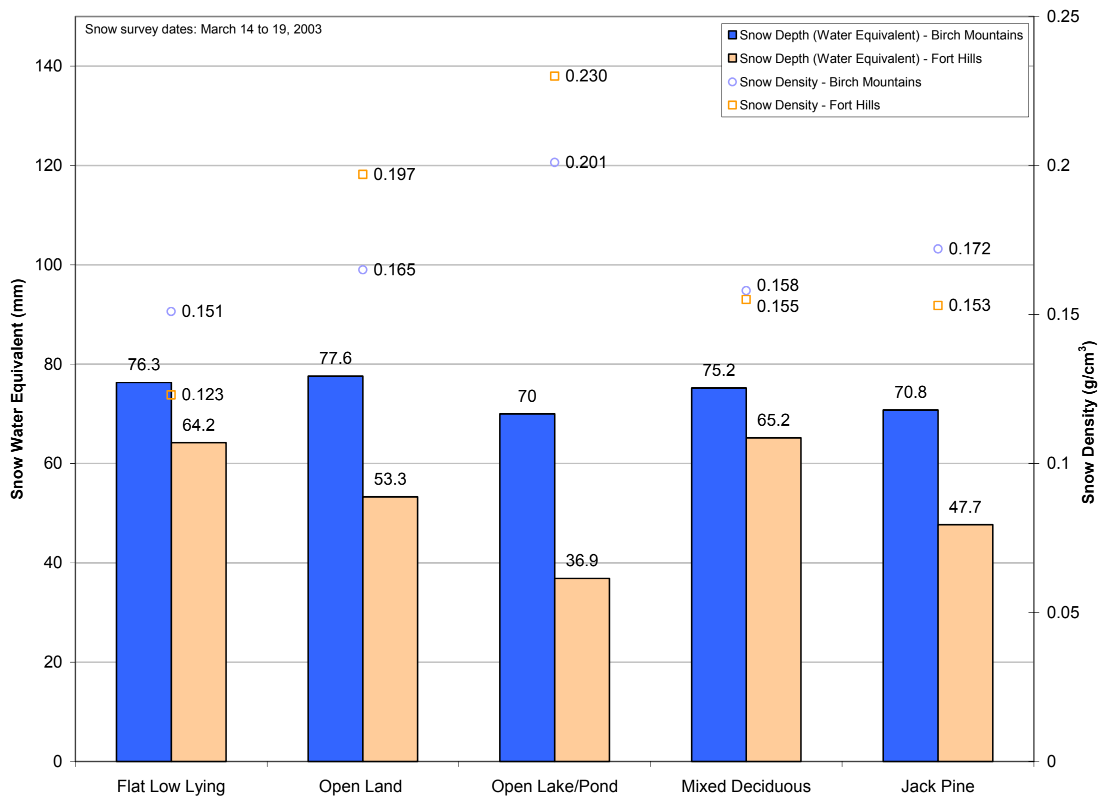


Table 2.5 Results of the 2003 snow survey.

Terrain Type	Plot No	Snow Density (g/cm3)	Snow Depth (cm)	Snow Water Equivalent (mm)
Birch Mountains East Slope Area				
Flat Low Lying	FL-03-1	0.100	55.1	54.9
	FL-03-2	0.170	47.1	79.9
	FL-03-3	0.172	50.0	86.2
	FL-03-4	0.163	51.9	84.3
	2003 Mean	0.151	51.0	76.3
Open Land	OP-03-1	0.152	51.7	78.5
	OP-03-2	0.178	43.1	76.7
	2003 Mean	0.165	47.4	77.6
Open Lake/Pond	OP-03-3	0.196	31.2	61.1
	OP-03-4	0.207	38.1	78.9
	2003 Mean	0.201	34.7	70.0

Table 2.5 (cont'd).

Terrain Type	Plot No	Snow Density (g/cm3)	Snow Depth (cm)	Snow Water Equivalent (mm)
Birch Mountains East Slope Area				
Mixed Deciduous	MD-03-1	0.148	50.6	75.0
	MD-03-2	0.141	47.2	66.5
	MD-03-3	0.181	39.2	71.0
	MD-03-4	0.160	55.0	88.3
	2003 Mean	0.158	48.0	75.2
Jack Pine	JP-03-1	0.156	47.2	73.5
	JP-03-2	0.167	38.8	64.7
	JP-03-3	0.180	42.4	76.3
	JP-03-4	0.185	37.3	68.9
	2003 Mean	0.172	41.4	70.8
Fort Hills Creek Area				
Flat Low Lying	FL-03-5	0.123	52.3	64.2
Open Land	OP-03-5	0.164	42.7	69.7
Open Lake	OP-03-5	0.230	15.8	36.9
Mixed Deciduous	MD-03-5	0.169	42.9	71.0
	MD-03-5	0.141	42.6	59.4
	2003 Mean	0.155	42.8	65.2
Jack Pine	JP-03-5	0.153	31.4	47.7

2.3.3 Hydrometric Monitoring

The results of the 2003 hydrometric monitoring program are summarized in Table 2.6, which shows the total runoff volume and the maximum and minimum daily discharges recorded at each streamflow station over the summer (May 5 – October 11). The table also includes an assessment of the quality of data collected at each station, rating it as excellent, good, fair or poor. Data quality is rated based on accuracy and completeness, considering the following factors:

- Consistency in the stage-discharge relationship. An inconsistent relationship, caused by changing hydraulics due to changes in downstream beaver dams, vegetation, ice, debris, stream aggradation or degradation reduces the accuracy of the discharges computed from the continuous water level data.

- The extent of the rating curve. When discharges have been measured to define the rating curve over the entire range of water levels measured, confidence in the conversion of continuous water levels to discharge is high. Conversely, when water levels occur significantly above or below the range of manual discharge measurements, the rating curve must be extrapolated to convert the continuous levels to discharge, and confidence in the discharge estimates is reduced.

- Performance of the monitoring equipment. Data can be lost due to wildlife damage, vandalism, or equipment failure. The quality assessment reflects the completeness of the data.

The observed 2003 discharge hydrograph or water level hydrograph for each station is presented below, along with the basis for the data quality assessment. The hydrographs are provisional, and subject to revision when the quality control process has been completed.

Spring break-up occurred around April 20 on most of the small streams in the area, and ice effects began to be significant in the streams about October 31.

Stage-discharge rating curves and tables of daily water level and discharge are provided in Appendix A2.3. Individual manual measurements are documented in spreadsheets provided with the hydrologic database. Appendix A2.4 also contains daily discharges at the Aurora clean water diversion, as contributed by Syncrude.

Athabasca River Mainstem and Delta

Athabasca River below Eymundson Creek (S24)

This site monitors water level and discharge on the Athabasca River, year round, downstream of existing and proposed mine developments, and has been operating since May 2001. Level monitoring equipment operated continuously through 2003. Manual measurements of discharge were conducted on six site visits in 2003, with three of these under ice covered conditions, and the other three conducted from a boat. The size of the river, nature of the ice cover and related safety aspects preclude manual measurements for longer periods around freeze-up and break-up than at other RAMP stations.

River discharges ranged from about 60 to 2100 m^3/s through the year, peaking in late June as shown on Figure 2.14. Water levels during spring break-up were strongly affected by ice, and discharges were estimated for that period by considering discharges measured at upstream stations that were less affected by ice.

Table 2.6 Summary of hydrometric measurements 2003.

Station	Catchment Area (km^2)	Monitored Period 2003	Maximum Daily Discharge (m^3/s)	Minimum Daily Discharge[1] (m^3/s)	Runoff Volume[1] (dam^3)	Data Quality Assesment
Athabasca River						
S24 - Athabasca River below Eymundson Creek	146,000	Jan 1 - Dec 31	1970	428	12,100,000	Fair
Athabasca River at McMurray (07DA001)	133,000	Jan 1 - Dec 31	1842	376	10,900,000	
Muskeg River Watershed						
S7 - Muskeg River near Fort MacKay (07DA008)	1,460	Mar 1 - Oct 31	12.2	1.40	94,000	Excellent
S33 - Muskeg River at the Aurora/Albian Boundary	712	May 1 - Dec 31	9.76	0.73	60,800	Good
S5A - Muskeg River above Muskeg Creek	552	Jan 1 - Dec 31	6.86	0.52	36,500	Good
S5 - Muskeg River above Stanley Creek	390	May 4 - Dec 15	5.99	0.25	n/a[3]	Fair
S8 - Stanley Creek near the Mouth		Apr 29 - Oct 14	n/a[3]	n/a[3]	n/a[3]	None
S2 - Jackpine Creek at Canterra Road	358	Apr 29 - Oct 11	7.49	0.53	31,200	Excellent
S21 - Shelley Creek near the Mouth		May 4 - Oct 14	n/a[3]	n/a[3]	n/a[3]	None
S22 - Muskeg Creek near the Mouth	157	Apr 28 - Oct 11	3.30	0.22	25,800	Good
S9 - Kearl Lake Outlet	736	Apr 29 - Oct 9	0.945	0.20	6,020	Good
S3 - Iyinimin Creek above Kearl Lake	32.3	May 4 - Aug 20	1.17	0.06	n/a[3]	Good
S28 - Khahago Creek below Blackfly Creek	212	May 5 - Oct 14	4.04	0.15	18,600	Good
S10 - Wapasu Creek at Canterra Road	90.7	Apr 29 - Dec 14	3.43	0.05	8,210	Good
S20 - Muskeg River Upland	157	May 2 - Oct 11	2.51	0.11	8,100	Fair
Athabasca River Tributaries Upstream of Fort McMurray						
S29 - Christina River near Chard (07CE002)	4,860	Mar 1 - Oct 31	63.6	9.06	348,000	Good
Athabasca River Tributaries Downstream of Fort McMurray						
S11 - Poplar Creek at Highway 63 (07DA007)	422	Apr 30 - Oct 12	6.11	0.13	24,100	Good
S26 - MacKay River near Fort MacKay (07DB001)	5,570	Mar 1 - Oct 31	46.0	2.01	213,000	Fair
S6 - Mills Creek at Highway 63	23.8	Apr 28 - Oct 15	0.06	0.01	351	Good
Steepbank River near Fort McMurray (07DA006)	1,320	Mar 1 - Oct 31	32.3	2.97	173,000	
S14 - Ells River above Joslyn Creek	2,450	May 28 - Oct 13[4]	27.1	3.52	113,000	Good
S19 - Tar River Lowland Tributary near the Mouth	11.5	May 2 - Oct 12	0.01	0.01	103	Poor
S17 - Tar River Upland Tributary	13.8	May 5 - Jun 18	1.75	0.02	n/a[3]	Poor
S15 - Tar River near the Mouth	301	May 2 - Oct 12	6.48	0.17	9,320	Excellent
S18A - Calumet River Upland Tributary	48	May 5 - Oct 13	0.51	0.00	314	Poor
S16 - Calumet River near the Mouth	182	May 5 - Jul 31	1.59	0.04	n/a[3]	Fair
S27 - Firebag River near the Mouth (07DC001)	5990	Mar 1 - Dec 31	107	17.3	593,000	Good
L1 - McClelland Lake	191	Jan 1 - Dec 15	0.36	0.00	984.0	Fair

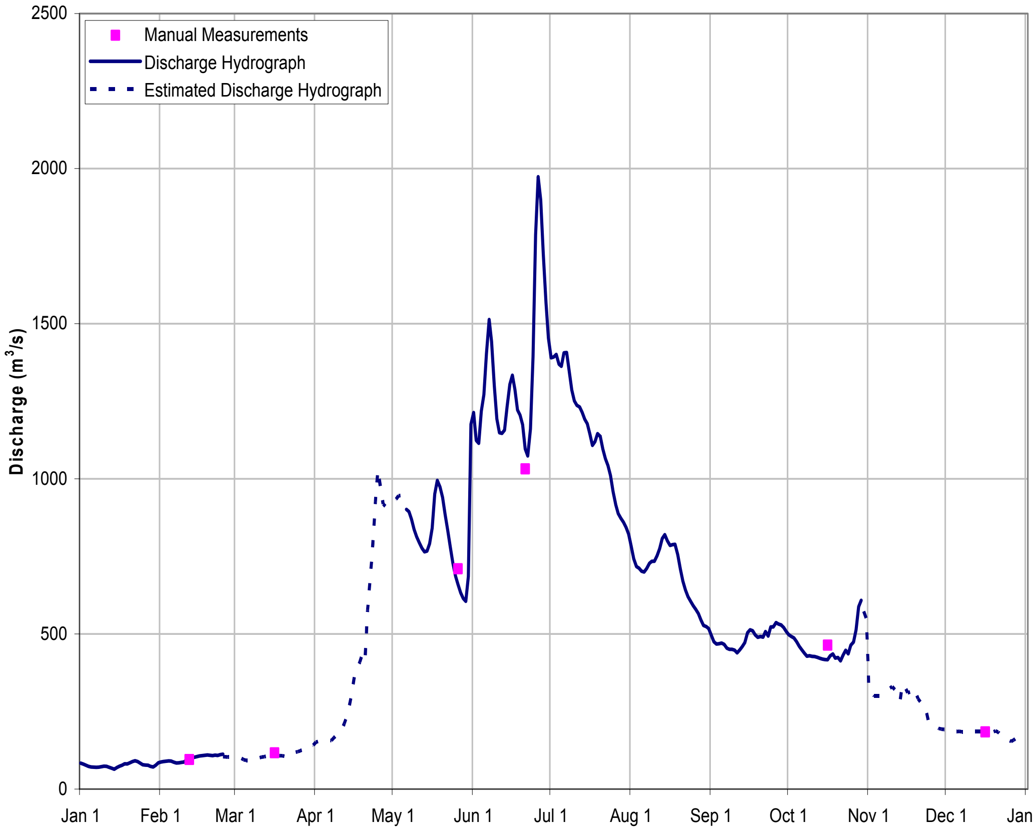
[1]Runoff volume and minimum daily discharge are for the period May 5 - Oct 11.

[2]Quantitiy assesment refers to RAMP discharge data only.

[3]Not applicable - this station does not have a continuous record of discharge.

[4]The runoff volume is based on a shorter period than at the other stations.

Figure 2.14 2003 hydrograph for the Athabasca River below Eymundson Creek (S24).



The station stage-discharge rating curve (shown in Appendix A2.3) is based on manual measurements up to 3000 m^3/s, but the second-highest measurement is only 1500 m^3/s. Therefore the highest values in the annual hydrograph are somewhat uncertain. There is some scatter in the lower portion of the rating curve, possibly because of the mobile sand bed of the Athabasca River.

Considering the lack of flow measurements during break-up and freeze-up and the quality of the rating curve, the quality of the data collected at the station in 2003 is considered to be fair.

2.3.3.1 Muskeg River Watershed

Muskeg River near Fort McKay (07DA008) (S7)

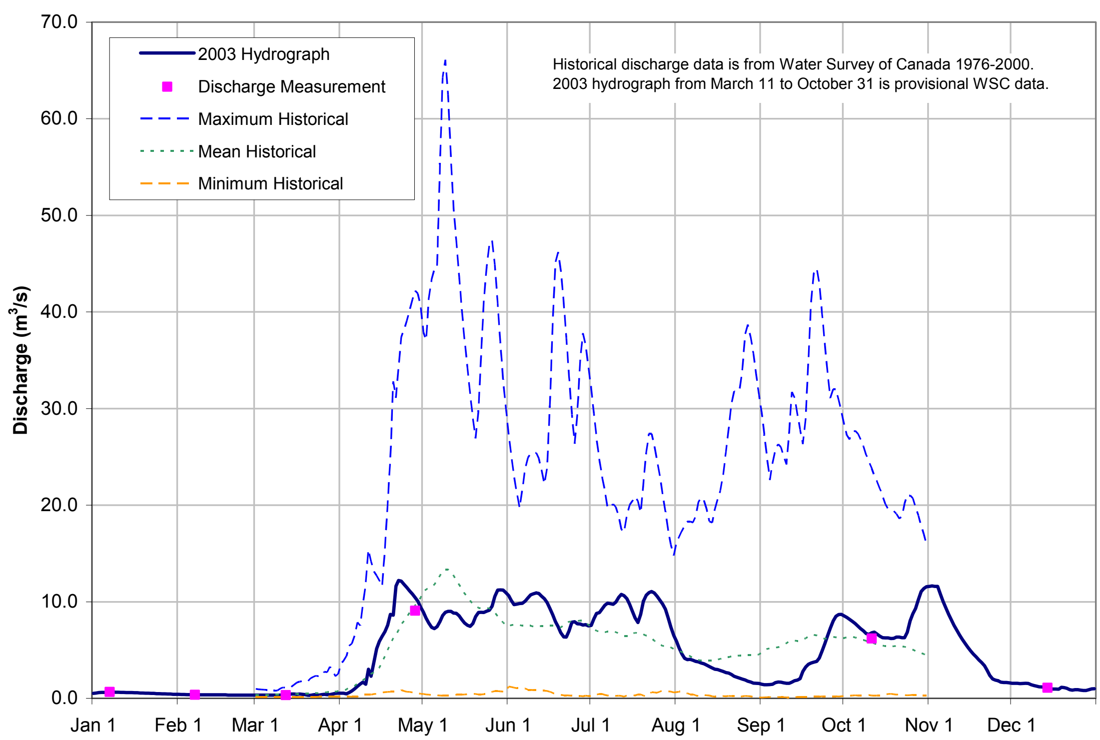
This site monitors water level and discharge near the downstream end of the Muskeg River to supplement open-water monitoring conducted there by WSC.

The RAMP station has been operating since 1999.

Level monitoring equipment operated continuously through 2003. Manual measurement of water level and discharges were conducted on six site visits in 2003, with four of these under ice covered conditions

River discharges ranged from about 0.3 to 20 m^3/s through the year, peaking in mid November as shown on Figure 2.15, which includes both RAMP and WSC monitoring. Discharges were greater than historical average values through much of the year, except in early May, August and September.

Figure 2.15 2003 hydrograph for Muskeg River near Fort McKay (07DA008) (S7).



The readily accessible site has stable local bank materials, locally straight alignment, a stable and well-defined rating curve, and a permanent water level sensor housing. In view of these factors, the quality of the winter data collected at the station is considered to be excellent.

Muskeg River at the Aurora/Albian Boundary (S33)

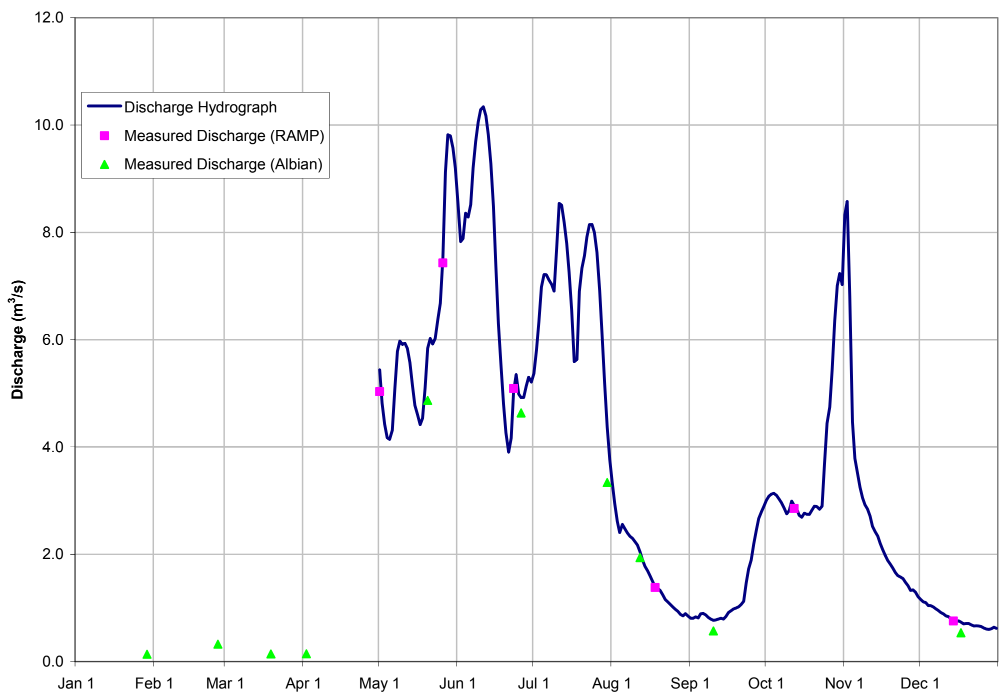
This site was established in April 2003, to monitor water level and discharge year round on the Muskeg River at the boundary between the Aurora North and

Albian Sands mines, below the mouth of Muskeg Creek, which drains the Khahago, Iyinimin and Kearl Lake basins.

Temporary level monitoring equipment installed in April 2003, was replaced with permanent, telemetry-capable equipment in October. (See Appendix A2.6 for permit documentation.) Sensing equipment has operated continuously since installation. Manual measurements of water level and discharge were conducted on six site visits in 2003, with one of these under ice covered conditions.

River discharges ranged from about 0.2 to 10 m^3/s, peaking in mid June as shown on Figure 2.16. Discharge measurements made by Albian Sands personnel are also shown on the graph, and tend to confirm the reported hydrograph. The measured pattern is very similar to that at other Muskeg River stations.

Figure 2.16 2003 hydrograph for Muskeg River at the Aurora/Albian Boundary (S33).



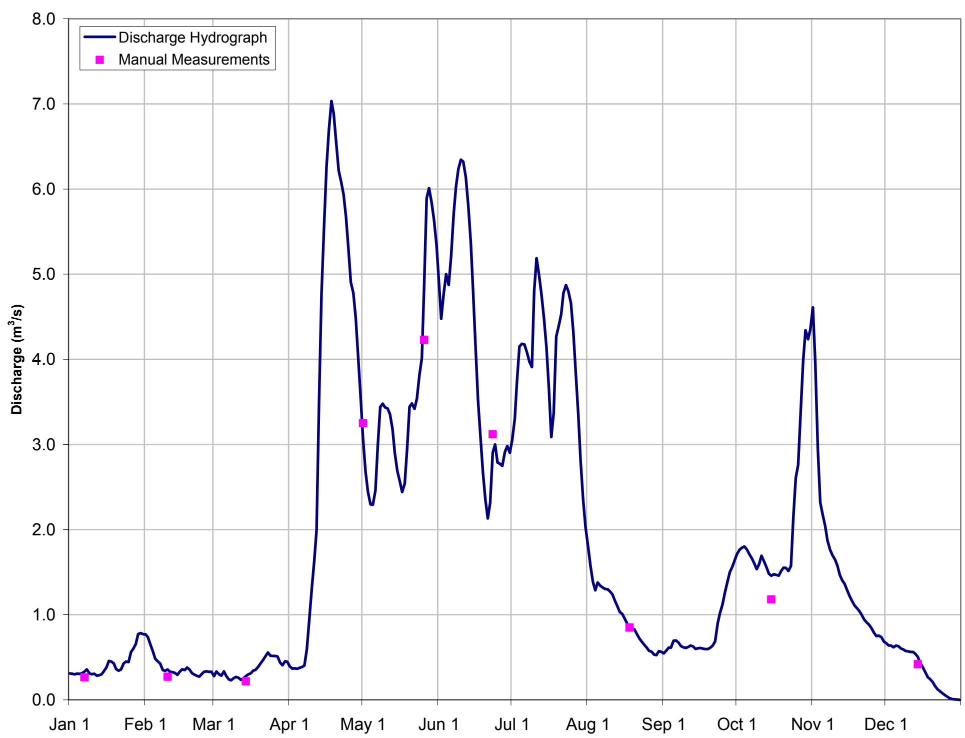
The local reach has a low longitudinal slope, meandering alignment and densely vegetated, muskeg overbank areas. Despite beaver activity evident around the site, the manual measurements made in 2003 indicate a stable and well-defined stage-discharge rating curve. Manual measurements captured discharges up to around 7 m^3/s. Discharge estimates associated with higher water levels are somewhat uncertain, because higher levels exceeded bankfull stage. The quality of the data collected at this station is considered to be good, and could be improved to excellent when the rating curve is extended based on manual measurements at higher flows.

Muskeg River above Muskeg Creek (S5A)

This site was established in 1998 to measure streamflows above the Aurora mine. Water level, water temperature and barometric pressure were recorded throughout 2003. Barometric pressure readings are reported in Section 2.3.1, and water temperature observations are reported in Section 2.3.6. Manual measurements of discharge and water level were made on each of eight site visits, with three of these being made under ice covered conditions.

River discharges ranged from about 0 to 6.9 m^3/s, peaking in mid June as shown on Figure 2.17. The measured pattern is very similar to that at other Muskeg River stations.

Figure 2.17 2003 hydrograph for Muskeg River above Muskeg Creek (S5A).



Like S33, the local reach has a low longitudinal slope, meandering alignment and densely vegetated, muskeg overbank areas. Beaver activity is evident in the vicinity, possibly accounting for some scatter in the points defining the rating curve. Water levels during 2003 were above bankfull stage and were somewhat higher than the highest manual measurement. Based on these factors, the quality of the data collected at this station is considered to be good.

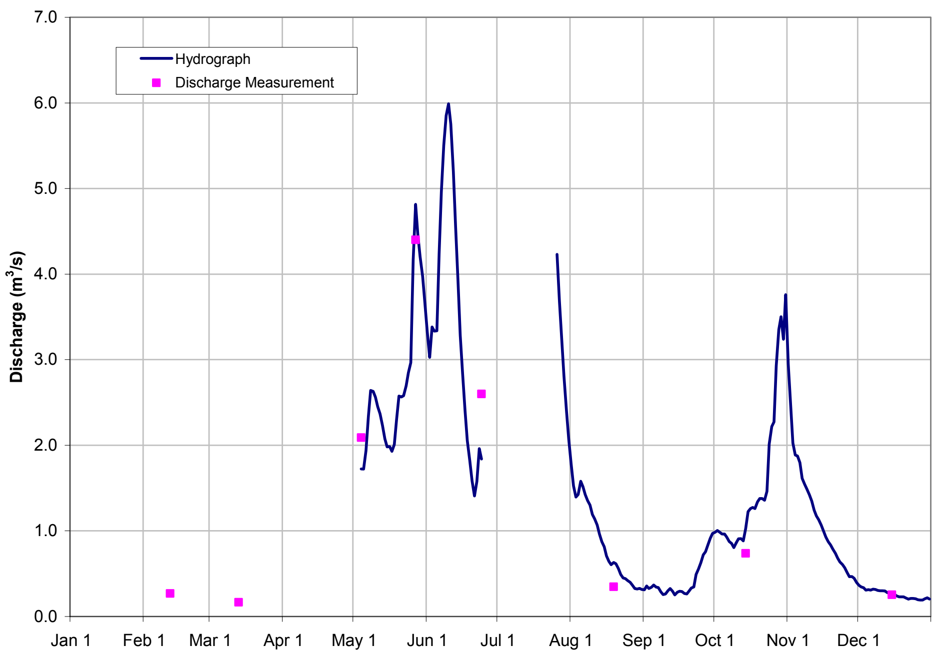
Muskeg River above Stanley Creek (S5)

Established in 1995 and discontinued in 1998, this site was reactivated in February 2003 to monitor Muskeg River water level and discharge above Stanley Creek. Manual measurements of discharge and water level were made on each of eight site visits, with three of these being made under ice covered conditions.

Temporary water level monitoring equipment was installed in early May 2003, and was replaced with permanent, telemetry-capable equipment in October. (See Appendix A2.6 for permit documentation.) Sensing equipment has operated continuously since installation.

The computed hydrograph, shown on Figure 2.18, is generally similar to that at other Muskeg River stations, but the magnitude of flows computed for July was too high based on flows measured downstream. Water levels recorded during that month may have been affected by downstream beaver dams or other activity. Therefore, the data is shown as missing.

Figure 2.18 2003 hydrograph for Muskeg River above Stanley Creek (S5).



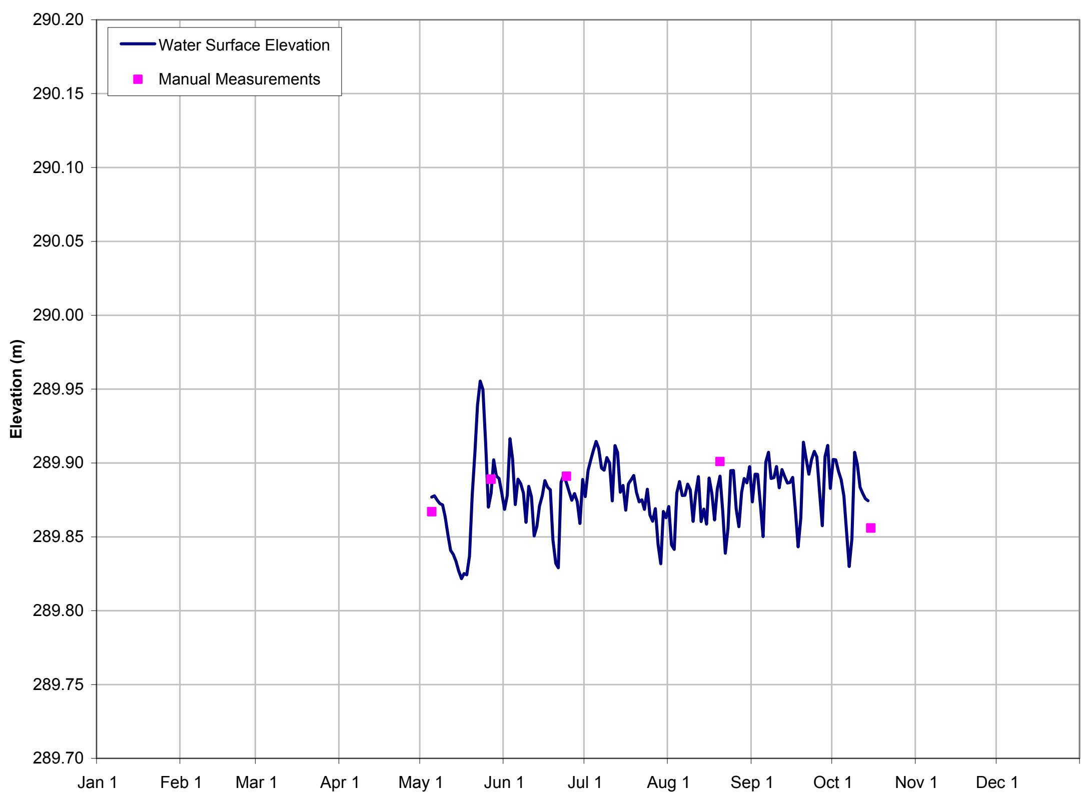
The local reach has a low longitudinal slope, meandering alignment and densely vegetated muskeg over bank areas. Beaver activity is evident in the vicinity, possibly accounting for scatter in the stage-discharge rating curve. Manual measurements have not yet captured the upper range of water levels monitored in 2003, so some uncertainty is associated with discharges higher than about 4.5 m^3/s. Based on these factors, the quality of the data collected at this station in 2003 is considered to be fair.

Stanley Creek near the Mouth (S8)

The S8 site was established in September 1999 to monitor water levels on Stanley Creek upstream of the Muskeg River during the open water season.

Level monitoring equipment was installed on April 29, 2003 and operated continuously through October 14. Manual water level measurements were made during each of five site visits throughout this period. As shown in Figure 2.19, water levels fluctuated within a range of about 13 cm between 289.83 m and 289.96 m.

Figure 2.19 2003 water level hydrograph for Stanley Creek near the Mouth (S8).



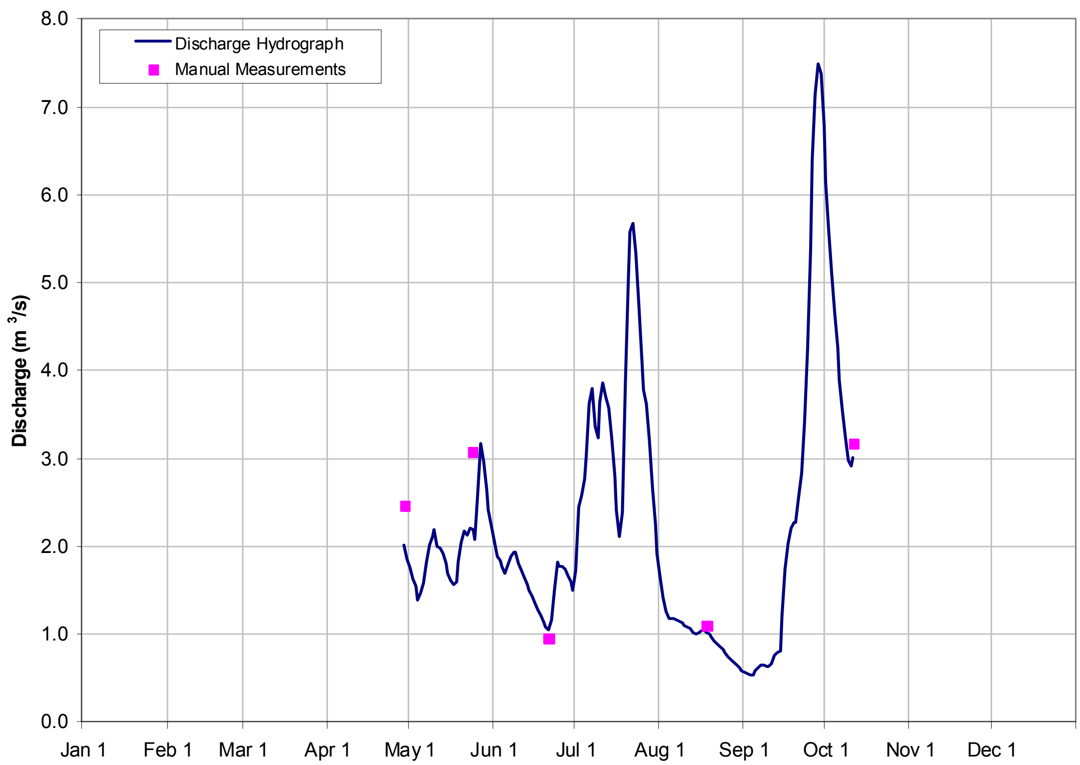
At the monitoring location, there is no defined channel and the water flows through a band of muskeg approximately 100 m wide. Therefore accurate discharge measurement and rating curve development are precluded and only water levels are measured. The quality of the water level data is considered excellent, in view of the relatively stable and protected level sensor location. However, no discharge data is obtained.

Jackpine Creek at Canterra Road (S2)

The S2 site was established in May 1995 to monitor water level and discharge on Jackpine Creek upstream of the Muskeg River, replacing the deactivated WSC station (07DA009). S2 was relocated in 2000 to allow road access and avoid beaver dams. Level monitoring equipment was installed on April 29 and operated continuously through October 11. Manual measurements of discharge and water level were made on each of five site visits.

Monitored river discharges ranged from about 0.5 to 7.5 m^3/s, peaking in mid July, and again in late September, as shown on Figure 2.20. The measured pattern is very similar to that at other Muskeg River basin stations.

Figure 2.20 2003 hydrograph for Jackpine Creek at Canterra Road (S2).

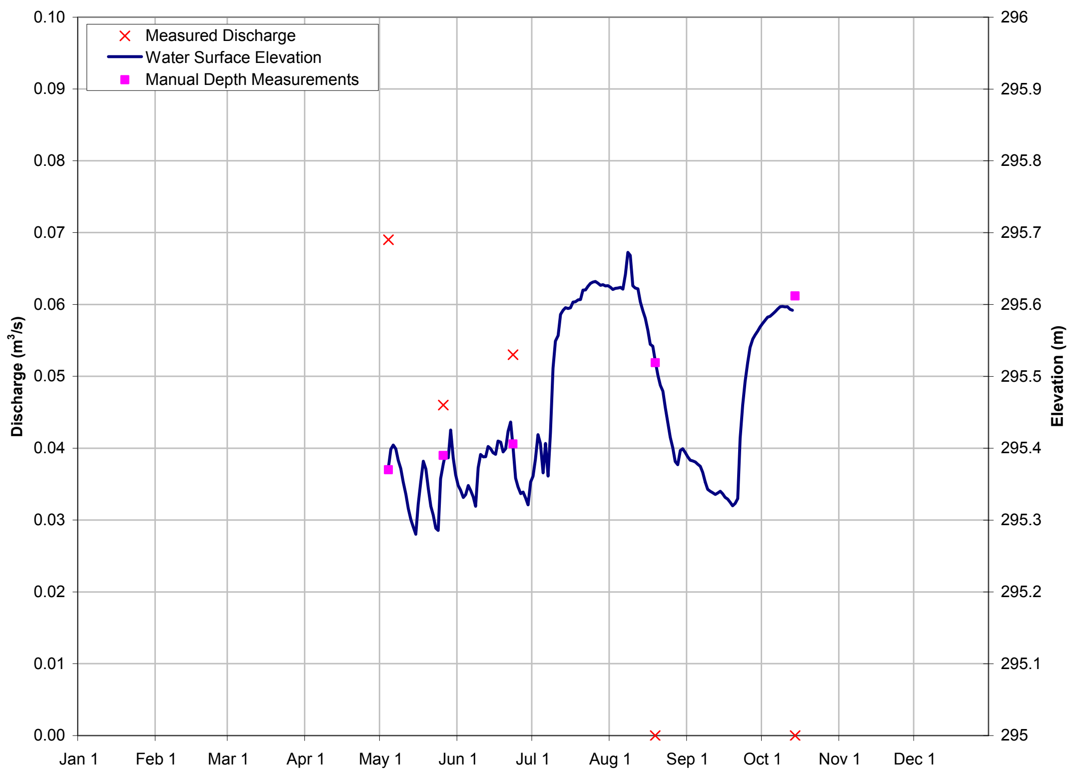


The site is located within a relatively steep, coarsely bedded local reach with relatively straight alignment. No beaver activity is evident in the immediate vicinity. The rating curve is well defined in the range up to approximately 4.5 m^3/s, but is extrapolated above that, creating some uncertainty in the highest discharges recorded for the year. However, the overall quality of the data collected at this station is considered to be excellent.

Shelley Creek near the Mouth (S21)

S21 was established in May 2001 to monitor water level and discharge on this small Muskeg River tributary during the open water season. Level monitoring equipment was installed on May 4 and operated through October 14. Manual measurements of discharge and water level were made on three of five site visits during this period. Water levels and discharges for Shelley Creek in 2003 are presented in Figure 2.21.

Figure 2.21 2003 water levels and discharge for Shelly Creek near the Mouth (S21).



The local gradient is very low, and the poorly defined channel flows through densely vegetated muskeg. Beaver activity is evident in the immediate vicinity, and a beaver dam roughly 0.6 m high was in place roughly 150 m upstream of the site throughout 2003. Manual measurements captured discharges up to 0.070

m^3/s, but there was no relationship between the water level and the discharge measurements, so a stage-discharge rating curve could not be constructed. Therefore no discharge data was obtained at the site in 2003.

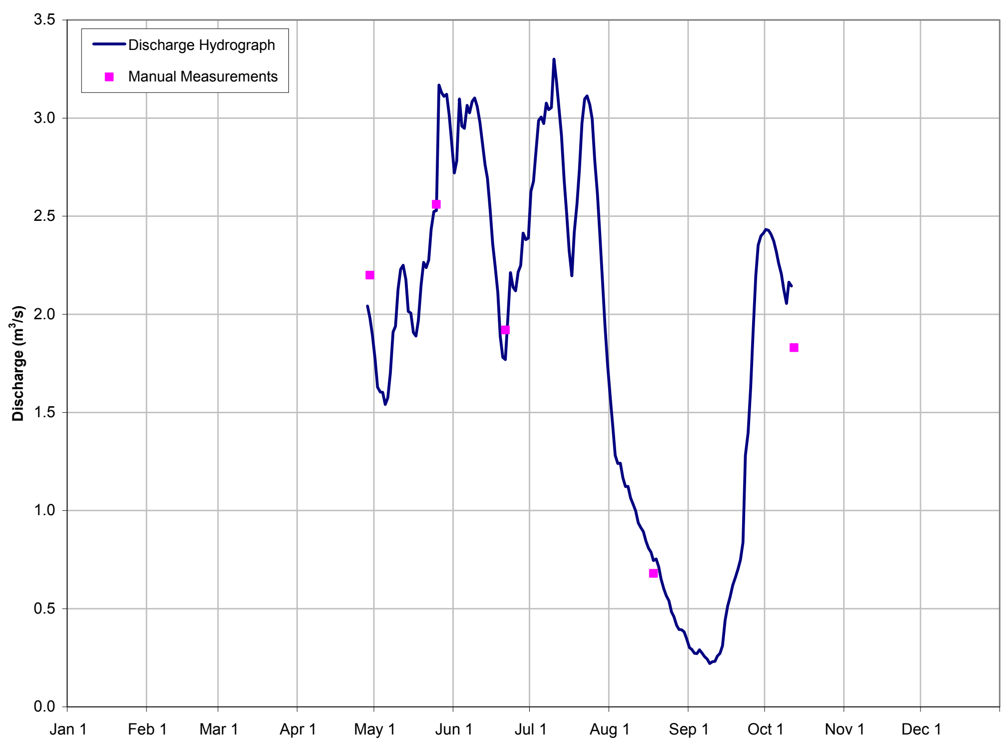
Muskeg Creek near the Mouth (S22)

S22 was established in May 2001 to monitor open water season discharge and water level on Muskeg Creek upstream of the Muskeg River, and downstream of the Kearl Lake and Khahago Creek basins. Level monitoring equipment was installed on April 28, 2003 and operated continuously through October 11, 2003. Manual measurements of discharge and water level were made on five site visits during this period.

Monitored river discharges ranged from about 0.2 to 3.3 m^3/s, peaking in early July, and again in late September, as shown on Figure 2.22. The measured pattern is very similar to that at other Muskeg River basin stations.

The site is located within a relatively steep, coarsely bedded local reach with relatively straight alignment. No beaver activity is evident in the immediate vicinity. There is some scatter in the rating curve, but overall the quality of the data collected at this site is good.

Figure 2.22 2003 hydrograph for Muskeg Creek near the Mouth (S22).



Kearl Lake Outlet (S9)

The S9 site was established in March 1998 to monitor discharge and water level during the open water season on the Kearl Lake outlet channel. Data collected provides information as to the lake water balance. Level monitoring equipment was installed on April 28 and operated continuously through October 11. Manual measurements of discharge and water level were made on five site visits during this period.

Monitored river discharges ranged from about 0.2 to 0.9 m^3/s, peaking in mid June, and, to a lesser degree, again in early October, as shown on Figure 2.23. The measured pattern is similar to that at other Muskeg River basin stations, but exhibits some attenuation and lag, as a result of the lake routing effect.

Figure 2.23 2003 hydrograph for Kearl Lake Outlet (S9).

S9 is located roughly 75 m upstream of a road culvert. The culvert is not in good condition, with some piping and uplift evident. Discharge at S9 appears to be controlled, at least in part, by the culvert inlet elevations. Blockage of the inlet by vegetation or other debris could alter the stage-discharge relationship at the site.

The local reach has heavily vegetated, relatively low lying muskeg overbank areas, and a meandering alignment. Considerable aquatic plant growth was observed during the season. Manual measurements capture the upper range of water levels monitored in 2003. However, the October discharge measurement indicated higher water levels than expected for the measured discharge, possibly due to debris or vegetation at the culvert inlets downstream. Therefore continuous data is shown as missing for the latter part of the year. Based on the quality of the data collected at this station for the majority of the year, the data collected at this station is considered to be good.

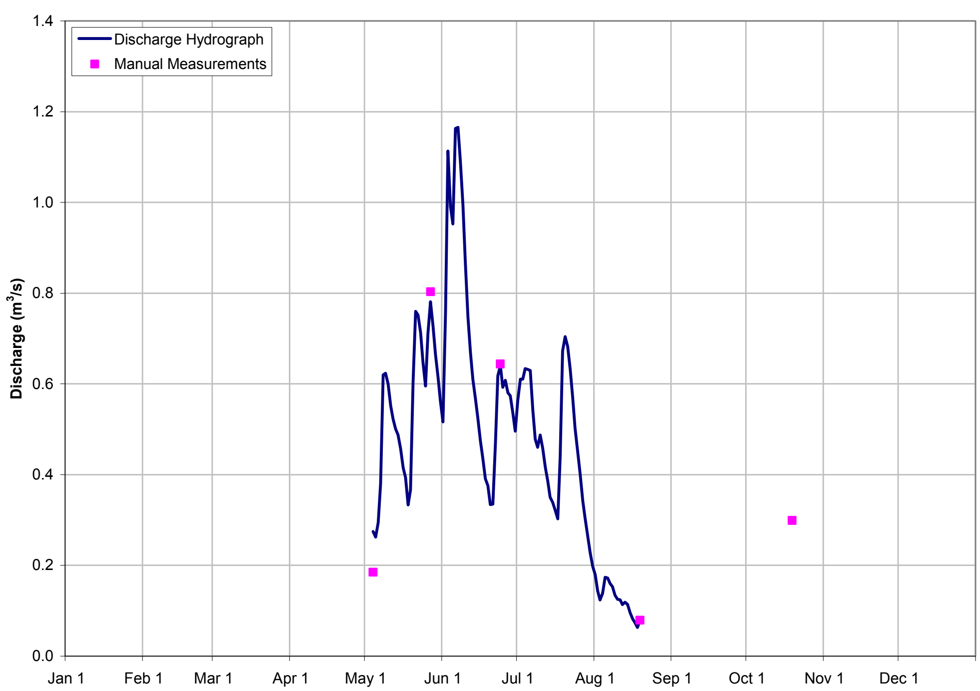
Iyinimin Creek above Kearl Lake (S3)

S3 was established in May 1995 to characterize seasonal runoff in the upper northwest slopes of Muskeg Mountain and provide input to Kearl Lake water balance calculations. A rain gauge was added to the station in 1998.

Water level monitoring equipment was installed on May 4. Equipment at the site was damaged by wildlife, and no reliable water levels were recorded after August 22. Manual measurements of discharge and water level were made on each of five site visits.

Monitored river discharges ranged from about 0.1 to 1.2 m^3/s, peaking in early June, as shown on Figure 2.24. The measured pattern is similar to that at other Muskeg River basin stations, though this steep upland basin is more responsive, with less attenuation and lag than larger, lowland stations.

Figure 2.24 2003 hydrograph for Iyinimin Creek above Kearl Lake (S3).



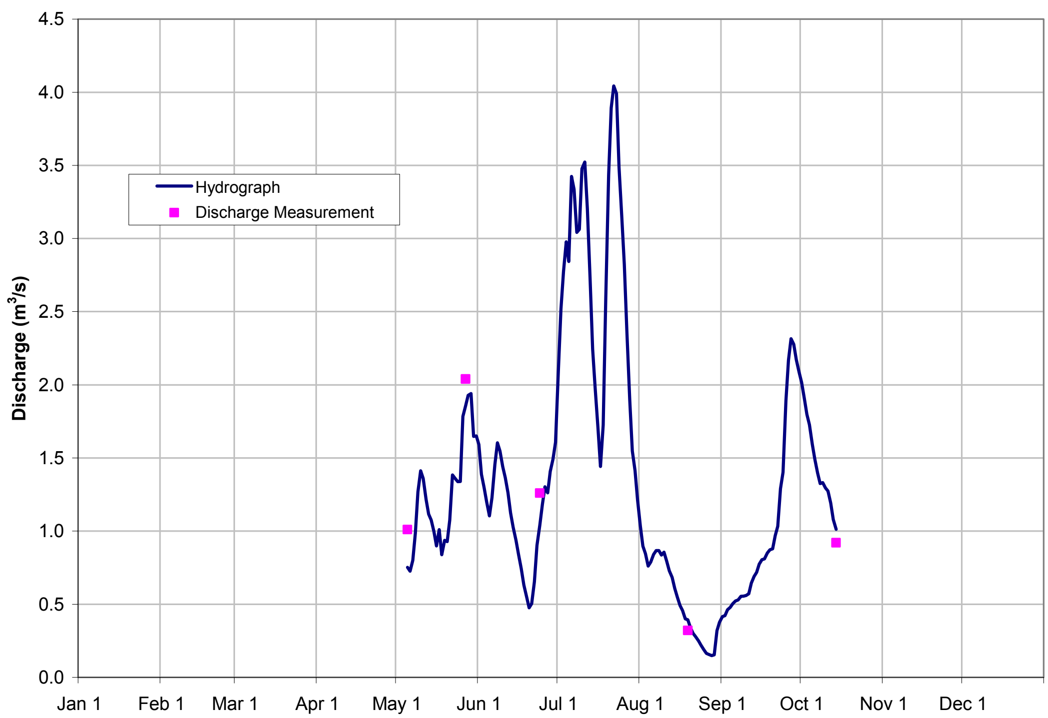
S3 is located within a relatively steep, coarsely bedded local reach, with considerable debris and relatively straight alignment. No beaver activity was evident in the immediate vicinity. Manual measurements made in 2003 fall on a consistent and well-defined rating curve extending up to about 0.8 m^3/s. However, the quality of the data collected at this station in 2003 is considered to be good, rather than excellent, because of the missing data after August 22.

Khahago Creek below Blackfly Creek (S28)

S28 was established in June 2001 to monitor water level and discharge on this Muskeg River tributary during the open water season, upstream of the boundary of oil sands Lease 13. Data was also collected at this site between 1998 and 1999. Level monitoring equipment was installed on May 5, 2003 and operated through October 14. Due to equipment problems, water levels during the night time period were not recorded between May 5 and 27. Manual measurements of discharge and water level were made on each of five site visits during the open water period.

Monitored river discharges ranged from about 0.1 to 4 m^3/s, peaking in July, and again in late September, as shown on Figure 2.25. The measured pattern is very similar to that at other Muskeg River basin stations.

Figure 2.25 2003 hydrograph for Khahago Creek below Blackfly Creek (S28).



The relatively well defined channel flows through densely vegetated areas that have relatively low overbank areas. Beaver activity is not evident in the immediate vicinity, but is evident locally. Manual measurements show some scatter around a stage-discharge rating curve. Due to the scatter, the quality of the data collected at this station is considered to be good, rather than excellent.

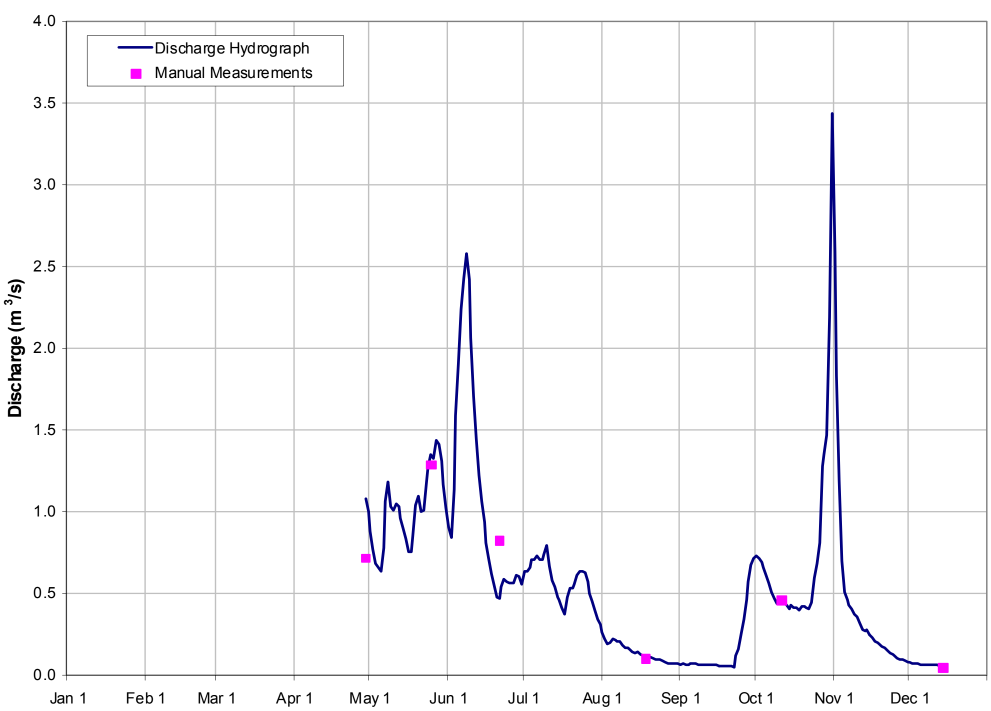
Wapasu Creek at Canterra Road (S10)

The S10 site was established in May 1998 to monitor water level and discharge on Wapasu Creek upstream of the Muskeg River. Beginning in 2003, the monitoring program at this station was extended to include winter monitoring, to characterize winter low flows.

Local forest fires destroyed water level sensing equipment and housings in July of 2002. Temporary level monitoring equipment installed in April 2003 was replaced with a permanent sensor housing in May. Sensing equipment has operated continuously since installation. Manual measurements of water level and discharge were conducted on five of the six site visits in 2003, with one of these under ice covered conditions.

Monitored river discharges ranged from about 0.05 to 3.4 m^3/s, peaking in mid July, and again in late October, as shown on Figure 2.26. The measured pattern is very similar to that at other Muskeg River basin stations.

Figure 2.26 2003 hydrograph for Wapasu Creek at Canterra Road (S10).



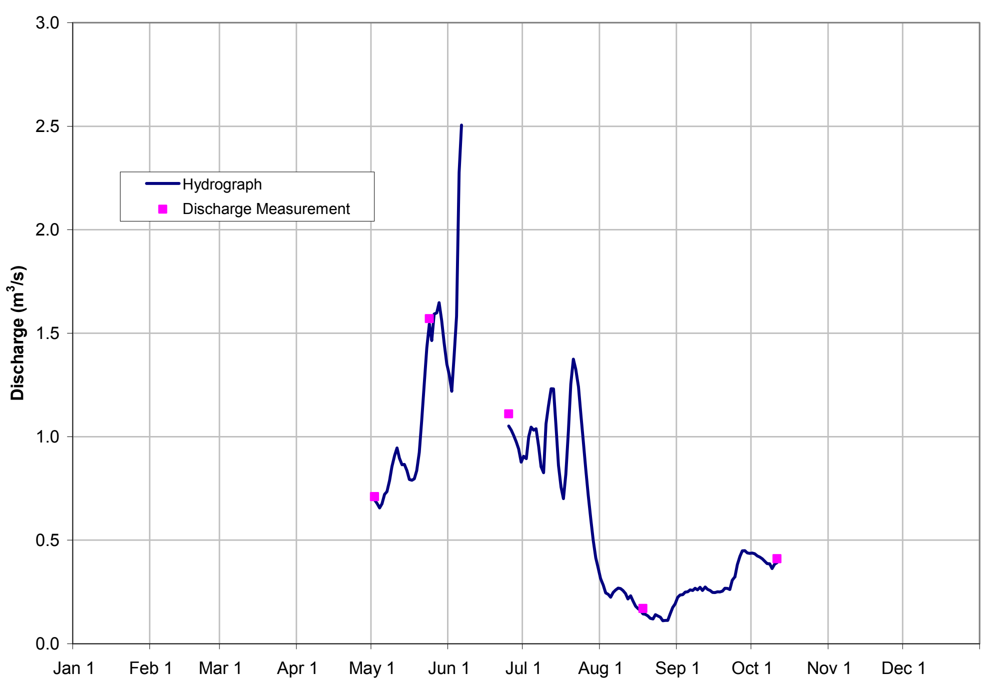
Beaver activity is evident in the immediate vicinity, with an abandoned and partially dismantled dam in place roughly 25 m upstream of the site. The main channel is divided and poorly defined further downstream of the site. There is some scatter in the stage-discharge points measured in 2003. Manual measurements do not capture the upper range of water levels monitored in 2003, so some uncertainty is associated with discharges higher than about 1.5 m^3/s. Based on these factors, the quality of the data collected at this station is considered to be good, rather than excellent.

Muskeg River Upland (S20)

S20 was established in May 2001 to monitor discharge and water level during the open water season in the upper reaches of the Muskeg River. Local forest fires destroyed the temporary water level sensing installation in July of 2002. Temporary level monitoring equipment was reinstalled in May 2003, along with a local elevation bench mark. The temporary equipment malfunctioned on June 13, was replaced with spare equipment on June 25 and operated until October 11. Manual measurements of water level and discharge were made during five site visits in 2003.

Monitored river discharges ranged from about 0.1 to 2.5 m^3/s, peaking in mid July, and again in late October, as shown on Figure 2.27. The measured pattern is very similar to that at other Muskeg River basin stations.

Figure 2.27 2003 hydrograph for Muskeg River Upland (S20).



The site is located within a meandering local reach, with a low left (north) bank. The site is located roughly 35 m upstream of a partially collapsed bridge, under which debris has accumulated. There is considerable scatter in the stage-discharge relationship, likely due to the accumulation and release of debris at the bridge downstream. The channel is divided or poorly defined both upstream and downstream of the site. Extensive beaver activity is evident in the immediate vicinity. Manual measurements do not capture the upper range of water levels monitored in 2003, so some uncertainty is associated with discharges higher than about 1.6 m^3/s. Based on these factors, the quality of the data collected at this station is considered to be fair.

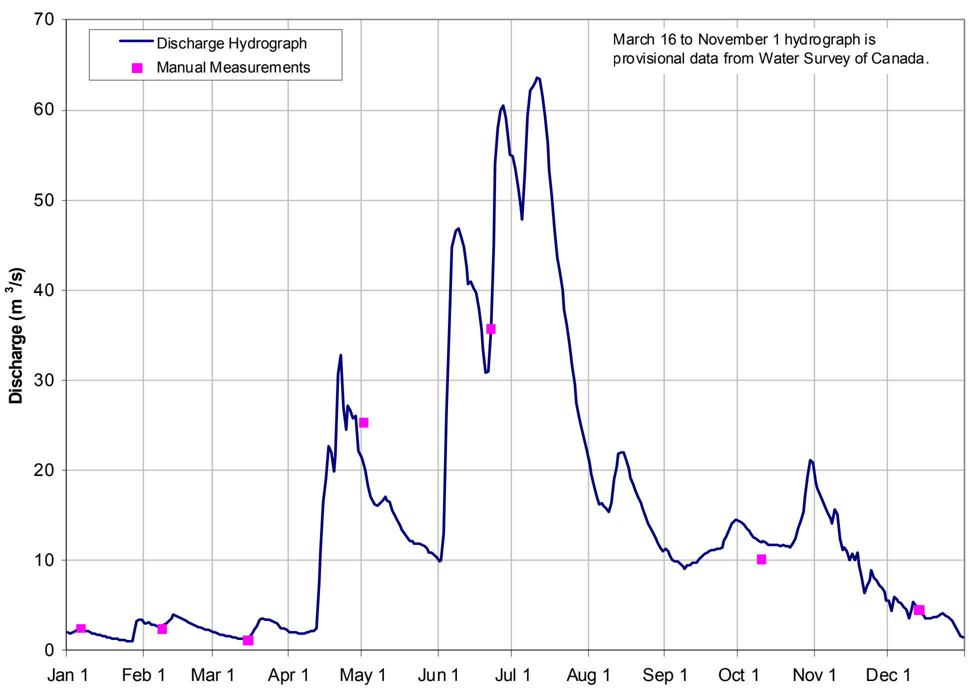
2.3.3.2 Athabasca River Tributaries Upstream of Ft. McMurray

Christina River near Chard (07CE002) (S29)

This site was established near the seasonal WSC Station 07CE002 in January 2002, to monitor water level and discharge during the winter. A rain gauge is operated during the open water season to record precipitation.

River discharges ranged from about 0 to over 60 m^3/s through the year, peaking in mid July as shown on Figure 2.28. Significant rainfall events in October caused significant runoff response through late October. Discharges were greater than historical average values through much of the year, except in late May.

Figure 2.28 2003 hydrograph for Christina River near Chard (07CE002) (S29).



Water levels increased markedly in early November. The water level rise is believed to be due to ice effects rather than increased discharge. Therefore the discharge hydrograph for November and early December is estimated based on typical hydrograph recession rates.

Level monitoring equipment operated continuously through 2003. Manual measurements of water level and discharges were made on six site visits in 2003, with three of these under ice covered conditions. The readily accessible site has stable local bank materials, and locally straight alignment, and a well-defined stage-discharge rating curve. However, because of the variable and unknown ice effects in November, the quality of the winter data collected at the station in 2003 is considered to be good, rather than excellent.

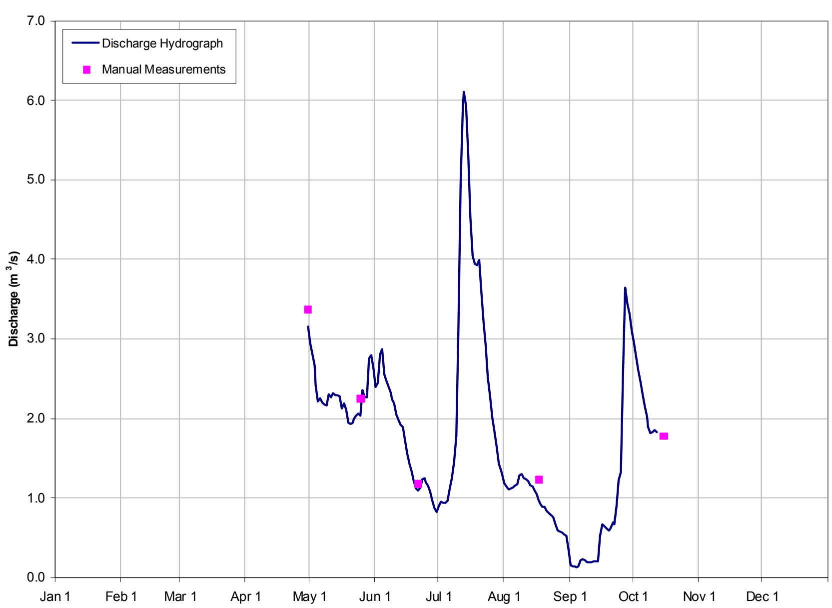
2.3.3.3 Athabasca River Tributaries Downstream of Ft. McMurray

Poplar Creek at Highway 63 (07DA007) (S11)

S11 was established in May 1997 to monitor open water season water level and discharge on Poplar Creek, replacing the WSC station (07DA007), which was discontinued in 1986. Water level monitoring equipment was installed on April 30 and operated continuously through October 15. Manual measurements of discharge and water level were made on each of five site visits.

Monitored river discharges ranged from about 0 to 6 m^3/s, peaking in mid July, and again, to a lesser extent, in late September, as shown on Figure 2.29.

Figure 2.29 2003 hydrograph for Poplar Creek at Highway 63 (07DA007) (S11).



The site is located within a relatively steep, coarsely bedded local reach with relatively straight alignment. No beaver activity is evident in the immediate vicinity. Manual measurements do not capture the upper range of water levels monitored in 2003, so some uncertainty is associated with discharges higher than about 6 m^3/s. There is some scatter in the stage-discharge relationship. Based on these factors, the quality of the data collected at this station is considered to be good.

MacKay River near Fort McKay (07DB001) (S26)

S26 was established near the seasonal WSC Station 07DB001 in November 2001, to monitor water level and discharge during the winter.

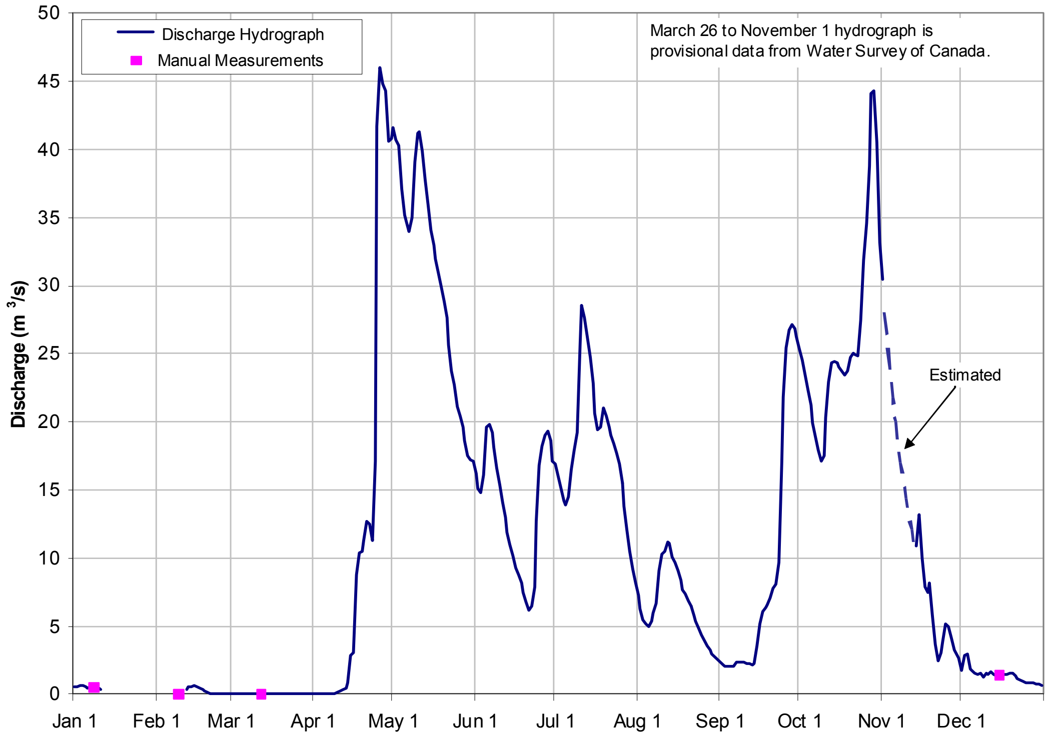
Level monitoring equipment operated continuously through 2003. Due to the steep river valley walls, little sunlight reached the solar panel charging the equipment, resulting in power loss and missing data between January 9 and February 12. Following maintenance on February 12, equipment operated continuously through 2003. Manual measurement of water level and discharges were conducted on five of the six site visits in 2003, with four of these under ice covered conditions. Very low discharge was recorded in February, and the river was dry during the March 12 site visit.

Water levels increased markedly in early November. The water level rise is believed to be due to ice effects rather than increased discharge. Therefore the discharge hydrograph for November and early December is estimated based on typical hydrograph recession rates.

The river reach surrounding the site has stable local bank materials and relatively straight alignment. However, because of the data loss in January – February and the strong effect of ice on water levels in November, the quality of the winter data collected at the station is considered to be fair.

River discharges ranged from 0 to 46 m^3/s through the year, peaking in mid November as shown on Figure 2.30.

Figure 2.30 2003 hydrograph for MacKay River near Fort McKay (07DB001) (S26).



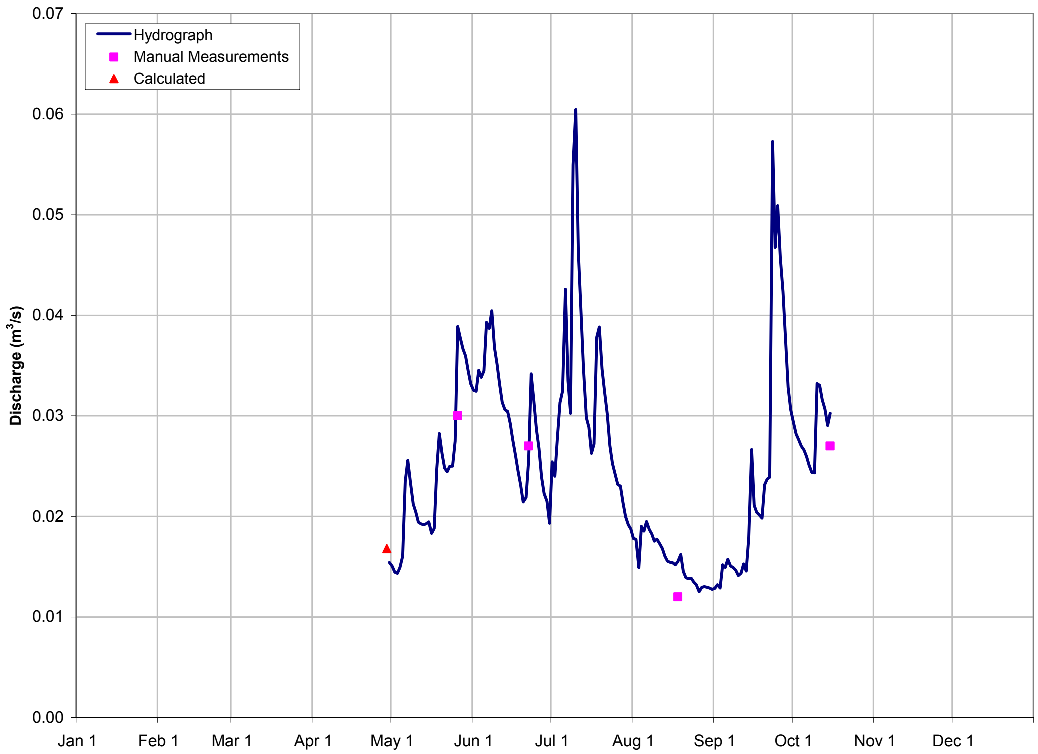
Mills Creek at Highway 63 (S6)

S6 was established in May 1997 to monitor the open water season discharge of Mills Creek, upstream of Isadore's Lake (L3). Level monitoring equipment was installed on April 29 and operated through October 15. Manual measurements of discharge were made on four of five site visits.

A sharp crested triangular weir is in place at the site to facilitate water level and discharge measurements. Some accumulation of plant debris at the weir was noted during late summer site visits. Manual measurements made in previous years do capture the upper range of water levels monitored in 2003, however these data do not closely emulate a theoretically expected weir discharge rating relationship. The weir is no longer vertical, possibly affecting the stage-discharge relationship, and is scheduled for replacement in early 2004. The range of discharge and water level fluctuation are small, due to the nature of the site, increasing the relative impact of routine measurement error. Based on these factors, the quality of the data collected at this station is considered to be good rather than excellent.

Monitored river discharges ranged from about 0.01 to 0.06 m^3/s, peaking in mid July and again in late September, as shown on Figure 2.31.

Figure 2.31 2003 hydrograph for Mills Creek at Highway 63 (S6).



Ells River above Joslyn Creek (S14)

S14 was established in May 1997 to monitor open water season water level and discharge, on the Ells River above Joslyn Creek, replacing a discontinued WSC station (07DA017). The level monitoring datalogger left on site through the winter was destroyed by an ice jam flood and debris event during break-up in April 2003. This event left 1 m thick blocks of ice debris up to 2 m above the spring water level and scoured vegetation from the banks.

Temporary equipment, installed on May 28 was replaced with permanent equipment on June 22 and operated continuously through October 13. A new permanent water level housing was installed on October 13. Manual measurements of discharge were made on four of five site visits during the open water season. Due to high flows no discharge measurement could be made on May 6, however, a measurement was made downstream of S14, from a bridge near the mouth of the Ells River.

Monitored river discharges ranged from about 4 to over 27 m^3/s, peaking in mid May, as shown on Figure 2.32.

Figure 2.32 2003 hydrograph for Ells River above Joslyn Creek (S14).

The site is located within a relatively steep, coarsely bedded local reach with broadly meandering alignment. No beaver activity is evident in the immediate vicinity. The site has a well-defined rating curve, with very little scatter in the manual measurements. The quality of the data collected at this station is considered to be excellent for the period it was in operation, but is considered to be good overall because of the missing period in the spring.

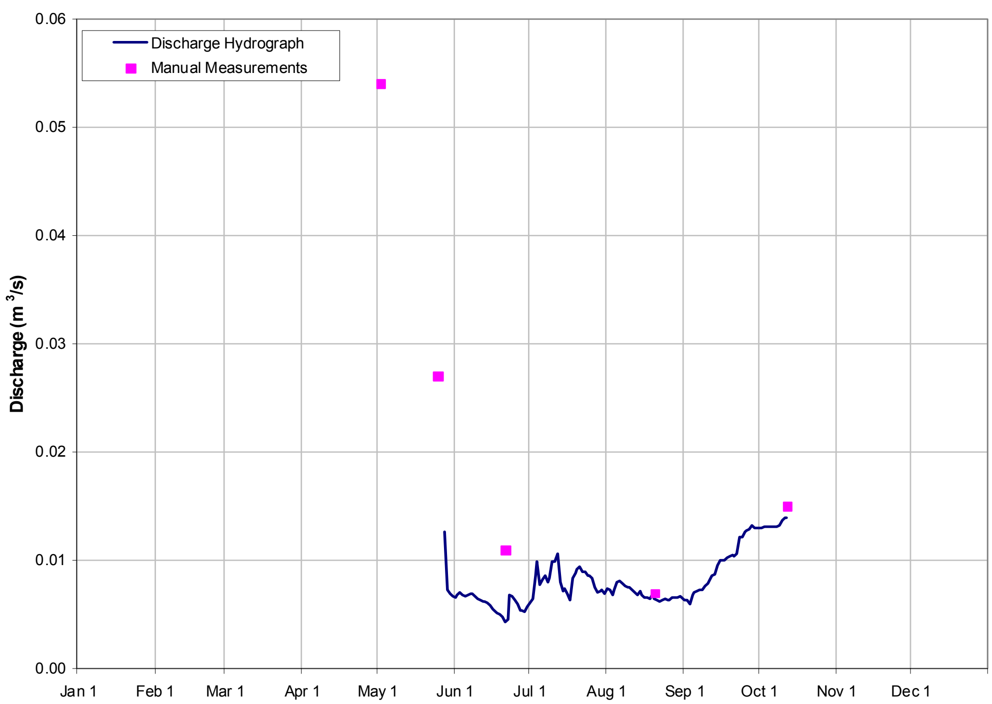
Tar River Lowland Tributary near the Mouth (S19)

S19 was established in May 2001 to characterize discharge on a small, lowland tributary to the Tar River, during the open water season. A rain gauge is also operated at the station.

Level monitoring equipment was installed on May 2. However, the equipment malfunctioned and reliable data was only collected after May 25, when the sensor was replaced. It was operated through October 12. The permanent sensor was replaced on June 21. Manual measurements of discharge and water level were made on each of five site visits during the open water period.

Monitored river discharges ranged from about 0.005 to 0.05 m^3/s, as shown on Figure 2.33.

Figure 2.33 2003 hydrograph for Tar River Lowland Tributary near the Mouth (S19).



Located within muskeg lowlands, S19 has a low local gradient, low banks and a small, easily obstructed and poorly defined channel. Beaver activity is evident in the immediate vicinity, and a beaver dam roughly 0.8 m high was in place roughly 30 m upstream of the site throughout 2003. Manual measurements capture discharges up to 0.054 m^3/s which includes the upper range of water levels monitored in 2003. However, the stage-discharge relationship is very poorly defined, possibly because of beaver activity. Therefore the quality of the data collected at this station is considered to be poor.

As a result of mining development in the area, this station was discontinued in October 2003.

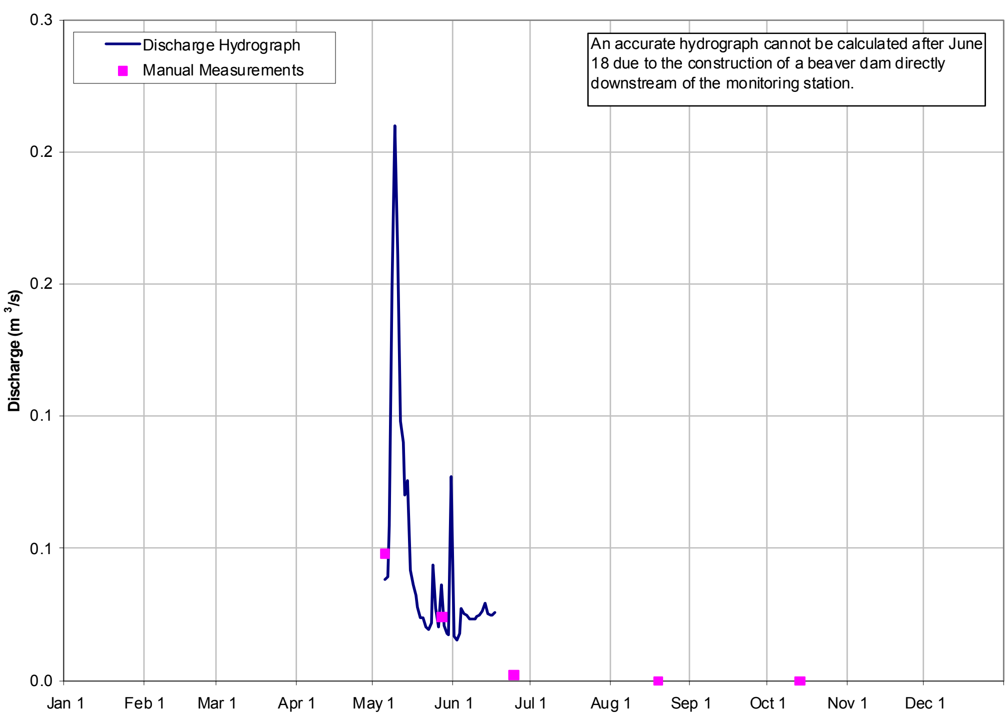
Tar River Upland Tributary (S17)

S17 was established in May 2001 to characterize discharge on a small, upland tributary to the Tar River, draining the east slopes of the Birch Mountains, during the open water season.

Level monitoring equipment was installed on May 5 and operated through October 13. Manual measurements of discharge were made on three of five site visits during the open water period. Discharges were too small to be measurable during the late summer and autumn site visits. A beaver dam was constructed immediately downstream of the station, disrupting the stage-discharge relationship after June 18.

The monitored river discharge hydrograph is shown on Figure 2.34.

Figure 2.34 2003 hydrograph for Tar River Upland Tributary (S17).



Located within densely vegetated forest, the Tar River at S17 consists of a deeply incised and erodible cross section, with relatively high banks but a narrow, easily obstructed channel. Beaver activity is evident in the immediate vicinity, and beaver dams roughly 0.5 m high were repeatedly constructed immediately downstream of the site. Manual measurements capture discharges up to 0.048 m^3/s which is less than the upper range of water levels monitored in 2003, however considerable uncertainty is associated with discharges at higher stage due to beaver dam obstructions. Based on these factors, the quality of the data collected at this station is considered to be poor.

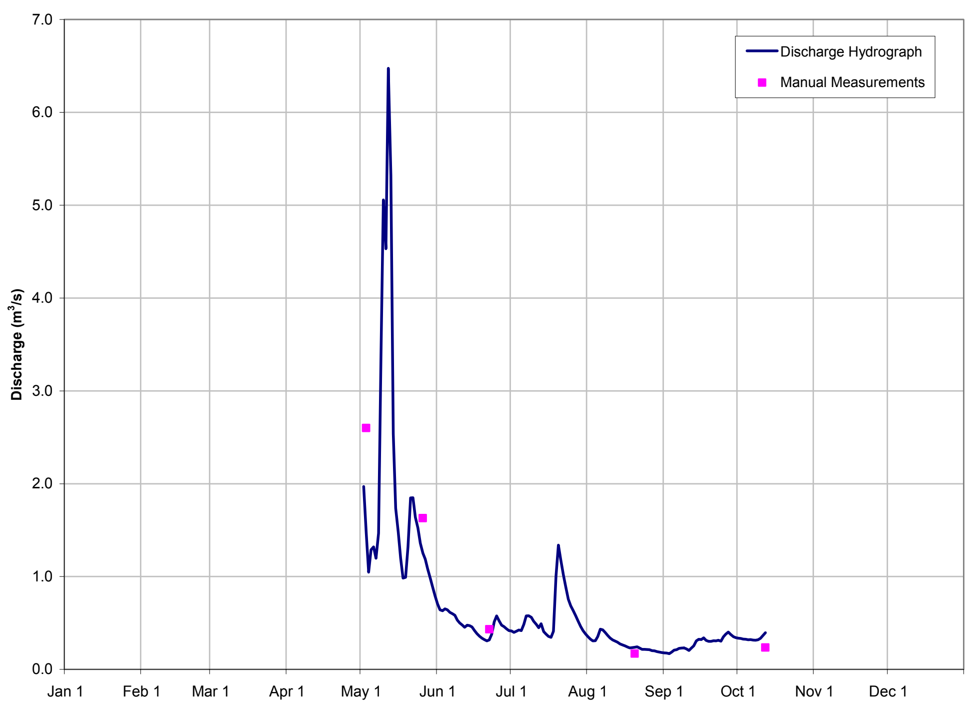
Tar River near the Mouth (S15)

S15 was established in May 2001 to monitor open water season water level and discharge on the Tar River, replacing a discontinued WSC station (07DA015).

Water level monitoring equipment was installed on May 2 and operated continuously through October 12. Manual measurements of discharge were made on each of five site visits during the open water season.

Monitored river discharges ranged from about 0.3 to over 6.5 m^3/s, peaking in mid May, as shown on Figure 2.35.

Figure 2.35 2003 hydrograph for Tar River near the Mouth (S15).



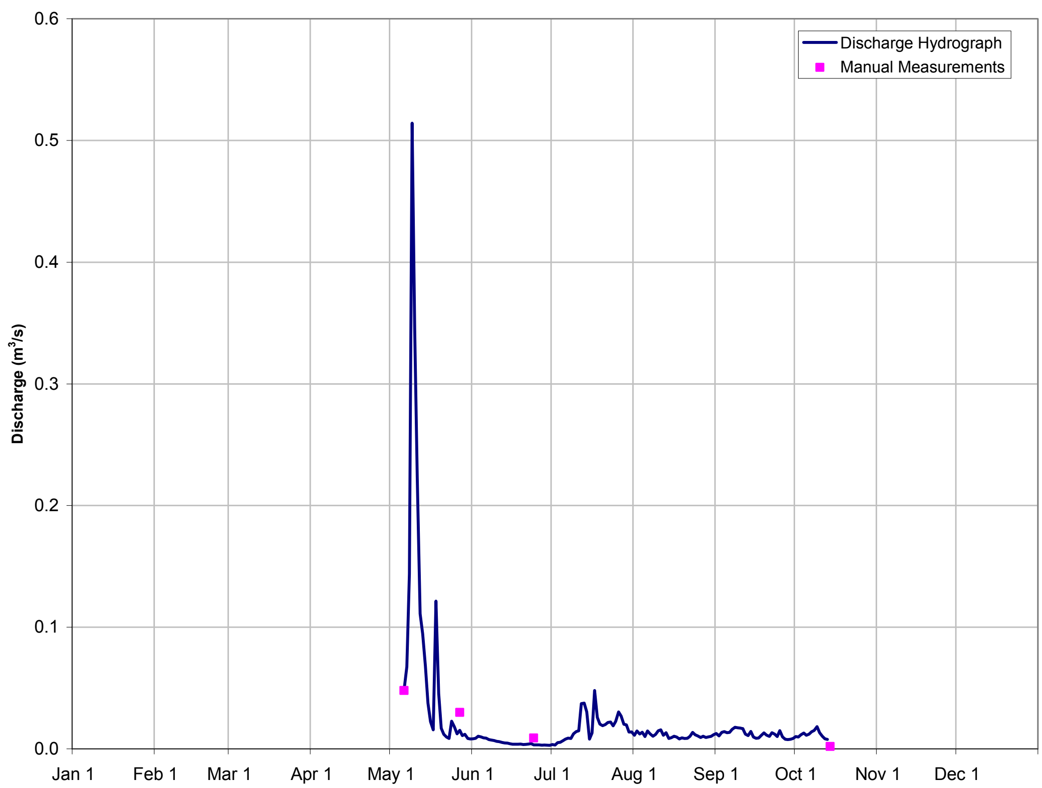
The site is located within a relatively steep, local reach with broadly meandering alignment. No beaver activity is evident in the immediate vicinity. Manual measurements do not capture the upper range of water levels monitored in 2003, so some uncertainty is associated with discharges higher than about 2.6 m^3/s. However, the stage-discharge relationship is well-defined, with very little scatter. The quality of the data collected at this station is considered to be excellent.

Calumet River Upland Tributary (S18A)

S18A was established in June 2002 to characterize discharge on a small, upland tributary to the Calumet River, draining the east slopes of the Birch mountains, during the open water season. S18A replaced station S18 which was situated on the mainstem of the Calumet River. Level monitoring equipment was installed on May 5 and operated through October 13. Manual measurements of discharge were made on four of five site visits during the open water period, as no significant discharge was evident during the late summer site visit.

Monitored river discharges ranged from about 0 to an estimated 0.5 m^3/s, peaking in May, as shown on Figure 2.36.

Figure 2.36 2003 hydrograph for Calumet River Upland Tributary (S18A).



The channel at S18A has an incised and erodible cross section, with relatively high banks but a narrow, easily obstructed channel. The meandering channel exhibited considerable vegetation growth by the late summer. The rating curve shows considerable scatter and is not supported by manual measurements above 0.048 m^3/s. Based on these factors, the quality of the data collected at this station is considered to be poor. Measurements at higher flows may extend the rating curve in the future, and, if so, the discharges presented here should be reviewed and the data quality assessment may be upgraded.

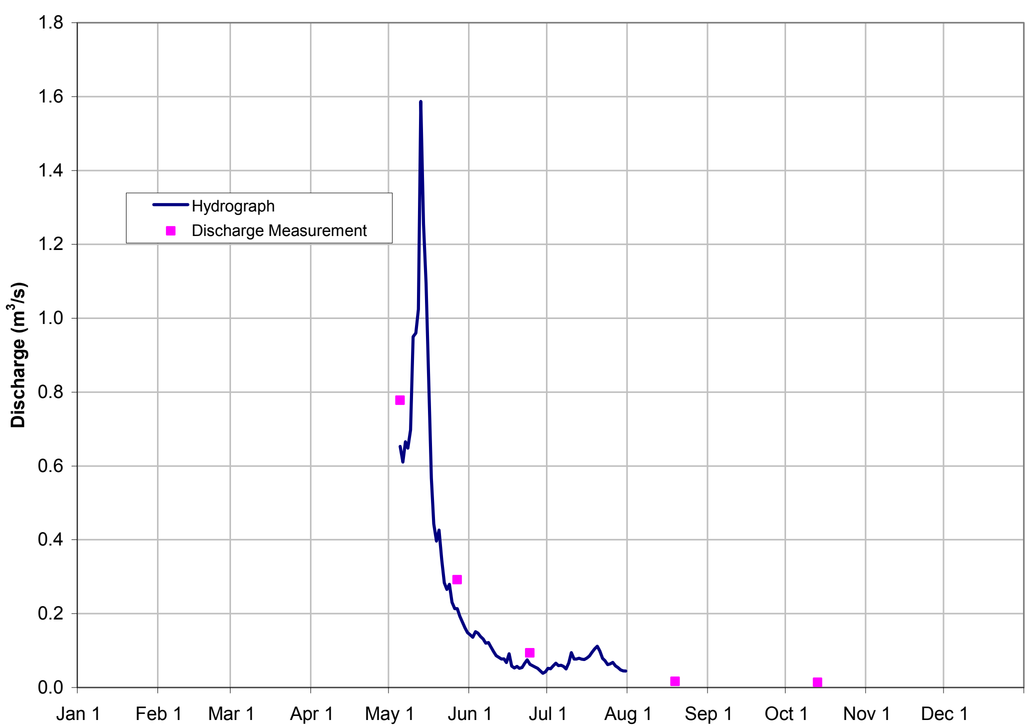
Calumet River near the Mouth (S16)

S16 was established in May 2001 to monitor open water season water level and discharge, replacing a discontinued WSC station (07DA014). Climate sensors are also operated at the site to monitor air temperature, water temperature, and precipitation.

Water level sensing equipment was installed on May 5 and operated continuously through to October 13. Manual measurements of discharge were made on each of five site visits during the open water season.

Monitored river discharges ranged from 0.014 to 1.6 m^3/s, peaking in mid May, as shown on Figure 2.37.

Figure 2.37 2003 hydrograph for Calumet near the Mouth (S16).



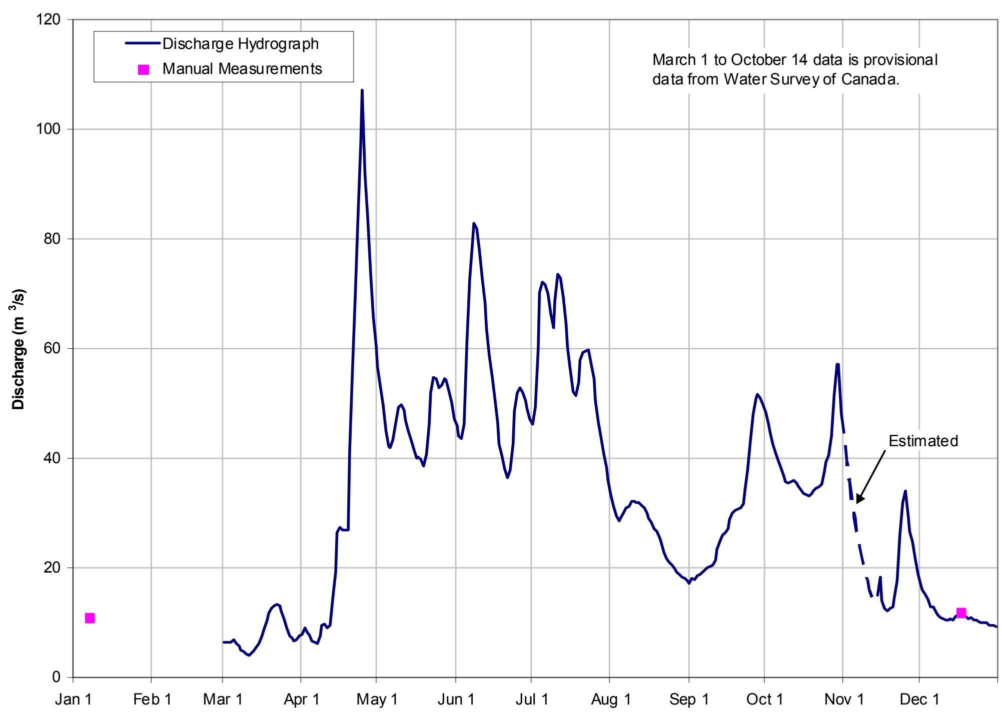
The site is located within a reach with extensive beaver activity and a meandering alignment. In July a beaver dam roughly 0.9 m high was constructed immediately over the water level sensor. Manual measurements capture the upper range of water levels monitored in 2003, however, due to the presence of the beaver dam during the late season, considerable uncertainty is associated with the water level measurements and consequently with the discharge estimates. The quality of the data collected at this station is considered to be fair.

Firebag River near the Mouth (07DC001) (S27)

Winter monitoring was initiated at the Firebag River station in November 2001 to supplement Water Survey of Canada open-water season monitoring. The station was discontinued at the end of 2002 due to the deferment of the True North project, but was reactivated in December 2003 at the request of Imperial Oil.

The hydrograph is shown on Figure 2.38.

Figure 2.38 2003 hydrograph for Firebag River near the Mouth (07DC001) (S27)



Water level sensing equipment had remained in place at the end of 2002 and operated throughout 2003. One discharge measurement was made in January 2003 to conclude the 2002 monitoring program, and a second discharge measurement was made in December 2003. Discharges during the open-water season were obtained from Water Survey of Canada, and discharges after October

14 were derived from the recorded water level. High water levels observed in November are believed to be due to ice effects, resulting in significant uncertainty in the discharge estimates during the freeze-up period. Because of that uncertainty, the quality of the winter data collected at this station during 2003 is considered to be fair.

2.3.3.4 Wetlands

McClelland Lake (L1)

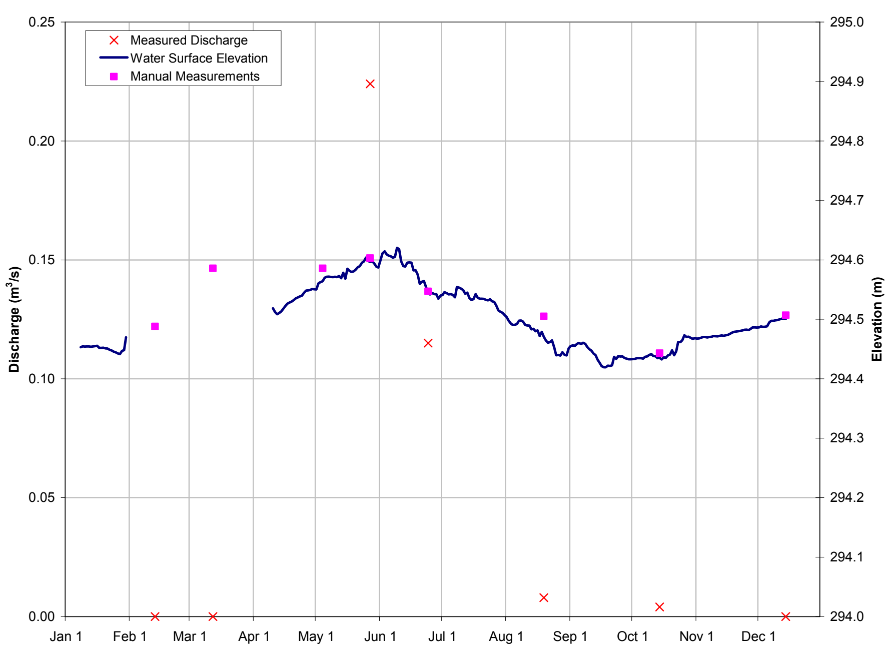
Lake water level and outflow have been monitored at L1 since 1997. A rain gauge is also operated at the site during the open water season.

Level sensing equipment was operated continuously throughout 2003, though ice effects and equipment malfunction prevented collection of reliable data between January 29 and April 12. On June 24, a newly calibrated water level sensor was installed. Manual measurements of lake outflow were made on four of the eight site visits.

The outflow channel is densely vegetated, poorly defined and easily obstructed. As a result, there is considerable scatter in the stage-discharge relationship, and the quality of the discharge data collected at this station is considered to be poor.

As shown in Figure 2.39, lake levels ranged within about 16 cm during the year.

Figure 2.39 2003 water level and discharge for McClelland Lake (L1).

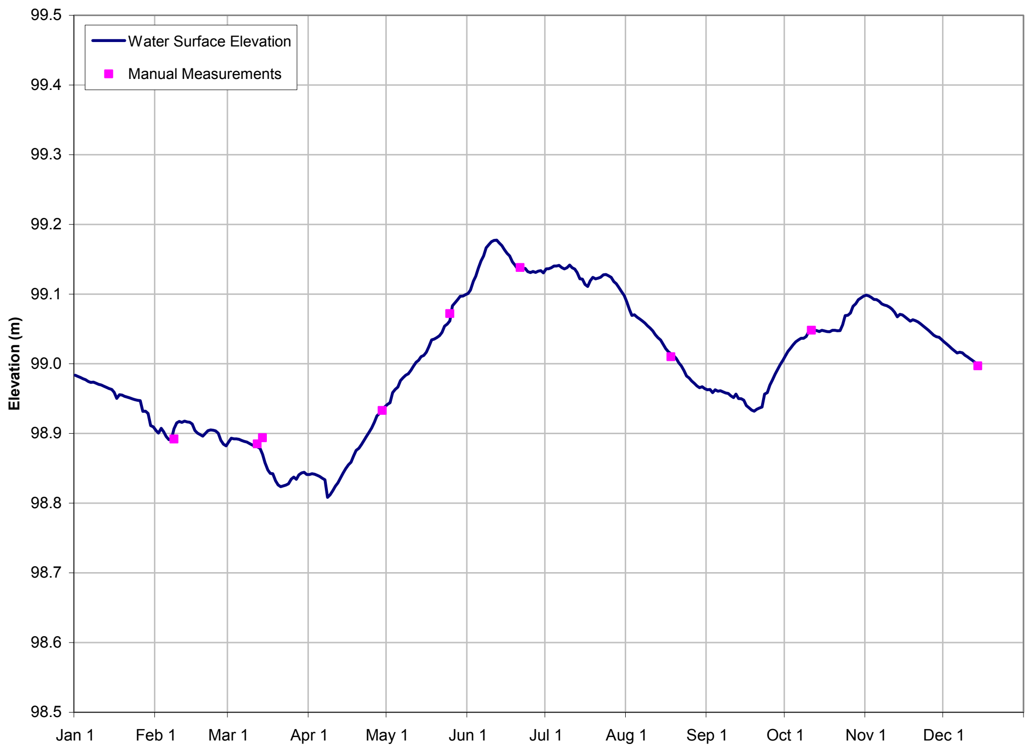


Kearl Lake (L2)

Lake water level has been monitored at L2 since 1999. Level sensing equipment was operated continuously throughout 2003. Manual measurements of lake water level were made on each of the eight site visits. The lake outflow is monitored at S9 as discussed above.

As shown in Figure 2.40, lake levels ranged within about 35 cm during the year, peaking in early June.

Figure 2.40 2003 water levels on Kearl Lake (L2).

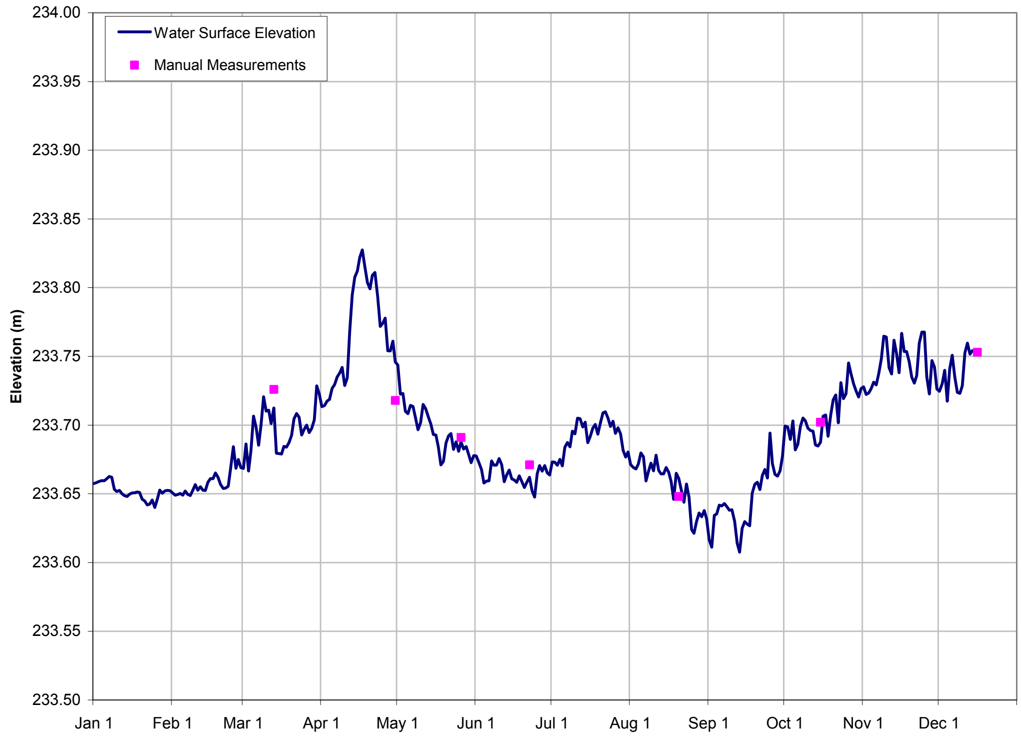


Isadore's Lake (L3)

Lake water level has been monitored at L3 since 2000. Level sensing equipment was operated continuously throughout 2003. Manual measurements of lake water level were made on each of the eight site visits.

As shown in Figure 2.41, lake levels ranged within about 20 cm during the year, peaking in mid April.

Figure 2.41 2003 water levels on Isadore's Lake (L3).

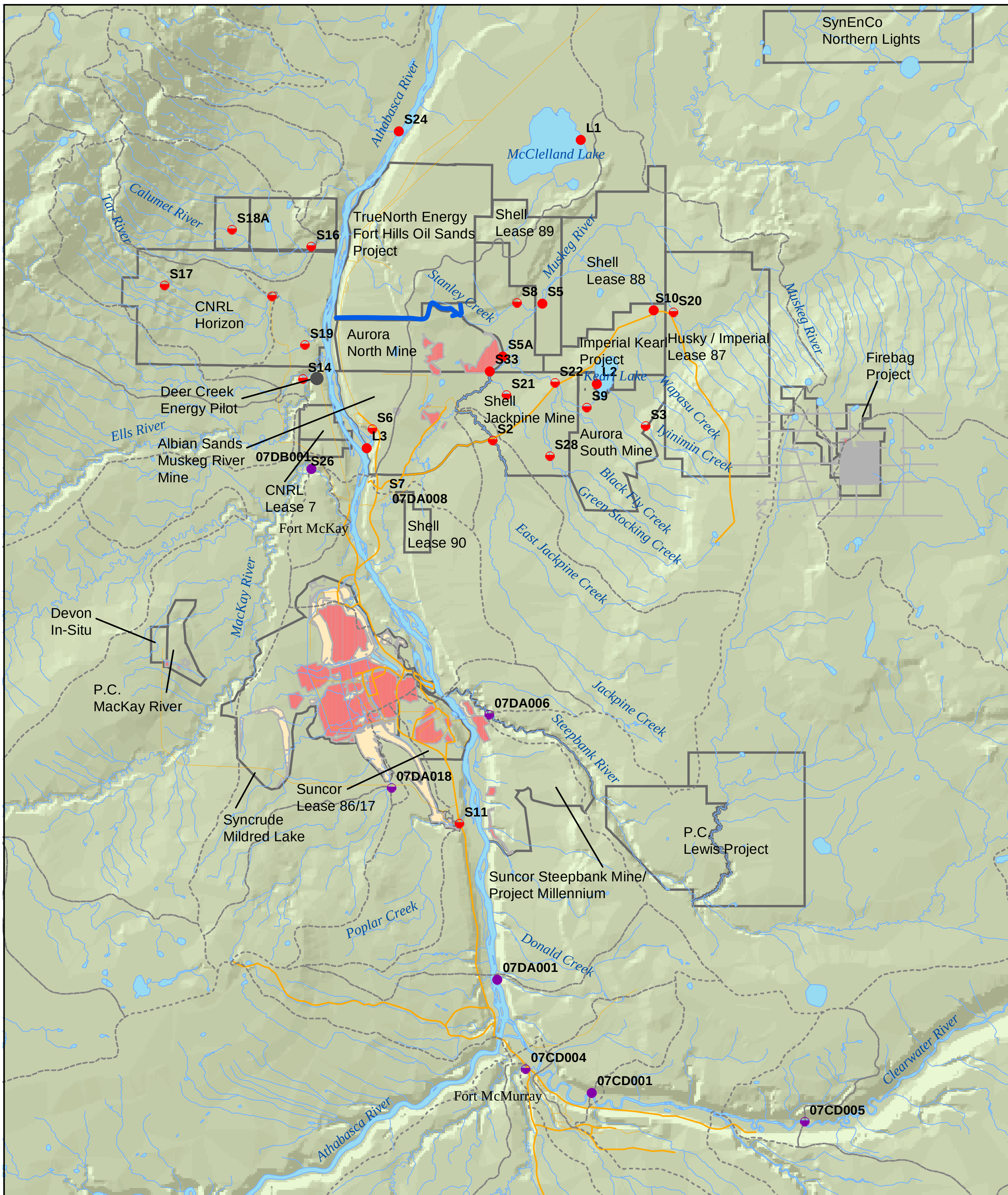


2.3.4 Catchment Changes

The usefulness of hydrometric data for many applications relies on knowledge of the catchment area contributing runoff to the monitored location. Therefore changes in catchment areas should be documented as part of a comprehensive hydrologic monitoring program.

Catchment areas contributing to each of the streamflow stations are shown on Figure 2.42. The data on the map is based on 2002 plans, and may not be entirely up to date for 2003. The map shows stream diversions, catchment disturbance and reclamation, and areas which do not contribute runoff to natural streams.

Figure 2.42 Oil Sands Area Catchment Status as of 2002.



Regional
Aquatics
Monitoring
Program

RAMP

DRAFT

Stream Diversion	
Major Roads	
Secondary Roads	
Rivers / Streams	
Lakes / Ponds	
Active Year-Round RAMP Hydrometric Station	
Active Seasonal RAMP Hydrometric Station	
Active Year-Round WSC Hydrometric Station	
Active Seasonal WSC Hydrometric Station	
Catchment Boundary	
Oil Sands Lease Boundary	
Undisturbed	
Disturbed	
Closed Circuit	
Reclaimed Area	

N W E S

0 5 10 20 km

Projection: UTM Zone 12 NAD83

Note: Station status is shown as of the end of 2003.

Data Sources:
National Topographic Data Base (NTDB) obtained from the Centre for Topographic Information - Sherbrooke, used under license.
Oil Sands Development Areas derived from CEMA Development Scenario GIS Mapping Database and Oil Sands Lease Boundaries from Alberta Government.
Catchment Boundary from PFRA Watershed Project Version 4, 2002, Agriculture and Agri-Food Canada.

G:\Data\Projects\RAMP1069\GIS\Fig2-42_OilSandsCatchment.mxd
18 March 2004

2.3.5 Suspended Sediment Data

Suspended sediment data collected at RAMP hydrometric stations in 2003 is presented in Table 2.7. Sediment concentrations are generally low, and frequently below detection limit.

Table 2.7 Suspended sediment data collected at RAMP streamflow stations in 2003.

Station No.	Stream Name	TSS (g/mL)	Date
L1	McClelland Lake	<3	4-May
		5	27-May
		<3	24-Jun
		5	14-Oct
L3	Isadore's Lake	<3	29-Apr
S2	Jackpine Creek at Canterra Road	7	29-Apr
		3	24-May
		10	23-Jun
		<10	18-Aug
		7	11-Oct
S3	Iyinimin Creek above Kearl Lake	5	4-May
		105	27-May
		52	23-Jun
		<10	19-Aug
		8	14-Oct
S5	Muskeg River above Stanley Creek	<3	4-May
		<3	27-May
		<10	23-Jun
		<10	19-Aug
		<3	14-Oct
S5A	Muskeg River above Muskeg Creek	5	30-Apr
		6	26-May
		13	23-Jun
		<10	18-Aug
		5	15-Oct
S6	Mills Creek at Highway 63	17	29-Apr
		<3	25-May
		<10	23-Jun
		<10	20-Aug
		3	15-Oct
S7	Muskeg River near Fort McKay (07DA008)	<3	28-Apr
		4	24-May
		<10	23-Jun
		<10	18-Aug
		5	11-Oct

Table 2.7 (cont'd).

Station No.	Stream Name	TSS (g/mL)	Date
S8	Stanley Creek near the Mouth	6	4-May
		<10	23-Jun
		19	19-Aug
S9	Kearl Lake Outlet	<3	28-Apr
		3	24-May
		<10	23-Jun
		<10	18-Aug
		<3	11-Oct
S10	Wapasu Creek at Canterra Road	5	29-Apr
		8	25-May
		<10	23-Jun
		<10	18-Aug
		<3	11-Oct
S11	Poplar Creek at Highway 63 (07DA007)	4	30-Apr
		23	25-May
		13	23-Jun
		<10	17-Aug
		5	15-Oct
S14	Ells River above Joslyn Creek	208	5-May
		99	28-May
		17	23-Jun
		<10	19-Aug
S15	Tar River near the Mouth	207	2-May
		31	25-May
		<10	23-Jun
		22	20-Aug
		5	12-Oct
S16	Calumet River near the Mouth	5	5-May
		3	27-May
		<10	23-Jun
		<10	19-Aug
		7	13-Oct
S17	Tar River Upland Tributary	47	5-May
		21	27-May
		<10	19-Aug
		12	13-Oct
S18A	Calumet River Upland Tributary	10	5-May
		5	27-May
		<10	23-Jun
		12	19-Aug
		3	13-Oct

Table 2.7 (cont'd).

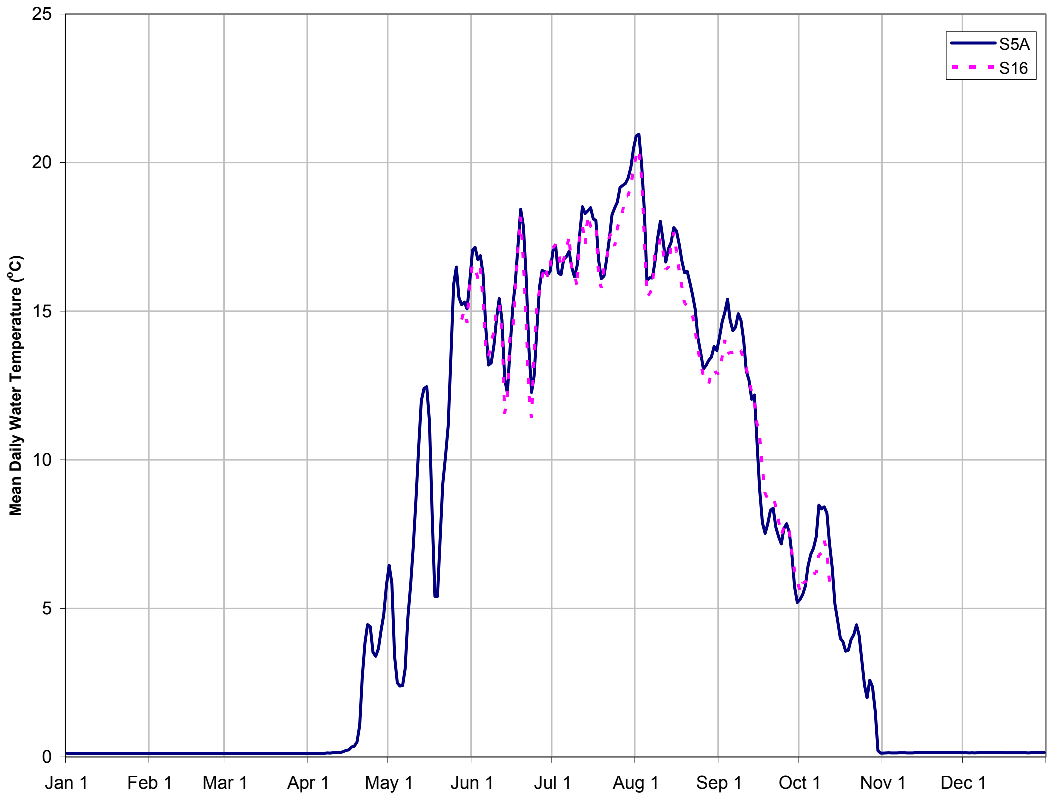
Station No.	Stream Name	TSS (g/mL)	Date
S19	Tar River Lowland Tributary near the Mouth	<3	2-May
		17	25-May
		16	23-Jun
		13	20-Aug
		<3	12-Oct
S20	Muskeg River Upland	<3	2-May
		3	24-May
		<10	23-Jun
		<10	18-Aug
		<3	11-Oct
S21	Shelley Creek near the Mouth	<3	4-May
		<3	27-May
		<10	23-Jun
		<10	19-Aug
		<3	14-Oct
S22	Muskeg Creek near the Mouth	10	28-Apr
		5	24-May
		<10	23-Jun
		<10	18-Aug
		3	11-Oct
S24	Athabasca River below Eymundson Creek	97	26-May
		109	23-Jun
		12	17-Oct
S26	MacKay River near Ft MacKay (07DB001)	7	18-Oct
S28	Khahago Creek below Black Fly Creek	<3	4-May
		<3	27-May
		<10	23-Jun
		<10	19-Aug
		<3	14-Oct
S29	Christina River near Chard (07CE002)	27	23-Jun
		11	20-Aug
		6	10-Oct
S33	Muskeg River at the Aurora / Albian Boundary	4	30-Apr
		6	26-May
		<10	23-Jun
		<10	18-Aug
		5	12-Oct

2.3.6 Water Temperature Data

Water temperature sensors are deployed at two of the RAMP hydrometric stations, Muskeg River above Muskeg Creek (S5A) and Calumet River near the Mouth (S16). Data collected at these stations is illustrated on Figure 2.43. Temperatures at the two locations were remarkably similar despite the differences in stream discharge and catchment aspect.

Water temperatures held at 0°C throughout the winter, as would be expected for flow below an ice cover. Temperatures began to increase at spring break-up in mid-April and peaked at over 20°C at the beginning of August. Temperatures in the range of 15°C were measured from late May to late August.

Figure 2.43 Mean daily water temperature at RAMP stations.



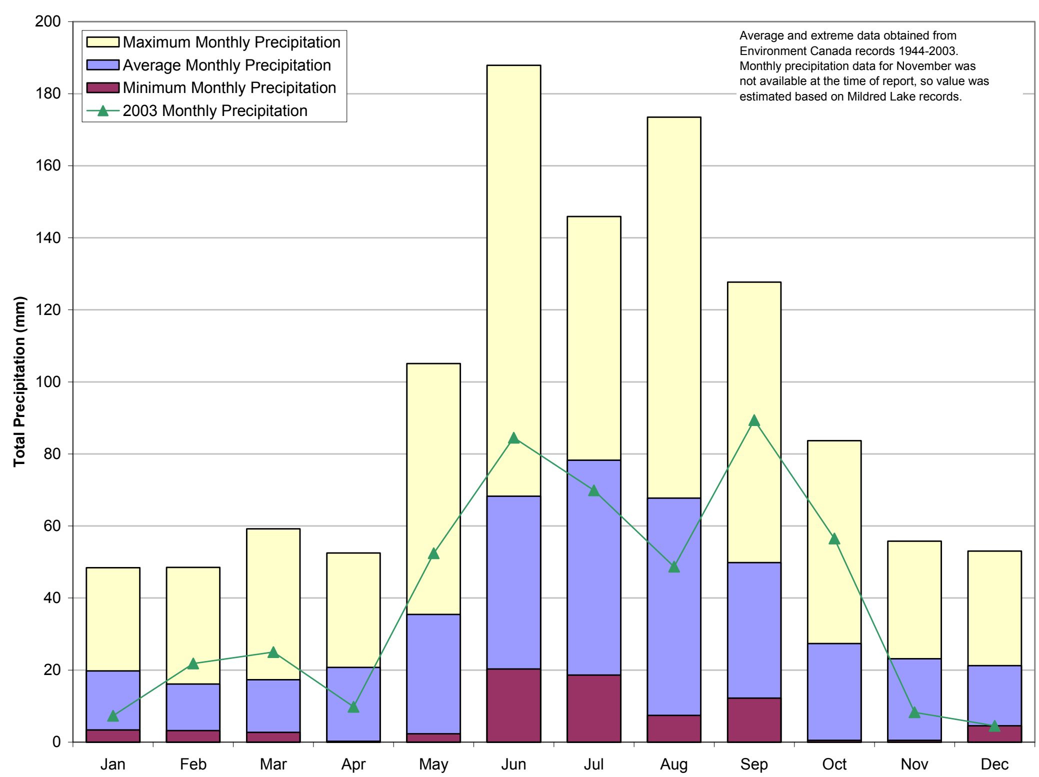
2.4 DISCUSSION

2.4.1 Historical Context

A general description of the 2003 climate and hydrology of the oil sands region, and comparison with previous years, is presented below to provide a context for the results of the 2003 RAMP monitoring program. The comparison is based primarily on Environment Canada climate and hydrometric monitoring stations because of the longer history available at those stations.

Precipitation in the area was slightly above normal in 2003. Total precipitation during 2003 measured at Fort McMurray Airport was 478 mm, compared to the 1944 to 2003 average of 445 mm. Precipitation over the water year November 1, 2002 to October 31, 2003 was 495 mm, 111% of normal. Distribution of the 2003 precipitation through the year is shown on Figure 2.44 compared to the average and extreme historical monthly precipitation. The 2003 monthly precipitation data are near average for most of the year, but well above average in September and October. December monthly precipitation was equal to the lowest previously recorded at Fort McMurray.

Figure 2.44 Total monthly precipitation at Fort McMurray.



For comparison, the annual rainfall measured at the Aurora Climate Station for the past eight years is shown on Figure 2.45 and in Table 2.8. The 323 mm of rainfall experienced in 2003 at the Aurora Climate Station was 92% of the eight-year average of 351 mm.

Figure 2.45 Historical annual rainfall at Aurora Climate Station (C1).

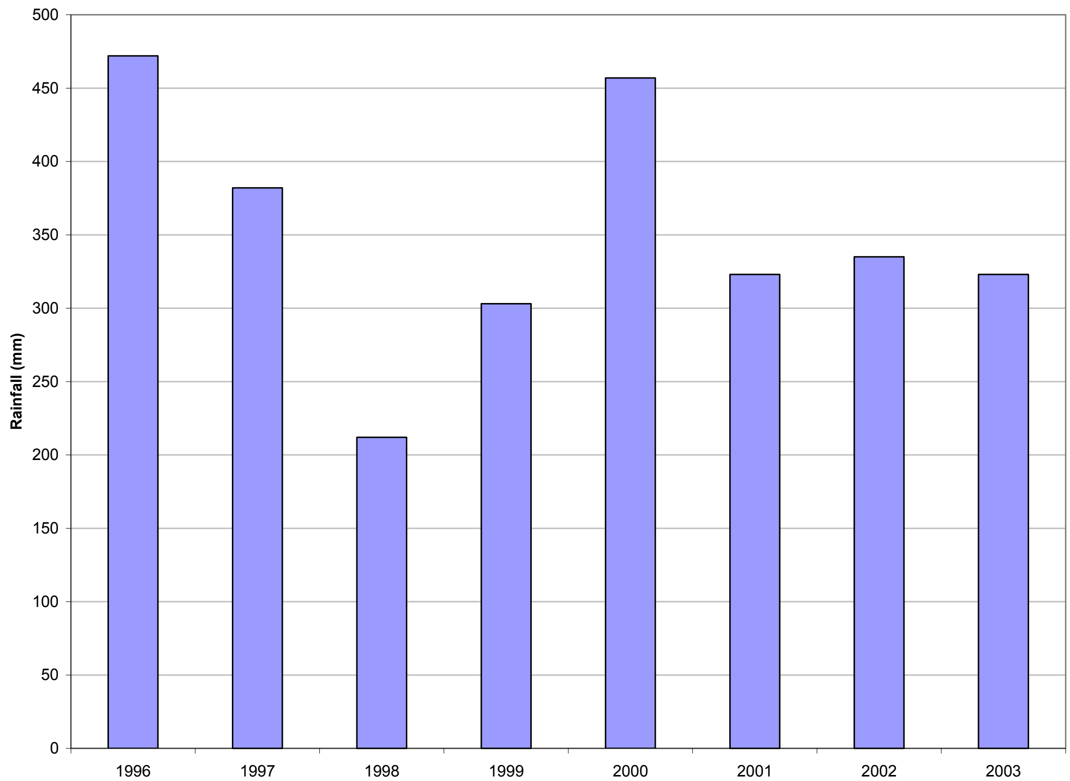


Table 2.8 Annual rainfall at C1 - Aurora Climate Station

Year	Rainfall (mm)
1996	472
1997	382
1998	212
1999	303
2000	457
2001	323
2002	335
2003	323
Mean	351

Snowpack measured in the Birch Mountains in 2003 was significantly greater than in the previous two years, averaging 74 mm across the various land types compared to 49 mm in 2001 and 39 mm in 2002.

Four representative regional WSC streamflow stations with long-term records were selected to characterize the 2003 streamflows in comparison with historical values. A summary of the mean annual runoff and maximum daily discharges observed at each station is provided in Table 2.9.

Table 2.9 2003 streamflow compared with historical flows.

	Athabasca River below McMurray (07DA001)	S7 - Muskeg River near Fort McKay (07DA008)	Steepbank River near Fort McMurray (07DA006)	S26 - MacKay River near Fort McKay (07DB001)
Effective Drainage Area (km^2)	131,000	1460	1320	5570
Period of Record	1957 - 2000	1974 - 2000	1972 - 2000	1972 - 2000
Annual Runoff Depth				
Historical mean (mm)	22.1	82.2[1]	105.8[1]	80.4[1]
2003 (mm)	17.0	86.7[1]	171.0[1]	55.9[1]
Annual Maximum Daily Discharge				
Historical mean (m^3/s)	2530	27.0	35.3	138.1
2003 (m^3/s)	1840	12.2	32.2	46.0

[1]Based on March 1 - October 31 volumes.

Flows in the Athabasca River measured at WSC station 07DA001 (Athabasca River below Fort McMurray) were well below normal, with a total annual volume of only 77% of the long-term average. The maximum daily discharge of 1840 m^3/s was well below the mean annual maximum daily discharge of 2530 m^3/s. The 2003 hydrograph is shown in Figure 2.46. The graph shows that streamflows were well below normal for much of the year, particularly before mid-April and from mid-July to late October.

In the Muskeg River basin, total runoff in 2003 was 5% above long-term average values, with a hydrograph as shown on Figure 2.47. However, the highest discharge of the year, which occurred in April, was less than half of the mean annual flood. An unusually late second peak of 11.4 m^3/s occurred in late October, presumably in response to 27 mm of precipitation over the four-day period of October 23 to 26.

Figure 2.46 Historical mean and extreme daily discharges for the Athabasca River at Fort McMurray (07DA001).

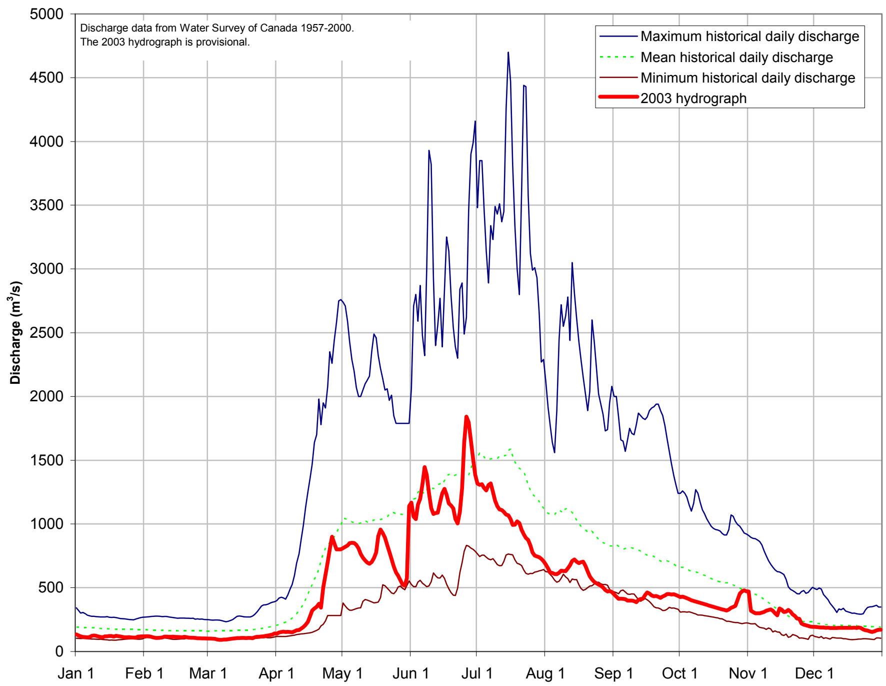
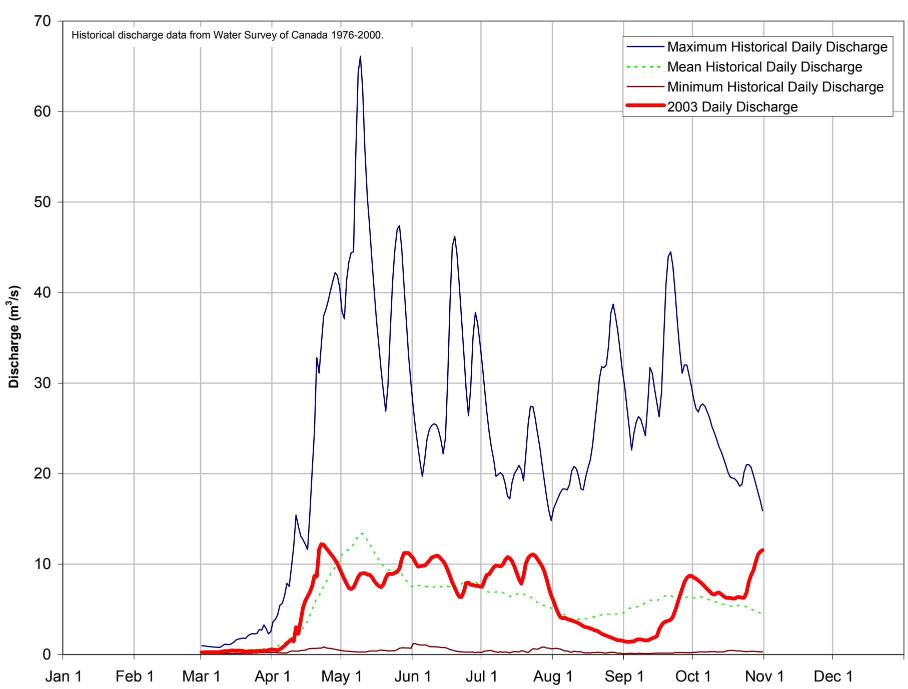
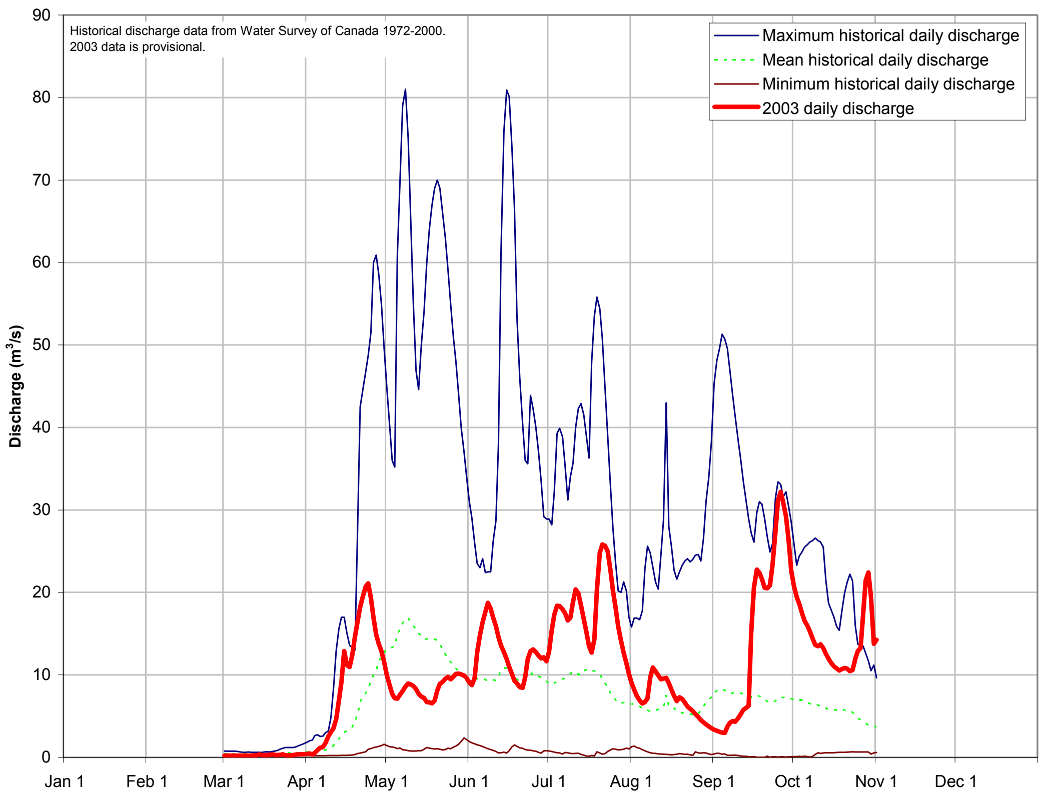


Figure 2.47 2003 discharge hydrograph at S7 - Muskeg River near Fort McKay (07DA008) compared to historical mean and extreme daily discharges.



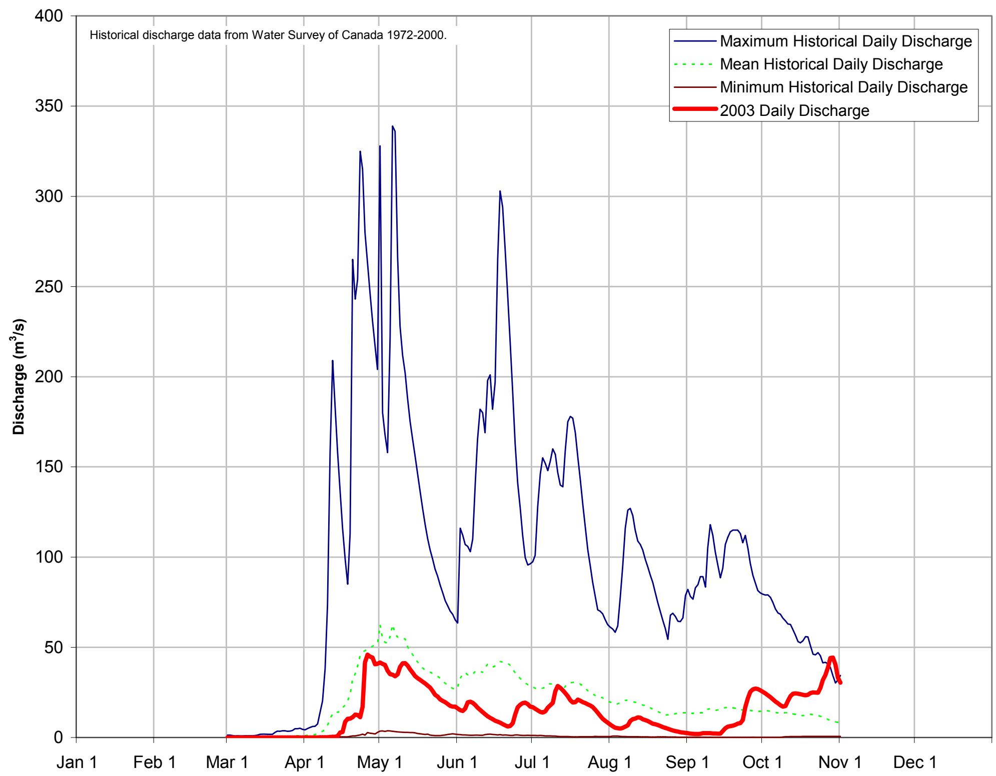
Runoff in the Steepbank River basin was much greater than usual, with an annual runoff volume 62% above average. The annual hydrograph for the Steepbank River near Fort McMurray (WSC 07DA006) is shown on Figure 2.48. The late October peak which was observed in the Muskeg River basin was also evident in the Steepbank, but the highest flow of the year occurred late in September after 26 mm of rain was recorded at the Aurora Climate station from September 22 through 25. The September flood peak of 32.2 m^3/s was close to the highest flow recorded after mid-September, and was only slightly lower than the historical mean annual flood.

Figure 2.48 Historical mean and extreme daily discharges for the Steepbank River near Fort McMurray (07DA006).



On the west side of the Athabasca River, the MacKay River basin experienced well below normal flows. The total annual runoff was only 70% of normal, and the maximum daily discharge was only 33% of the mean annual flood. The 2003 hydrograph is compared to historical means and extremes on Figure 2.49.

Figure 2.49 2003 discharge hydrograph at S26 - MacKay River near Fort McKay (07DB001) compared to historical mean and extreme daily discharges.



In summary, 2003 was near average in terms of precipitation in the RAMP study area. Basin runoff varied significantly between basins, being below normal in the MacKay and Athabasca basins, near normal in the Muskeg basin, and well above normal in the Steepbank basin. Peak flows were below normal in all four basins. Unusual hydrologic features of the year included the uncharacteristically warm temperatures in early January and a relatively wet autumn.

2.4.2 Assessment of 2003 Monitoring Results

Results of the 2003 hydrometric monitoring at RAMP and selected Environment Canada stations as presented in Table 2.6 are compared on Figure 2.50 for summer runoff, Figure 2.51 for maximum daily discharge, and Figure 2.52 for summer minimum daily discharge. The figures illustrate the hydrologic variability of the various catchments, and provide a basis for comparison of hydrologic conditions upstream and downstream of development. Stations downstream of development include the Athabasca River below Eymundson Creek (S24), Muskeg River near Fort McKay (S7) and Muskeg River at the Aurora/Albian Boundary (S33).

Figure 2.50 illustrates the relationship between summer runoff volume and catchment area at the various catchments. Summer runoff is defined for this figure as the runoff between May 5 and October 11 to consider the concurrent period of record and provide a consistent basis for comparison of the various stations. As shown in Figure 2.50, there is considerable scatter in the relationship, illustrating differences in climate and in hydrologic response of the catchments. There is no evident difference between the stations downstream of development (S24, S7 and S33) and the other stations.

Figure 2.50 2003 summer runoff volume from monitored catchments in the study area.

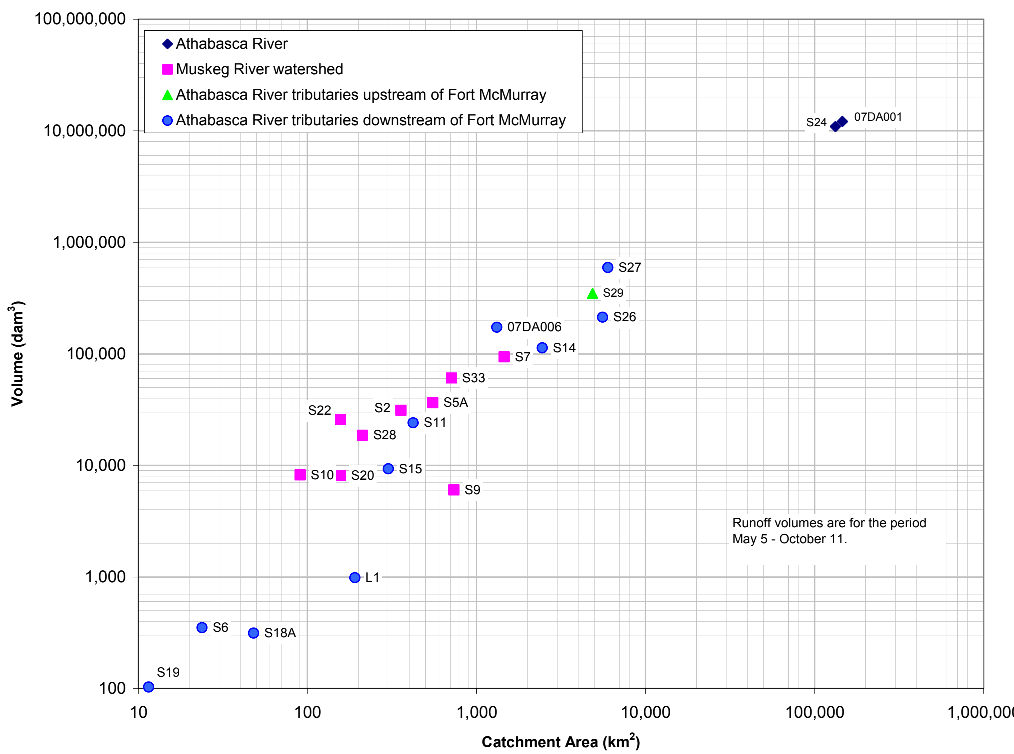


Figure 2.51 illustrates the relationship between the annual maximum daily discharge and catchment area at the various stations. Again, there is significant scatter in the relationship, and the stations downstream of development exhibit no evident deviation from the general trend. The maximum daily discharge at Kearl Lake Outlet (S9) is well below the general trend because of the attenuating effect of Kearl Lake on peak discharges.

Figure 2.52 illustrates the relationship between the minimum daily summer (May 5 – October 11) discharge and catchment area. Stations S24, S7 and S33 fall well within the scatter observable on the figure.

Figure 2.51 2003 maximum daily discharge in monitored streams.

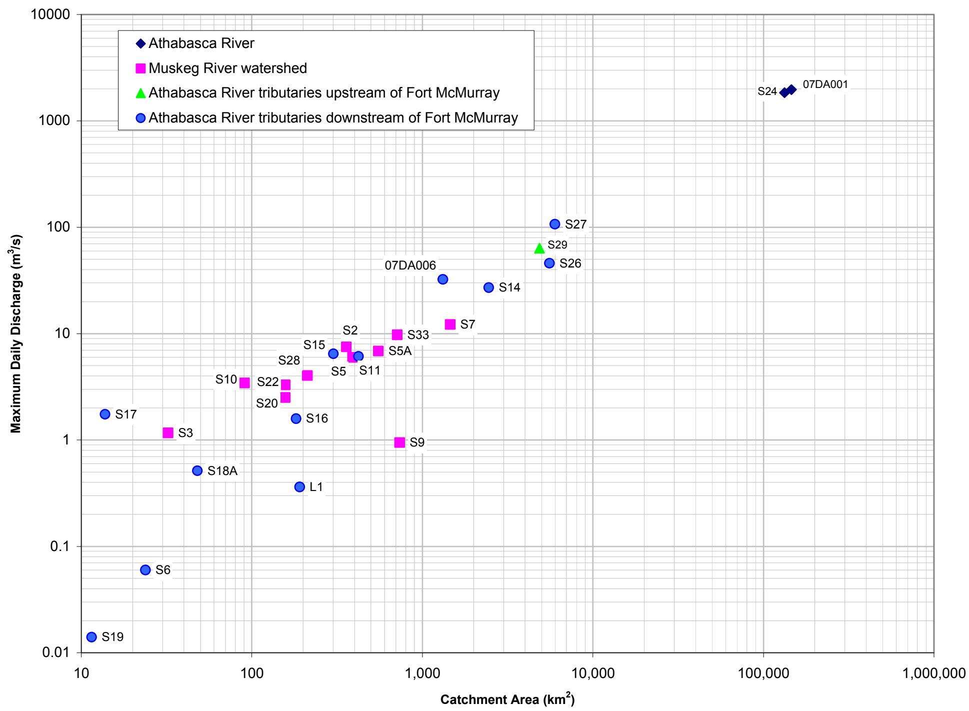
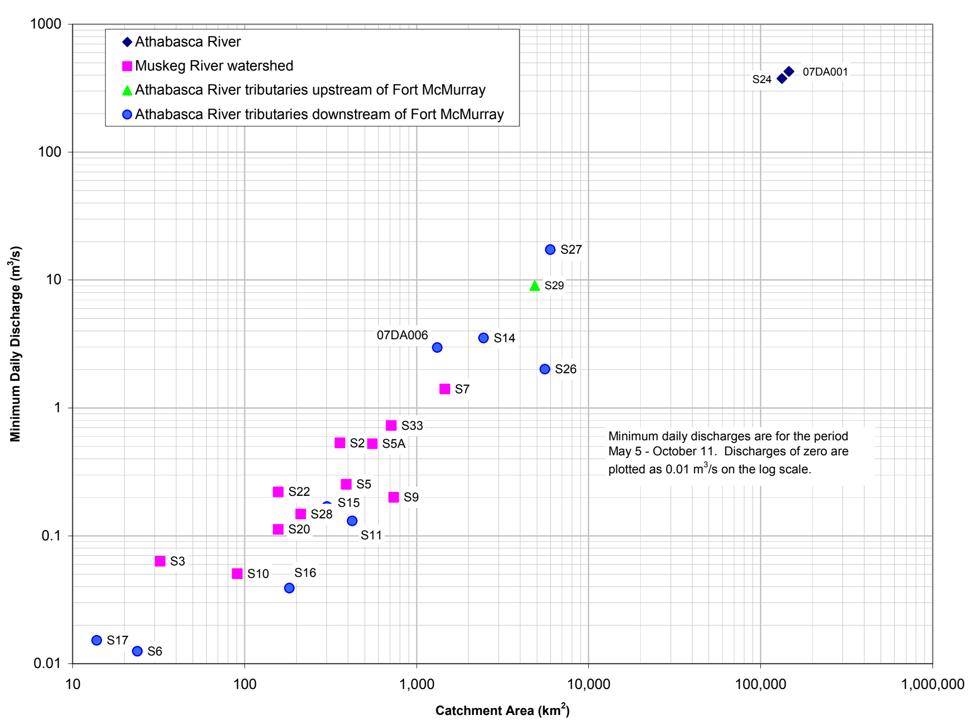


Figure 2.52 2003 minimum daily discharge in monitored streams.



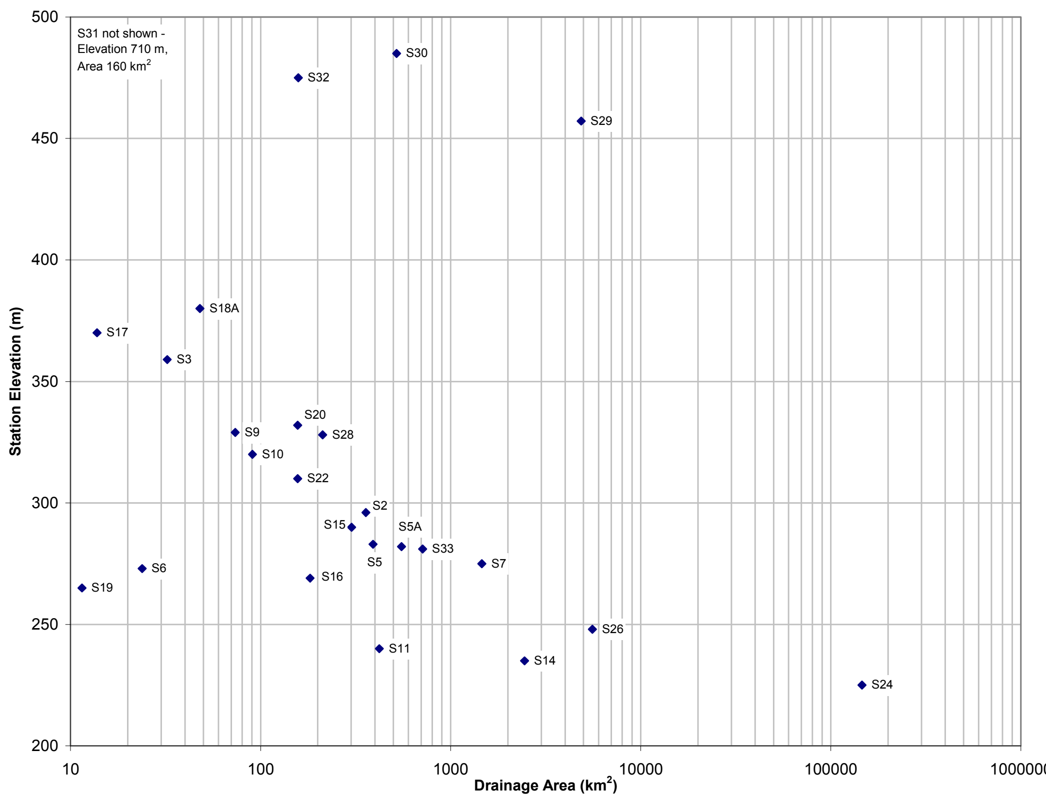
2.4.3 Program Evaluation

The hydrologic component of RAMP was evaluated against four of the RAMP objectives listed in Chapter 1 that are most relevant to the climate and hydrology component. The program performance in terms of each of the objectives is discussed below, and opportunities to improve the program are identified.

Objective No. 1: *To collect scientifically defensible baseline and historical data to characterize variability in the oil sands area.*

Collection of scientifically defensible baseline data sufficient to characterize natural variability in terms of runoff requires that streamflows originating on a variety of natural catchments across the area be monitored at consistent locations, with high accuracy, over a period of twenty years or more. Streamflows from a number of natural catchments are included in the RAMP program. Locations of the streamflow stations are shown on Figure 2.7 and Figure 2.8. The catchments vary in size, aspect and elevation. The distribution of station elevations and catchment sizes is illustrated in Figure 2.53, and illustrates a good variety and range of both parameters.

Figure 2.53 RAMP station elevation and drainage areas.



The accuracy of the data that is being obtained from the existing stations varies widely due to the hydraulic conditions at the various stations. The current program includes a quality assessment of each streamflow measurement, rating curve and streamflow record, so that users of the data can assess the value and accuracy of the information. Specific problems at some of the stations are discussed in Section 2.3.3 above.

The streamflow data must be supported by systematic climate monitoring, particularly the basic parameters of precipitation and temperature. Locations of both RAMP and MSC rainfall gauges are shown in Figures 2.5 and 2.6, and show good coverage of the area north of Fort McMurray. The area south of Fort McMurray is well covered during the summer, but there are no active year-round climate stations in that area. Snow surveys have been conducted in the area north of Fort McMurray, but a consistent snow survey program has not been adopted.

The period of record at the RAMP stations varies, as shown in Table 2.2. The earliest stations were established in 1995, and so have accumulated nine years of data by the end of 2003. Unfortunately, some disturbance has occurred in many of the catchments contributing to these stations, and many of the other stations have much shorter periods of record. It is important that the program be continued to augment the periods of record at the various stations, and that future stations installed to monitor baseline data be located where the potential for future disturbance of the catchment is minimal.

In summary, the program performance in terms of the first objective is generally good. The streamflow network includes a good range of catchments. Accuracy of the collected data ranges from fair to excellent, and the period of record is developing. The program could be improved by ensuring that each streamflow station operates long enough at the same location to develop a long period of record, by developing a consistent wide-area snowcourse survey program, and by establishing a year-round climate station for the area south of Fort McMurray.

Objective No. 2: *To collect data against which predictions contained in environmental impact assessments (EIAs) can be verified.*

Predicted hydrologic impacts contained in EIAs consisted of changes in streamflow parameters such as the magnitude of the mean annual discharge, the magnitude of extreme discharges (e.g. 1:10 year maximum instantaneous discharge, 1:10 year minimum winter discharge), and the timing of streamflows. Those predictions were based on predicted water withdrawals and releases, and on predicted catchment changes such as stripping, muskeg drainage, runoff containment, and stream diversions.

Large changes could potentially be detected by comparison of the specified streamflow parameters for periods before and after development, or at stations upstream and downstream of development. However, reliable estimates of the streamflow parameters require many years of data because of the large natural variability of hydrologic response, as illustrated on Figure 2.50, Figure 2.51 and Figure 2.52. Uncertainty in the parameters is large enough to mask small impacts.

Another way to verify the changes predicted in the EIAs is to compare the annual hydrograph which actually occurs at a monitoring location with the natural hydrograph that would have occurred without development. This method can quantify small changes and does not require long periods of record for analysis. The natural hydrograph is computed by adjusting the recorded hydrograph to account for water withdrawals, releases, stream diversions and changes in catchment area. Recorded streamflows could then be compared to natural streamflows, and impacts could be quantified and compared to EIA predictions.

The existing RAMP program is focused on monitoring actual streamflows, but does not collect the data required to estimate what natural streamflows would have been. That data includes:

- an annual map of catchment area disturbance and reclamation, changes to catchment boundaries, and stream diversion locations, as shown on Figure 2.42; and

- daily discharges at water diversion, withdrawal and release points.

The RAMP program could be improved by including this data in the RAMP database. Much of this data is already being collected for other purposes, and it should not be difficult to incorporate it into RAMP. Some of the RAMP operators have already contributed data to the 2003 RAMP database, and that data is included in the current report.

Objective No. 3: *To monitor aquatic environments in the oil sands area to detect and assess cumulative effects and regional trends.*

The data required to detect and assess cumulative effects is the same information as is required to verify EIA predictions (Objective No. 2). Detecting and assessing regional trends requires the same information as is required for a hydrologic baseline (Objective No. 1).

Objective No. 4: *To collect data that may be used to satisfy the monitoring required by regulatory approvals of developments in the oil sands area.*

The program is adjusted on an ongoing basis to meet regulatory monitoring requirements identified by RAMP members, so that the station network is believed to be adequate to meet this objective.

2.4.4 Recommendations

The following recommendations are based on recommendations made in previous reports, input from technical subcommittee meetings, and experience gained during 2003.

1. Include information about catchment changes and water withdrawals and releases in the RAMP database and reports.

As discussed in Section 2.4.3, collection of this data is essential to allow calculation of natural flows and consequently the potential impact of development.

2. Conduct a regional snow survey. The program should address both spatial and temporal considerations, meaning different terrain types, and should include several trips over the winter to monitor snowpack change over the season.

The rationale for this recommendation is that there is no other snow survey program or historic data source. There is a concern that long-term variability has not been captured due to extended dry conditions, and data is required for further model calibration and validation.

This recommendation has been incorporated into the 2004 program. Snow surveys are planned for January, February and March 2004. Locations of the snow survey sites were selected to:

- Obtain wide distribution across the study area;
- obtain representative coverage within dominant terrain and vegetation types, elevation, aspect, and geographic location;
- permit direct comparison with data collected from continuous climate monitoring equipment;
- allow for comparison with locations of snow surveys conducted in previous years;
- maximize efficiencies relating to other monitoring activities; and
- facilitate efficient access.

The sixteen proposed snow survey plots are distributed throughout the RAMP study area, as far north as McClelland Lake (L1) and as far south as the Christina River catchment near Chard (S29), with eight sites concentrated within the Muskeg River basin and four along the east slopes of the Birch Mountains. It is intended that the same sites be monitored routinely for several years.

3. Establish flow monitoring at new locations in the CNRL lease area to replace stations S15 (to be discontinued in 2004) and S19 (potentially discontinued in the near future).

Selection of a discontinued WSC site is preferred because of the opportunity to correlate new monitoring with historical data. The recommended site is Joslyn Creek near Fort McKay (WSC 07DA016). The establishment of the station has been included in the planned 2004 program.

4. Re-evaluate the distribution of rainfall/precipitation/climate stations.

A prerequisite to the re-evaluation is the preparation of a comprehensive map of existing climate stations including both RAMP stations and Environment Canada stations, which has been completed as shown on Figures 2.5 and 2.6. The evaluation should also include consultation with other components of RAMP.

5. Improve monitoring south of Fort McMurray by upgrading the Christina River rainfall gauge to measure snowfall, and by re-establishing two of the discontinued Petro-Canada Meadow Creek stations S31 – Hangingstone Creek near the Mouth, and S32 – Surmont Creek at Highway 881.

An alternative to one of the Petro-Canada stations is the discontinued WSC station at Roberts Creek. However, that station is considered to provide low-quality data based on information from WSC. Therefore re-establishment of that station is not recommended. Establishment of two new stations is included in the 2004 program.

6. Investigate ways to obtain data from the field on a more timely basis.

Based on 2003 experience, the remote download system has been unreliable, cumbersome, and time-consuming. Before investing in additional telemetry equipment, means of improving the system reliability should be investigated. If a reliable system can be developed, the highest priority for a new installation should be the Aurora Climate Station, because of the more general and immediate interest in the data from that station. If a more reliable system cannot be found, the number of field visits should be increased from ten to twelve per year, to accommodate monthly reporting requirements by industry.

7. Review the value of selected stations in the network.

Several stations included in the program appear to provide little value in terms of Objectives No. 1 to 3 discussed in the previous section. Unless those stations are required for regulatory compliance or specific purposes beyond the RAMP objectives, it is recommended that consideration be given to discontinuing or modifying these stations, as discussed below.

- S8 – Stanley Creek near the Mouth is located on a poorly-defined stream. The stream boundaries are so poorly defined that ordinary streamflow measurements are not feasible, and the RAMP program to date has included only water level measurements. Water level measurements without streamflow information have little value except in a lake or wetland where the water level has an influence on aquatic habitat. The station is relatively costly to operate, requiring helicopter access. Therefore the need for this station should be re-examined.

- S21 – Shelley Creek near the Mouth is similar to S8, in that it is located within muskeg lowlands on an poorly-defined stream. The local gradient is very low, and the water flows through densely vegetated muskeg. Beaver activity is evident in the immediate vicinity, and a beaver dam roughly 0.6 m high was in place roughly 150 m upstream of the site throughout 2003. There appears to be no definable relationship between water level and discharge at this location. S21 is only accessible by helicopter, and is therefore costly to operate. The need for this station should be re-examined, or the station should be relocated.

8. Present historical maximum, mean and minimum daily discharges along with the current year's recorded daily discharge for each RAMP hydrometric station in the annual report.

Inclusion of the mean and range of previous discharges would provide a context for the current year's observations, enabling quick interpretation of the current year's hydrograph and illustrating the range of historical variability.

Conversion of the hydrologic database from the previous Excel files to Access will enable the mean and range to be extracted and graphed quickly and easily.

3.0 WATER QUALITY

3.1 OVERVIEW OF 2003 PROGRAM

Water quality was sampled by RAMP at 47 stations throughout the lower Athabasca River watershed in 2003, including:

- 14 stations on the Athabasca River mainstem (two sampled by Alberta Environment), from upstream of Fort McMurray to the Athabasca River delta;
- One station in the Athabasca River delta;
- Nine stations in the Muskeg River watershed, including two sampled by industry and one by industry and Alberta Environment;
- Four stations in the Clearwater River watershed, including two in the Christina River;
- Three stations in the Steepbank River watershed, including the Steepbank and North Steepbank rivers;
- Two stations in the MacKay River;
- Two stations in the Firebag River;
- Seven stations in other tributaries to the Athabasca River, including McLean Creek, Poplar Creek, Beaver River, Ells River, Tar River, Calumet River and Fort Creek; and
- Three regional lakes, including Kearl Lake, Shipyard Lake, and McClelland Lake.

All stations were sampled in fall, while several stations were also sampled in winter (20 stations sampled), spring (22 stations sampled) and summer (23 stations sampled).

At each station, numerous water quality variables were measured, including:

- Physical variables (e.g., temperature, dissolved oxygen, conductivity and colour)
- Ion balance, buffering capacity and concentrations of major ions (i.e., pH, alkalinity, bicarbonate, hardness, calcium, sodium, potassium, magnesium, chloride, sulphate and sulphide);

- Nutrients (i.e., nitrogen and phosphorous) and BOD;
- Concentrations of various metals (both total and dissolved fractions); and
- Aromatic organic compounds (i.e., total phenolics, naphthenic acids, total recoverable hydrocarbons, and at selected stations in the Athabasca River mainstem in fall, polycyclic aromatic hydrocarbons [PAHs]).

Additionally, chronic toxicity of ambient river waters was assessed in fall for the Ells, Tar, and Calumet rivers. Detailed methods and results of the 2003 water quality program appear below.

3.2 METHODS

The 2003 RAMP water quality program included quarterly sampling of rivers and lakes in the RAMP Study Area, to document water quality and assess any changes in water chemistry or quality that may occur due to oil sands development or other factors affecting the natural environment. Specific timing of seasonal sample programs in 2003 appears below (Table 3.1).

Table 3.1 RAMP water quality sampling field campaigns, 2003.

Season	Duration
Winter 1[1]	January 7, 2003
Winter 2	March 21 to March 26, 2003
Spring	May 21 to May 28, 2003
Inter-lab "round robin" comparison[2]	July 1, 2003
Summer	July 21 to July 23, 2003
Fall[3]	September 6 to September 22, 2003

[1] Winter 1 water quality sampling (at Athabasca River station ATR-DD) was undertaken by the 2002 RAMP implementation team and was reported in the 2002 RAMP report. All other sampling was undertaken by the 2003 RAMP implementation team.

[2] Quality Assurance sampling program is discussed further in Appendix A1.

[3] Fall program conducted in conjunction with sediment quality sampling.

Generally, stations were selected to serve one of three purposes: to provide baseline data for characterization of natural variability prior to development; to measure water quality near to and downstream from existing oil sands developments; or, to act as an upstream reference station for comparison with areas possibly affected by oil sands development.

3.2.1 Station Locations

Discrete water quality sampling in 2003 was focused on the Athabasca River and its major tributaries in the Athabasca oil sands region, as well as regionally important lakes and wetlands. Sampling was conducted by RAMP, with data also contributed from Alberta Environment (AENV) and individual oil sands operators for some locations. Water quality was examined at a total of 47 stations in 2003. Table 3.2 summarizes water quality sampling stations, frequency of seasonal sampling, and water quality parameters measured at each station.

Table 3.2 Summary of the RAMP 2003 water quality program.

Station identifier and location		Analytical package[A] / Season				Sample type
		W[B]	S	S	F	
Athabasca River mainstem						
ATR-UFM	*Upstream of Fort McMurray*	*13*	*11*	*13*	*11*	*AENV sampling*
ATR-DC-CC	Upstream of Donald Creek (x-channel)	-	-	-	3	Cross-channel comp.
ATR-DC-W	Upstream of Donald Creek (west bank)	-	-	-	1	West bank grab
ATR-DC-E	Upstream of Donald Creek (east bank)	-	-	-	1	East bank grab
ATR-SR-W	Upstream of Steepbank River (west bank)	-	-	-	1	West bank grab
ATR-SR-E	Upstream of Steepbank River (east bank)	-	-	-	1	East bank grab
ATR-MR-W	Upstream of Muskeg River (west bank)	-	-	-	1	West bank grab
ATR-MR-E	Upstream of Muskeg River (east bank)	-	-	-	1	East bank grab
ATR-FC-W	Upstream of Fort Creek (west bank)	-	-	-	1	West bank grab
ATR-FC-E	Upstream of Fort Creek (east bank)	-	-	-	1	East bank grab
ATR-DD	Downstream of development (x-channel)	1,1	1	1	3	Cross-channel comp.
ATR-FR	Upstream of Firebag River	-	-	-	1	Cross-channel comp.
EMR-1	Embarras River	-	-	-	1	Mid-channel grab
ATR-OF	*At Old Fort*	*12*	*12*	*12*	*12*	*AENV sampling*
Athabasca River delta						
ARD-1	Big Point Channel	-	-	-	1	Mid-channel grab
Athabasca River tributaries south of Fort McMurray (Clearwater River and tributaries)						
CLR-1	Clearwater R. (u/s of Fort McMurray)	1	7	7	8	Cross-channel comp.
CLR-2	Clearwater River (u/s of Christina River)	1	7	7	8	Mid-channel grab
CHR-1	Christina River (mouth)	1	1	1	3	Mid-channel grab
CHR-2	Christina River (upstream of Janvier)	1	1	1	3	Mid-channel grab
Athabasca River tributaries north of Fort McMurray						
MCC-1	McLean Creek (mouth)	-	6	6	7	Mid-channel grab
POC-1	Poplar Creek (mouth)	-	-	-	1	Mid-channel grab
STR-1	Steepbank River (mouth)	-	-	-	1	Mid-channel grab
STR-2	Steepbank R. (u/s of Suncor-Millennium)	-	-	-	1	Mid-channel grab
NSR-1	North Steepbank R. (u/s of PC-Lewis)	1[C]	1	1	1	Mid-channel grab
BER-1	Beaver River (mouth)	-	-	-	1	Mid-channel grab
MAR-1	MacKay River (mouth)	-	-	-	1	Mid-channel grab
MAR-2	MacKay River (upstream of PC-MacKay)	1	1	1	1	Mid-channel grab
ELR-1	Ells River (mouth)	1[C]	1	1	2	Mid-channel grab
Athabasca River tributaries north of Fort McMurray						
TAR-1	Tar River (mouth)	1[C]	1	1	2	Mid-channel grab
FOC-1	Fort Creek (mouth)	-	6	6	7	Mid-channel grab
FIR-1	Firebag River (mouth)	1	1	1	1	Mid-channel grab
FIR-2	Firebag R. (upstream of Suncor-Firebag)	1	1	1	1	Mid-channel grab

Table 3.2 (Cont'd.)

Station identifier and location		Analytical package[A] / Season				Sample type
		W[B]	S	S	F	
Muskeg River and tributaries						
MUR-1	Muskeg River (mouth)	-	-	-	1	Mid-channel grab
MUR-2	*U/S of Canterra Rd. crossing*	*4*	*4*	*4*	*4*	*Albian sampling*
MUR-2	*U/S of Canterra Rd. crossing*	*15*	*15*	*15*	*14*	*AENV sampling*
MUR-4	*Upstream of Jackpine Creek*	*4*	*10*	*10*	*10*	*Syncrude sampling*
MUR-5	*Upstream of Muskeg Creek*	*10*	*10*	*10*	*10*	*Syncrude/Albian*
MUR-6	Upstream of Wapasu Creek	-	6	6	7	Mid-channel grab
JAC-1	Jackpine Creek (mouth)	-	-	-	1	Mid-channel grab
MUC-1	Muskeg Creek (mouth)	-	-	-	1	Mid-channel grab
STC-1	Stanley Creek (mouth)	1[C]	1	1	1	Mid-channel grab
Wetlands						
KEL-1	Kearl Lake (composite)	1	-	-	1	Multi-location comp.
SHL-1	Shipyard Lake (composite)	-	-	1	1	Multi-location comp.
MCL-1	McClelland Lake (composite)	-	-	-	1	Multi-location comp.
Additional sampling (Non-core programs)						
CAR-1	Calumet River (mouth)	1[C]	1	1	2	Mid-channel grab
-	Potential TIE[D]	-	-	-	-	Not undertaken[D]
Quality Assurance/Quality Control						
-	Field & trip blanks	1,1	1	1	1	N/A
-	Inter-laboratory comparison[E]			1		N/A

[A] Legend to Analytical Packages:

1 RAMP standard (conventionals, major ions, nutrients, tot./diss. metals, rec. HC, napth. acids)

2 RAMP standard + toxicity

3 RAMP standard + PAHs

4 RAMP standard + PAHs + toxicity

5 OPTI Lakes analytical package (2002)

6 Continuously-monitoring thermograph

7 RAMP standard + thermograph

8 RAMP standard + PAHs + thermograph

9 RAMP standard + toxicity + thermograph

10 RAMP standard + PAHs + toxicity + thermograph

11 AENV routine

12 AENV routine +RAMP standard

13 AENV routine + PAHs

14 AENV routine + DataSonde

15 AENV routine + PAHs + DataSonde

[B] Includes both Winter 1 and Winter 2 sampling of ATR-DD.

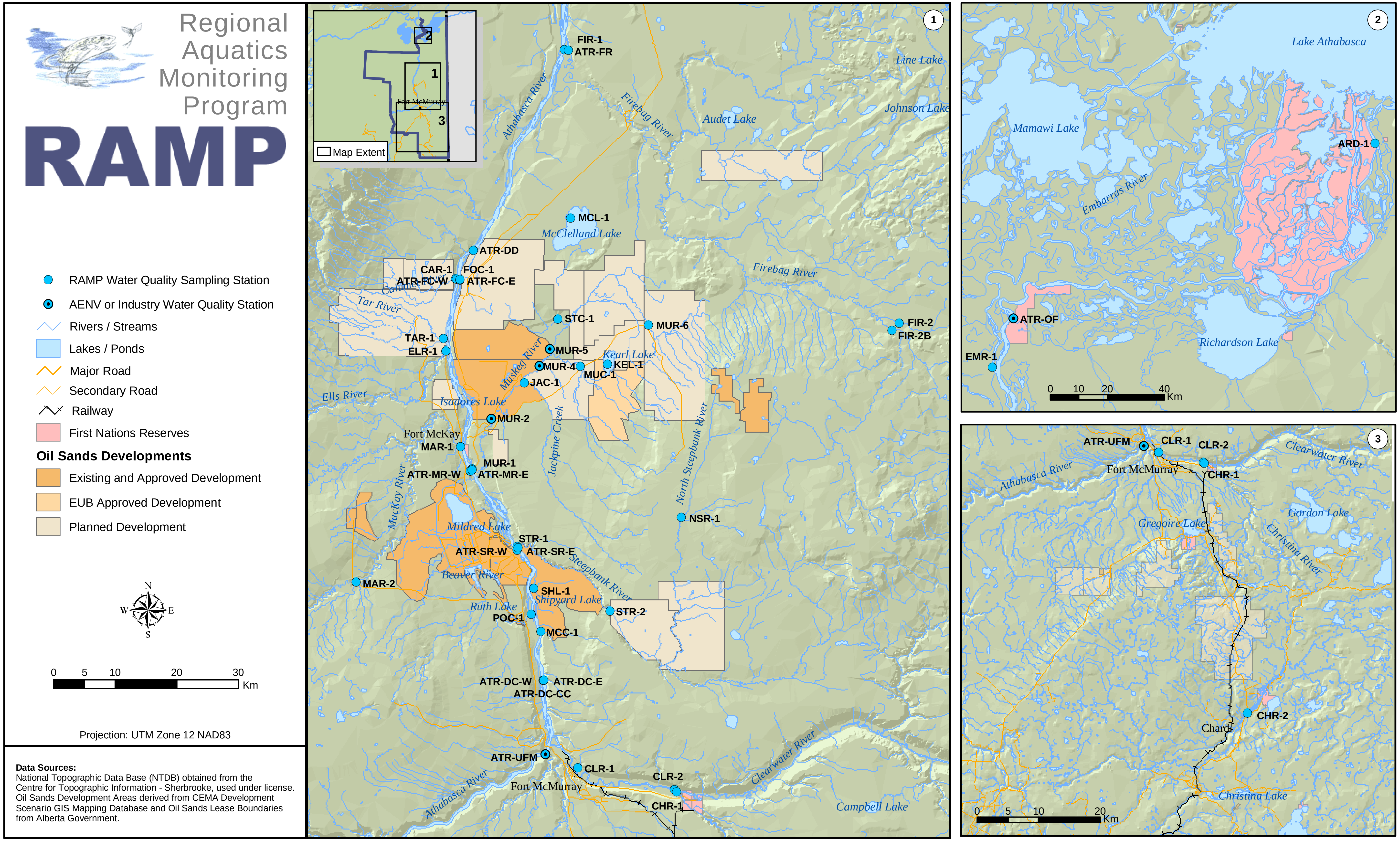
[C] Samples not collected, as river was frozen to bottom.

[D] Provision for Toxicity Identification Evaluation (TIE).

[E] See Appendix A1 of this report for description and discussion of QA/QC program.

All data collection for the 2003 water quality program was conducted by the RAMP implementation team, with the exception of three stations on the Muskeg River mainstem (MUR-2, MUR-4 and MUR-5) that were monitored by industry (i.e., Syncrude Canada Ltd. and Albain Sands Ltd.) and AENV and two stations on the Athabasca River (ATR-UFM and ATR-OF) monitored by AENV. Water quality monitoring station locations in 2003 appear in Figure 3.1. Detailed descriptions of location and access to all stations, including specific geographic coordinates, are included in Appendix A3.

Figure 3.1 RAMP Water Quality Sampling Locations, 2003.



Data Sources:
National Topographic Data Base (NTDB) obtained from the Centre for Topographic Information - Sherbrooke, used under license. Oil Sands Development Areas derived from CEMA Development Scenario GIS Mapping Database and Oil Sands Lease Boundaries from Alberta Government.

Mxd: G:\DATA\PROJECTS\RAMP1069\GIS\Fig3-1_Water2003.mxd
Last Modified: 2/17/2004 3:32:04 PM

3.2.2 Discrete Sampling Methods

Sampling involved collection of single grab samples of water from smaller creeks or rivers, collection of cross-channel composite samples or bank-adjacent grab samples in large rivers, or collection of multi-location composites in lakes/wetlands. Grab samples were collected by submerging each sample bottle to a depth of approximately 30 cm, uncapping and filling the bottle, and recapping at depth. Each bottle was triple-rinsed using this procedure prior to the final sample collection.

Composite samples were collected at stations where average concentrations of monitored variables were desired, including lentic waterbodies (i.e., lakes or wetlands) and selected stations along the Athabasca River. Composites were collected through combining a series of 2 L grabs collected at regularly spaced intervals (Table 3.3), into a triple-rinsed polymer bucket. Samples were removed from the composite bucket with a clean glass vessel and transferred to laboratory-supplied sample bottles. Caution was taken to ensure that the composite sample remained covered when not in use and that no contaminants were introduced during the course of sub-sampling.

Table 3.3 RAMP water quality composite sample sub-groups.

Wetted width	Grab Location and Frequency
> 50m	Three 2L grabs at each of five equally spaced locations along a river cross-section
20-50m	Four 2L grabs collected at each of three equally spaced locations along a river cross-section
< 20m	Ten 2L grabs from a single centre-channel position

At each station, *in situ* measurements of dissolved oxygen (DO), temperature and conductivity were collected using a YSI Model 85 multi-probe water meter and/or a handheld thermometer (temperature), a handheld conductivity meter (conductivity) and a LaMott portable Winkler titration kit (dissolved oxygen). Most dissolved oxygen measurements during the fall 2003 program were determined through Winkler titration due to calibration problems with the YSI 85's DO probe.

Station locations were identified using GPS coordinates in conjunction with written descriptions from past RAMP reports. Stations were accessed by boat, helicopter, snowmobile and/or four-wheel drive vehicle. To avoid influences of adjacent water on sampled water quality at each station, samples taken at mouths of tributaries were collected approximately 100 m upstream of its confluence where possible. Similarly, stations located on river mainstems upstream of influent tributaries were sampled approximately 100 m upstream of the influent tributary confluence.

Sampling methods were modified during winter in response to environmental conditions, and to account for and preclude any sampling error or contamination associated with the requisite use of secondary sample transfer vessels and ice augers. Water was collected through holes in the river/lake ice drilled using a gas-powered auger. For stations designated as single grab, one hole was drilled at the estimated stream thalweg. For stations where cross-channel composites were collected, multiple holes were drilled following guidelines outlined in Table 3.3.

Samples were collected from approximately 0.2 m below the bottom of river/lake ice using a 2-L Van Dorn sampler, to minimize the possibility of contaminant introduction associated with augering. Each grab was composited into a triple-rinsed polymer bucket. Composite water was transferred to individual sample bottles using a clean, triple-rinsed glass vessel, and then preserved.

All waterbodies sampled during the spring, summer and fall programs were clear of ice.

3.2.3 Continuous Monitoring Methods

As part of the spring water quality program RAMP deployed five HOBO Water Temp Pro automatic temperature sensor/data-loggers for collection of open-water temperature data. Each sensor was attached to the interior portion of a cinder block, cabled to the bank and placed in a pool or other deep area that was likely to contain water for the entire monitoring period. All sensors were programmed to collect temperature data at 15-minute intervals for the duration of their installation. Sensors remained in the water column until removal during the fall field program (Table 3.4).

Table 3.4 Locations of continuous water temperature monitoring stations, May to September 2003.

Location	Installation Date	Removal Date
Fort Creek (FOC-1)	May 21, 2003	September 13, 2003
Clearwater River mouth (CLR-1)	May 22, 2003	September 8, 2003
McLean Creek (MCC-1)	May 28, 2003	September 12, 2003
Upper Clearwater River (CLR-2)	May 22, 2003	September 8, 2003
Upper Muskeg River (MUR-6)	May 25, 2003	September 16, 2003

Three additional thermographs were deployed on the Muskeg River in 2003 by employees of oil sands operators, including two on the Muskeg River mainstem: one above Jackpine Creek (MUR-4) and one above Muskeg Creek (MUR-5).

Alberta Environment collected continuous year-round dissolved oxygen monitoring data on the Muskeg River upstream of Stanley Creek (Station D2), with a DataSonde continuous water quality monitor purchased by RAMP.

3.2.4 Sample Shipment and Analysis

For all seasons, samples were filled, filtered (dissolved organic carbon only), preserved and shipped according to protocols specified by consulting laboratories, namely Enviro-Test Laboratories (ETL) in Edmonton, Alberta Research Council (ARC) in Vegreville, and HydroQual Laboratories in Calgary.

Samples were shipped via Greyhound or through the ETL/MMRT collaborative drop depot in Fort McMurray. RAMP standard water quality variables and poly-aromatic hydrocarbons (PAHs) were analyzed by ETL (Table 3.5, Table 3.6). Metals (dissolved and total, including ultra-trace total mercury) were measured by ARC (Table 3.7). Chronic toxicity of water to aquatic organisms was evaluated by HydroQual (Table 3.8).

Table 3.5 RAMP conventional water quality variables.

Group	Water quality variable	
Conventional variables	Colour	Total dissolved solids (TDS)
	Dissolved organic carbon (DOC)	Total hardness
	pH	Total organic carbon
	Specific conductance	Total suspended solids
	Total alkalinity	
Major ions	Bicarbonate	Potassium
	Calcium	Sodium
	Carbonate	Sulphate
	Chloride	Sulphide
	Magnesium	
Nutrients	Nitrate + nitrite	Phosphorus – total
	Ammonia nitrogen	Phosphorus – dissolved
	Total Kjeldahl nitrogen	Chlorophyll *a*[1]
Biological oxygen demand	Biological oxygen demand	
Organics	Naphthenic acids	Total recoverable hydrocarbons
	Total phenolics	

[1] Chlorophyll *a* was not sampled in 2003.

Table 3.6 RAMP target and alkylated PAH compounds.

Group	Polyaromatic hydrocarbon (PAH)	
Target PAHs	Acenaphthene	Dibenzo(a,h)anthracene
	Acenaphthylene	Dibenzothiophene
	Anthracene	Fluoranthene
	Benzo(a)anthracene/chrysene	Fluorene
	Benzo(b&k)fluoranthene	Indeno(c,d-123)pyrene
	Benzo(a)pyrene	Naphthalene
	Benzo(g,h,i)perylene	Phenanthrene
	Biphenyl	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)	

Table 3.7 RAMP total and dissolved metals.

Group	Metal		
Total and dissolved metals	Aluminum (Al)	Chromium (Cr)	Selenium (Se)
	Antimony (Sb)	Cobalt (Co)	Silver (Ag)
	Arsenic (As)	Copper (Cu)	Strontium (Sr)
	Barium (Ba)	Iron (Fe)	Thallium (Tl)
	Beryllium (Be)	Lead (Pb)	Thorium (Th)
	Bismuth (Bi)	Lithium (Li)	Tin (Sn)
	Boron (B)	Manganese (Mn)	Titanium (Ti)
	Cadmium (Cd)	Mercury (Hg)[1]	Uranium (U)
	Calcium (Ca)	Molybdenum (Mo)	Vanadium (V)
	Chlorine (Cl)	Nickel (Ni)	Zinc (Zn)

[1] Total mercury (Hg) measured to ultra-trace levels (0.000006 mg/L)

Table 3.8 Chronic toxicity assessment of ambient river water.

Group	Sublethal Toxicity Test
Sublethal toxicity	Algal growth inhibition, using the freshwater alga *Selanastrum capricornatum*
	Invertebrate survival and reproduction, using the cladoceran *Ceriodaphnia dubia*
	Fish early life-stage survival and growth, using fathead minnows (*Pimephales promelas*)

3.2.5 Seasonal Differences in Analyses

All water quality samples were analyzed for the RAMP standard variables in all sampling seasons except for one station located upstream of Fort McMurray, which instead was analyzed for AENV routine parameters in winter, spring and summer, and additionally for PAHs in the winter and summer programs. PAHs were measured in water by RAMP in fall only.

Supplemental to RAMP standard parameters, additional water quality analyses were conducted on three stations on the Muskeg River mainstem and one tributary to the Muskeg River during the winter, spring and/or fall programs as follows:

- The Muskeg River upstream of Canterra Road (MUR-2) was sampled for PAHs and chronic toxicity by industry and by AENV for routine water quality variables and through operation of a continuously-monitoring DataSonde during the winter, spring and summer field programs; and

- The Muskeg River was sampled for chronic toxicity testing and PAHs quarterly in 2003 upstream of Muskeg Creek (MUR-5), upstream of Jackpine Creek (MUR-4) and upstream of the Canterra Road crossing (MUR-2).

Sampling intensity was much greater in the fall water quality program relative to other seasons, with samples collected at all RAMP water quality monitoring stations. Additional analyses conducted by RAMP and specific to the fall season are summarized in Table 3.9 below.

Table 3.9 Fall 2003 analyses conducted by RAMP and supplemental to the RAMP standard suite of parameters.

Station location	ID	Supplemental analyses			
		PAHs	Chronic Toxicity	AENV routine variables	DataSonde
Athabasca R. upstream of Donald Ck.	ATR-DC	√			
Athabasca River d/s of all development	ATR-DD	√			
Lower Clearwater River	CLR-1	√			
Upper Clearwater River	CLR-2	√			
Lower Christina River	CHR-1	√			
Upper Christina River	CHR-2	√			
Muskeg R. upstream of Jackpine Ck.	MUR-4	√	√		
Muskeg R. upstream of Muskeg Ck.	MUR-5	√	√		
Muskeg R. u/s of Canterra Rd. crossing	MUR-2	√	√	√	√
Ells River	ELR-1		√		
Tar River	TAR-1		√		
Calumet River	CAR-1		√		
Athabasca River at Old Fort	ATR-OF			√	

3.2.6 Changes from the 2002 Study

Station location and methodology was largely consistent with 2002 efforts, with the following variations in the 2003 program:

- PAH sampling was conducted on the Athabasca River upstream of Donald Creek (ATR-DC-CC, cross-channel composite);

- Fall sampling was conducted on Big Point Channel (BPC) in the Athabasca Delta and the Embarras River (EMR-1);
- Winter sampling was excluded from McLean (MCC-1), Poplar (POC-1) and Fort (FOC-1) creeks, at the mouth of the MacKay (MAC-1) and at the mouth and upper Steepbank locations (STR-1, STR-2);
- Chronic toxicity testing was undertaken on water from the Ells River (ELR-1), the Tar River (TAR-1) and the Calumet River (CAR-1);
- Spring and summer sampling was done at the upper MacKay River (MAR-2);
- Summer and fall sampling was undertaken at the Beaver River (BER-1);
- Fall sampling was undertaken on McClelland Lake (MCL-1);
- Winter sampling was included for Kearl Lake (KEL-1);
- No sampling was conducted on the OPTI Lakes;
- The list of dissolved and total metals analyzed by ARC changed slightly relative to 2002, with magnesium, potassium, sodium and sulphur not analyzed and bismuth, chlorine, and thorium added to metals scans in 2003;
- Chlorophyll *a* was not analyzed in water samples for 2003; and
- Composite sampling intensity was amended from five, approximately equally spaced, locations positioned between the respective river bank and 25% of the river width to protocol based on estimated channel width (Table 3.3).

Station locations remained consistent with previous RAMP studies, with the exception of upper Firebag River station FIR-2. During the March 2003 winter survey, it was determined that in 2002 the Upper Firebag station had been inadvertently established on a small tributary to the Firebag, rather than the mainstem itself. RAMP collected data from this tributary and a newly established station (FIR-2B) on the Firebag River mainstem during the winter, spring and summer field programs to allow for water quality comparisons. In fall 2003, sampling was undertaken at the newly established station on the Firebag mainstem only.

3.2.7 Data Analysis

3.2.7.1 Analytical Approach

Analysis of the RAMP 2003 water quality data set built upon results of previous RAMP studies, particularly those of the RAMP 5-year report (Golder 2003a) describing inter-correlation among water quality variables and variables considered most relevant for detecting, monitoring, and assessing potential effects of oil sands development on water quality. Also, specific temporal trends in water quality identified in the RAMP 2002 report (Golder 2003b) were explicitly assessed again in this study through re-analysis using additional data collected in 2003.

Analysis of water quality data in this report followed a tiered structure, from examination of the Athabasca River to its delta and immediate tributaries and finally to specific watersheds of these tributaries, and included the following:

- Characterization of water quality in the Athabasca River mainstem and delta, and tributaries to the Athabasca, including inter-correlation of water quality variables and examination of spatial relationships and trends in water quality among sampling stations;

- Examination of water quality in the Athabasca River mainstem, to describe and assess any downstream changes in water quality that may occur as the river flows from Fort McMurray through areas of oil sand development;

- Examination of water quality in tributaries of the Athabasca, to describe and assess water quality in these tributaries as well as their potential effects of water quality in the Athabasca River mainstem;

- Examination of water quality within specific tributary watersheds of the Athabasca, particularly the Muskeg River watershed, but also including the Steepbank, Clearwater, MacKay and Firebag watersheds;

- Examination of water quality in specific lakes in the study area;

- Examination of seasonal variability in water quality at stations monitored in multiple seasons;

- Assessment of potential effects of oil sands operations on water quality in specific tributaries or specific sampling stations where such effects may occur due to local discharges or development;

- Re-analysis of trends identified in the 2002 RAMP report in specific water quality variables at specific stations to include 2003 data, and further trend analysis where historical data is suggestive of trends or where such trends may be expected (where sampling history permits); and

- Screening of all water quality data collected against Alberta acute and chronic water quality guidelines for the protection of aquatic life (AENV 1999) and Canadian Council of Ministers of the Environment (CCME) Canadian Water Quality Guidelines (CWQG) (CCME 2002).

3.2.7.2 Statistical Methods

Relationships between Water Chemistry Variables

Correlations were used to assess relationships between water chemistry variables and similarity or differences in water chemistry at different locations, for two groups of stations:

1. Stations located along the Athabasca River mainstem; and
2. Stations located along the Athabasca River mainstem, delta, and at the mouths of the tributaries that drain into the Athabasca River.

This assessment was conducted using water quality data collected in fall 2003 only, as all 2003 stations within these station groups were represented in the fall data set. Station EMR-1 (Embarras River) was included in the Athabasca River mainstem station group, given the Embarras River is a channel of the Athabasca River flow, rather than a separate confluent tributary to the Athabasca River.

Prior to conducting correlation analyses, the water quality data set was reduced into a smaller number of variables using principal components analysis (PCA), as described below. All analyses were conducted using SYSTAT 10 (SPSS 2000).

Water quality data collected by Alberta Environment for stations ATR-UFM (Athabasca River mainstem upstream of Fort McMurray) and ATR-OF (Athabasca River mainstem at Old Fort, just upstream of the Athabasca River delta) were not received in time to include these data in statistical analyses described in this report.

Data Screening

Before any PCA or correlation analyses were conducted, data were screened to exclude any variables with concentrations below detection limits in over 70% of observations (i.e., stations) in each station group. For variables that were measured both in the laboratory and the field (e.g., conductivity), results of laboratory analyses were used.

Data Reduction

PCA was used to reduce the water chemistry data set, and to facilitate broad comparisons of water quality among stations. PCA is a data reduction technique that reduces a large number of variables into a small number of summary variables called principal components (PCs). These summary variables, which are independent and orthogonal, are formed from linear combinations of the original variables. PCA is a useful technique because it can often reveal patterns or relationships that were not previously apparent, particularly when analyzing large data sets containing numerous variables.

Separate PCAs were conducted for both station groups (i.e., Athabasca River mainstem and Athabasca River mainstem, delta, and tributaries), for the following water quality variable groups:

- Dissolved metals;
- Total metals; and
- Major ions, which included calcium, magnesium, potassium, sodium, chloride, sulphate and sulphide.

Performance of separate PCAs for different groups of chemicals (i.e., dissolved metals, total metals and ions) differed from the approach to PCA undertaken in the RAMP 5-year report (Golder 2003a) for water quality data. PCAs performed on water quality data in the 5-year report combined all analytes, including conventional variables, ions, nutrients, and total metals, into a number of summary variables. The key advantage of conducting separate PCA analyses for groups of chemicals, such as dissolved metals, total metals, ions, etc. is that the resulting summary variables are more meaningful because they explain a greater percentage of the variance in the data set. In addition, such summary variables are more easily interpreted in subsequent analyses.

PCAs were conducted using both untransformed and $\log_{10}$-transformed data. The analysis that provided the best separation of the original variables with the summary variables (PCs) was used.

To identify differences and similarities in metal or ion concentrations between stations, the primary PCs were plotted against each other. These plots were used to assess any spatial patterns related to metal or ion concentrations. The resulting PCs also were used in subsequent correlation analyses as surrogates for the metals and ions.

Correlation Analyses

Relationships between the original variables and summary variables were evaluated using Pearson's correlation coefficients (r), to determine which individual variables (i.e., specific metals or ions used to create the PCs) were most strongly represented by the PCs. The direction of correlation was used to determine whether metals or ions increased or decreased as the factor scores (i.e., PCs) increased. Correlations (r) greater than $|0.50|$ but less than $|0.75|$ (i.e., between either 0.50 and 0.75 or -0.50 and -0.75) were described as moderate correlations; correlations of over $|0.75|$ were described as strong.

The degree and direction of these correlations may be used to interpret PC scores in subsequent analyses. For example, if a high Total Metals PC2 score was observed at a particular station, and through correlation analysis Total Metal PC2 is determined to be strongly correlated with increasing concentrations of boron and chlorine and strongly negatively correlated with barium and antimony, then this station likely exhibited high concentrations of boron and chlorine and low concentrations of barium and antimony. Analytes that were moderately positively or negatively correlated (i.e., in the same direction) with both PCs cannot be used to predict concentrations of the original variables.

Spearman's rank correlations (r_s) were used to assess relationships between principal components and conventional water chemistry variables, including hardness, alkalinity, bicarbonate, conductivity, total dissolved solids (TDS), total suspended solids (TSS), total organic carbon (TOC), dissolved organic carbon (DOC), total phosphorous, dissolved phosphorous, temperature, Kjeldahl nitrogen, ammonia, pH and dissolved oxygen. Critical values of Spearman's rank correlation were used to determine whether a correlation was statistically significant. For the Athabasca River mainstem (n=12), a correlation was significant if $r_s > |0.587|$. For the Athabasca River mainstem, delta, and tributaries (n=24 or 25), a correlation was significant if $r_s > |0.406|$ or $|0.398|$, respectively. Qualitatively, correlations of $|0.50| < r_s < |0.75|$ were defined as moderate, while strong correlations were defined as $r_s > |0.75|$. Regardless of statistical significance, correlations of $r_s < |0.5|$ were defined as weak. All significance tests were conducted at a significance level of $\alpha = 0.05$.

Trend Analyses

Eleven water quality variables were identified in the RAMP 5-year Trend Report (Golder 2003a) as key monitoring indicators of water quality in the RAMP study area, including:

- *Indicators of nutrient status:* Dissolved organic carbon (DOC), total Kjeldahl nitrogen (TKN), and total phosphorus;
- *Indicators of acidification:* pH and total alkalinity;

- *Indicators associated with potential effects of oil sand development:* sulphate, total dissolved solids (TDS), total boron, total chromium, and total aluminum; and

- Total suspended solids (TSS), given its likely influence on total metal concentrations.

The following additional parameters were included in the 2003 analysis:

- *Indicators of nutrient status:* Dissolved phosphorous, given dissolved phosphorous (typically, ortho-phosphate) is the primary bioavailable species of phosphorous (Wetzel 1973) and that previous evidence that total phosphorous levels are strongly associated with total suspended solids (e.g., Golder 2003a), suggesting total phosphorous may primarily be an indicator of particulate-bound phosphorous that is not bioavailable as a nutrient for aquatic organisms;

- *Indicators associated with oil sands development:* Dissolved aluminum, total aluminum has been demonstrated to be strongly associated with suspended solids (Golder 2003a), that dissolved aluminum values are very low relative to total aluminum values observed in RAMP studies (e.g., Golder 2001, 2002, 2003a, and data in this report) and that dissolved aluminum more accurately represents biologically available forms of aluminum that may cause toxicity to aquatic organisms (Butcher 2001); and

- *Principal Component scores* (PC1 and PC2) generated by all principal component analyses undertaken for this report, describing concentrations of dissolved metals, total metals, and major ions.

These water quality variables and summary variables were examined using correlation analysis to assess relationships between these variables, and also provided the focus for analyses of temporal or spatial trends in water quality in the RAMP study area that could be influenced by oil sands development or other human activities. Such trend analyses were undertaken either statistically or descriptively, depending on the size and duration of the historical data set available for analysis.

Variation in these water quality variables over time was examined using correlation analyses. Rank Kendall's correlations were conducted to assess whether concentrations of these variables had increased or decreased over time.

In order to effectively assess temporal trends in water quality, data spanning a large number of years are needed. Trend analyses were conducted for stations with at least six years of data, including Muskeg River mouth (MUR-1) and upstream (MUR-6), Steepbank River mouth (STR-1), and Shipyard Lake (SHL-1).

Because of data limitations related to small sample sizes (i.e., number of years), further analyses such as rate of change determinations, were not conducted.

Fall data was used for all water quality trend analyses, with the exception of SHL-1. Fall data for SHL-1 only included 5 years of data; consequently the summer data set, which included 6 years of data, was used. Prior to conducting the analyses, any non-detectable values were substituted with a value equal to one half of the analytical detection limit. All analyses were conducted in SYSTAT 10 (SPSS 2000). The significance of the temporal trend for each analyte was determined by comparing Kendall's correlation coefficients (τ) to critical values. For stations with 6 years of data, $\tau > |0.867|$ was significant. For stations with 7 years of data, $\tau > |0.714|$ was significant.

3.2.7.3 Descriptive Methods

In addition to statistical approaches to water quality analysis, various descriptive and/or qualitative approaches to water quality assessment were undertaken, including:

- Screening of water quality data against water quality guidelines for the protection of aquatic life, namely Alberta Environment acute and chronic guidelines (AENV 1999), Canadian Council of Ministers of the Environment (CCME) Canadian Water Quality Guidelines (CWQG) and guidelines from other jurisdictions as appropriate;

- Comparison of 2003 water quality data with those from previous years, to assess annual variability and consistency of water quality at specific stations and assess possible trends over time;

- Comparison of water quality data among seasons, to assess seasonal variability of water quality in sampled water bodies;

- Qualitative comparison of water quality at upstream with downstream stations in watersheds with upstream stations, where historical sample size did not permit a statistical approach to trend analysis; and

- Focus on specific water quality variables, stations, watersheds and/or historical trends previously identified by RAMP, particularly in the 5-year trend report (Golder 2003a) and the 2002 annual technical report (e.g., Golder 2003b).

3.3 RESULTS

The following section summarizes results of the RAMP 2003 water quality program. Detailed statistical outputs (including all PC scores, significance tests and correlation values), the complete water quality data set collected by RAMP in 2003 and associated industry and AENV monitoring data, appear in Appendix A3.

3.3.1 Athabasca River Mainstem, Delta and Tributaries

3.3.1.1 Data Screening and Reduction

Analytes excluded from all principal component analyses of the RAMP fall 2003 water quality data set included:

- All PAHs, given these data were available for few stations and over 70% of observations were non-detectable;
- All other hydrocarbons (i.e., total recoverable hydrocarbons, hydroxides and naphthenic acids) and phenolic compounds, given over 70% of values were non-detectable;
- Dissolved silver, mercury, and selenium and total silver and tin, given over 70% of values were non-detectable; and
- BOD and nitrates+nitrites, given over 70% of values were non-detectable.

In water samples where the above analytes were detectable, observations concentrations usually were near analytical detection limits, with the exception of phenols and total tin. Phenol concentrations were 11 times higher than the detection limit of 0.001 mg/L at ELR-1 (Ells River); total tin concentrations were up to 12 times higher at ARD-1 (Athabasca River delta).

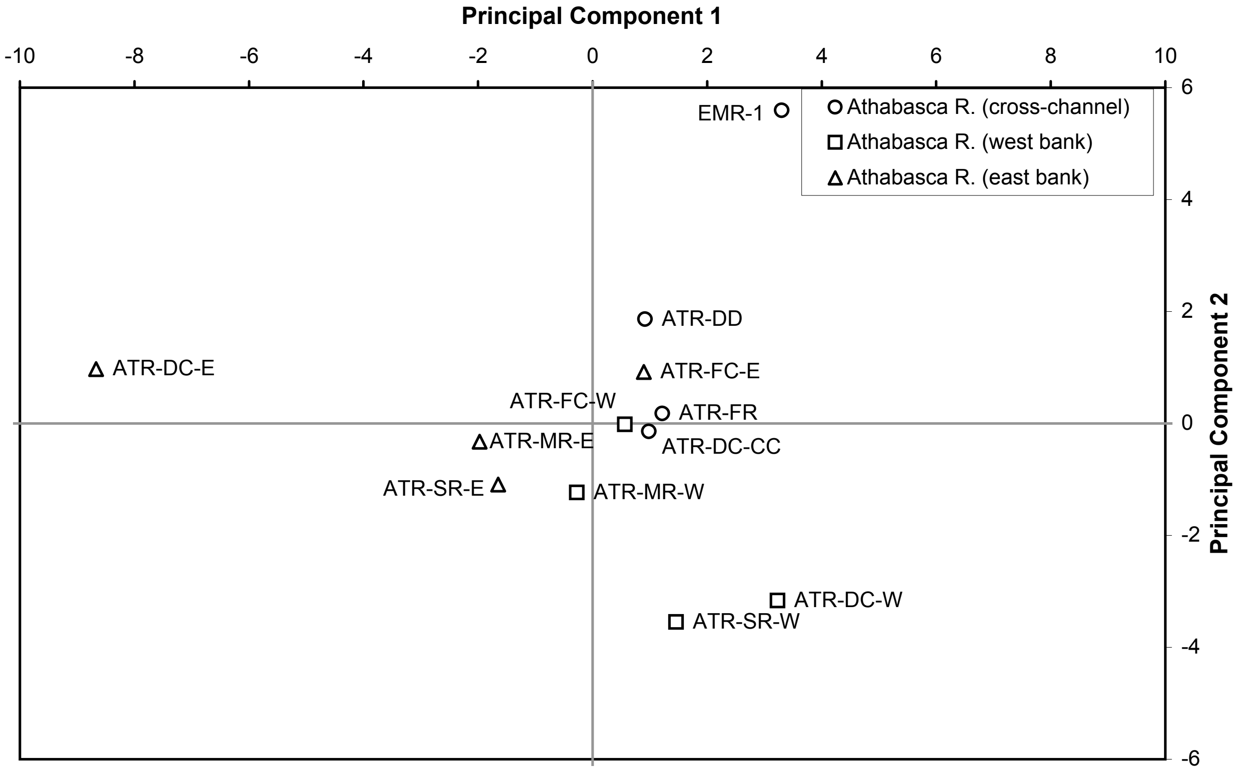
3.3.1.2 Dissolved Metals

Athabasca River Mainstem

Four principal components (PCs) were formed from analyses of the dissolved metals data set. The first two PCs (PC1 and PC2) accounted for 38.3% and 21.7%, respectively of the variance in the data set (60.1% combined). Dissolved metals including cobalt, antimony, molybdenum, uranium, strontium, barium, and calcium exhibited strong positive correlations (i.e., $r > 0.75$) with PC1 ($r = 0.85$ to 0.99). Dissolved boron was strongly, negatively correlated with PC1 ($r = -0.92$), while dissolved chlorine and iron were moderately negatively correlated with this PC. PC2 was strongly positively correlated with dissolved beryllium, lithium, nickel and titanium, and moderately positively correlated with dissolved cadmium, chlorine, copper, lead, and thorium. Analytes including dissolved copper, thorium, and cadmium did not separate well between the two PCs, exhibiting similar and consistent moderate correlations with both PCs. A scatterplot of PC1 against PC2 appears in Figure 3.2

Most Athabasca river mainstem stations (ATR-#) did not separate clearly on either PC1 or PC2; these stations appear near the origin (0,0) of the scatterplot. Station ATR-DC-E (upstream of Donald Creek, east bank) separated from all other stations along PC1 with the most negative PC1 score, while ATR-DC-W (upstream of Donald Creek, west bank) and ATR-SR-W (upstream of Steepbank River, west bank) separated from the main group of stations on PC2 with more negative scores of this PC. Station EMR-1 (Embarras River) also stood apart from all other stations, positively on PC2.

Figure 3.2 Results of principal component analysis (PCA) on dissolved metal concentrations in the Athabasca River mainstem, September 2003.



A. Specific dissolved metals correlated with Athabasca River Dissolved Metals PC1 and PC2

	Negative Correlations		Positive Correlations	
	Moderate (-0.5 > r > -0.75)	Strong (r < -0.75)	Moderate (0.5 < r < 0.75)	Strong (r > 0.75)
PC1	Iron, chlorine	Boron	-	Cobalt, antimony, uranium, molybdenum, strontium, barium, calcium
PC2	-	-	Lead, chlorine	Lithium, titanium, nickel beryllium

Note: Analytes that were correlated with both principal components in the same direction (i.e., +/+ or -/-) were excluded.

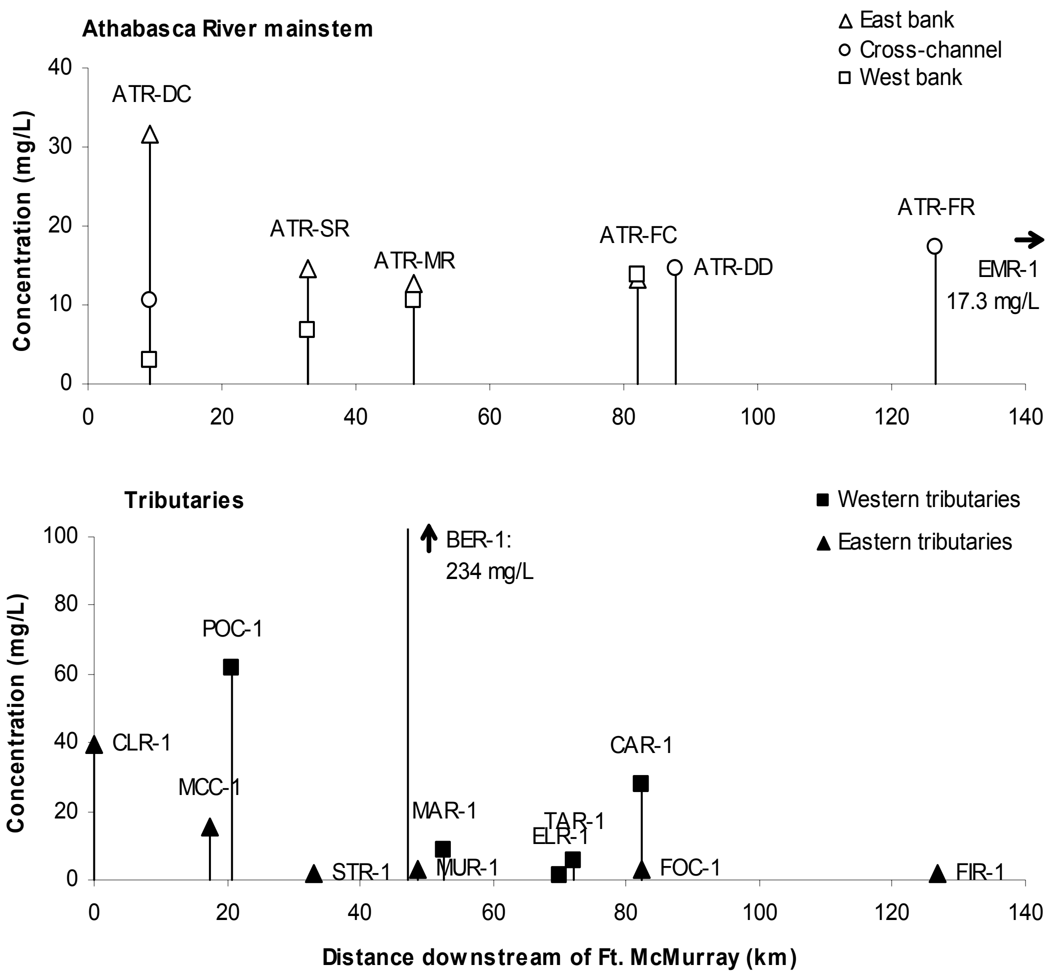
B. Conventional water quality variables correlated with Athabasca River Dissolved Metals PC1 and PC2[1]

	Negative Correlations		Positive Correlations	
	Moderate (-0.5 > r > -0.75)	Strong (r < -0.75)	Moderate (0.5 < r_s < 0.75)	Strong (r_s > 0.75)
PC1	DOC	-	Alkalinity, bicarbonate	-
PC2	pH, DO	-	-	Conductivity

[1] Variables assessed included hardness, alkalinity, bicarbonate, conductivity, TDS, TSS, DOC, TOC, colour, total phosphorous, dissolved phosphorous, temperature, Kjeldahl nitrogen (TKN), ammonia, pH, and dissolved oxygen.

Figure 3.3 illustrates dissolved chlorine concentrations in the Athabasca River and its tributaries in September 2003. Relative to other Athabasca River mainstem stations, ATR-DC-E exhibited high concentrations of dissolved chlorine (i.e., 31.7 mg/L relative to 2.7 to 17.3 mg/L at other stations). This station scored lowest on PC1, consistent with the negative correlation of dissolved chlorine concentrations with PC1. Similarly, stations ATR-DC-W and –SR-W, which exhibited lowest dissolved chlorine concentrations relative to all other ATR stations (i.e., 2.87 and 6.67 mg/L, respectively), scored lowest on PC2, which was positively correlated with increasing dissolved chlorine.

Figure 3.3 Concentrations of dissolved chlorine in the Athabasca River and its tributaries downstream of Fort McMurray, September 2003.



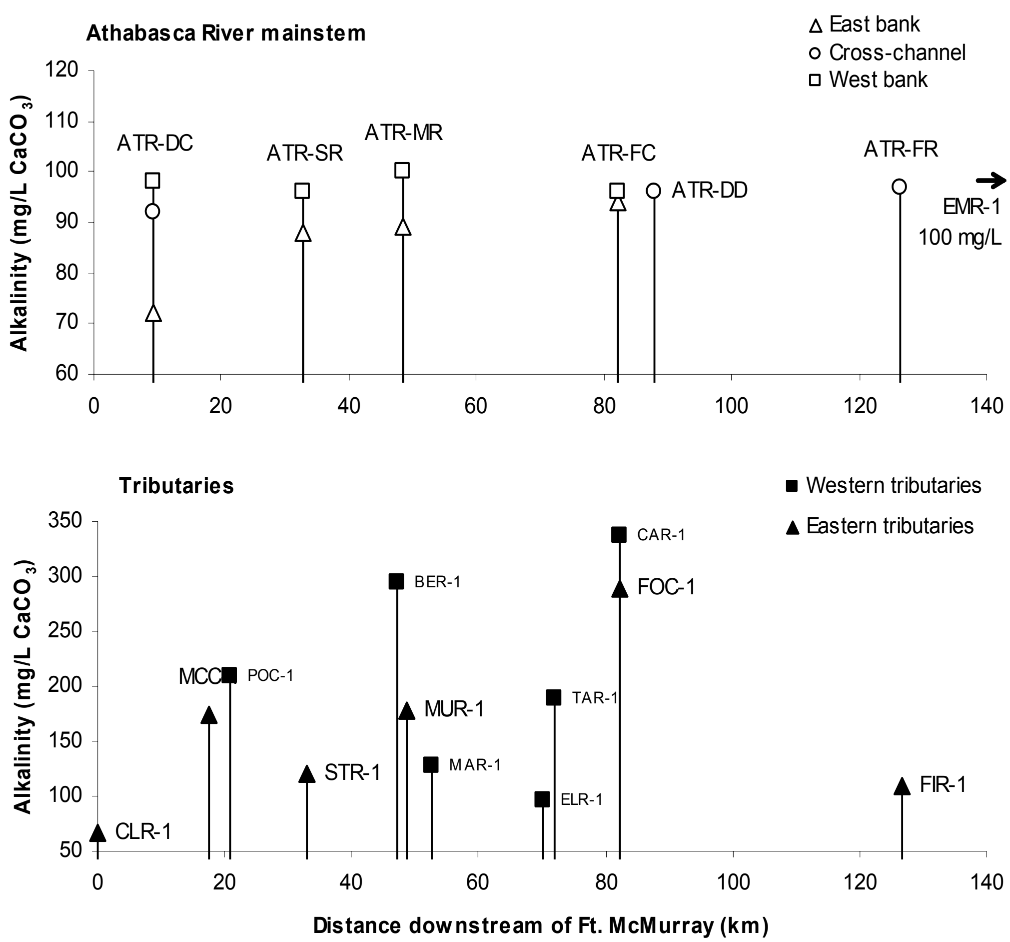
Separation of EMR-1 (Embarras River) from the main group of stations on PC2 may in part be due to much higher dissolved nickel concentration measured at

EMR-1 relative to all other ATR mainstem stations (i.e., 0.0145 mg/L relative to 0.0002 to 0.0006 mg/L), as dissolved nickel was strongly, positively correlated with PC2.

Conventional water quality parameters correlated with PC1 included total alkalinity and bicarbonate (moderate, positive r_s), and dissolved organic carbon (moderate, negative r_s). Stations along the eastern bank of the Athabasca River from Duncan Creek to Muskeg River (i.e., ATR-DC-E, ATR-SR-E, and ATR-MR-E) exhibited the lowest alkalinity of all ATR stations sampled (Figure 3.4), consistent with the negative PC2 scores of these stations relative to all other stations.

PC2 was correlated strongly with water conductivity; EMR-1, which separated positively on PC2, exhibited relatively high conductivity compared with other ATR stations (295 µS, relative to 246 to 300 µS at other stations).

Figure 3.4 Total alkalinity in the Athabasca River and its tributaries downstream of Fort McMurray, September 2003.



Athabasca River Mainstem, Delta, and Tributaries

Figure 3.5 contains a scatterplot of the first two principal components generated from the analysis of dissolved metals data for all Athabasca River (ATR) stations, Athabasca River delta station ARD-1, and stations on tributaries entering the Athabasca River, sampled shortly upstream of their confluence with the Athabasca.

This analysis generated six principal components, of which the first two (PC1 and PC2) accounted for 26.5% and 20.3% respectively (46.8% combined) of the total variance in the data set. Dissolved strontium was the only dissolved metals to exhibit a strong, positive correlation with PC1 (r = 0.77); numerous dissolved metals (i.e., nickel, lithium, bismuth, thorium, lead, chromium, boron, cobalt, chlorine, copper, calcium, thallium, and barium) exhibited moderate positive correlations with PC1 (r = 0.54 to 0.73).

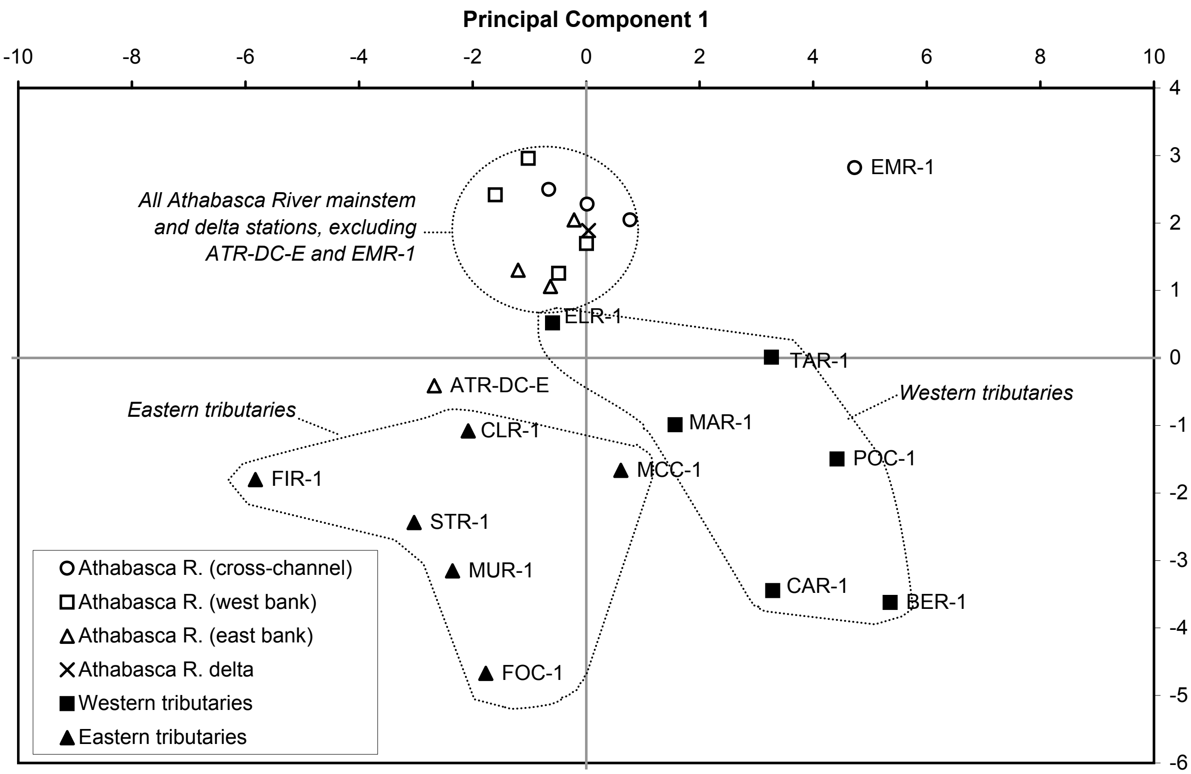
PC2 was strongly, positively correlated with dissolved molybdenum (r=0.78), and strongly, negatively correlated with dissolved manganese (r=0.86). Dissolved calcium, iron, lithium, and boron exhibited moderate, negative correlation with this PC. Analytes including dissolved nickel, copper, and antimony did not separate well between the two PCs.

Water conductivity was the only conventional water quality variable that correlated with PC1 (moderately and positively); PC2 was strongly negatively correlated with several water quality variables, including alkalinity, total dissolved solids (TDS), colour, pH, dissolved oxygen, dissolved phosphorous and Kjeldahl nitrogen, and dissolved organic carbon (DOC). Total organic carbon (TOC) was moderately, negatively correlated with PC2.

Three groupings of stations can be identified in Figure 1.5: (1) all Athabasca River mainstem (ATR) and delta stations (ARD-1), excluding ATR-DC-E and EMR-1; (2) eastern tributaries to the Athabasca, including the Clearwater River (CLR-1), McLean Creek (MCC-1), Steepbank River (STR-1), Muskeg River (MUR-1), Fort Creek (FOC-1) and the Firebag River (FIR-1); and (3) western tributaries to the Athabasca, including Poplar Creek (POC-1), Beaver River (BER-1), MacKay River (MAR-1), Ells River (ELR-1), Tar River (TAR-1) and the Calumet River (CAR-1).

All Athabasca River mainstem stations except ATR-DC-E grouped separately from all tributary stations on PC2, which generally placed more negatively on this PC. Based on the moderate to strong negative correlations of compounds known to impart colour to water (i.e., iron, manganese and DOC) with PC2, as well as the moderate correlation of colour itself with this PC, PC2 likely discriminates the more highly-coloured waters of the Athabasca River tributaries from the Athabasca River mainstem (Figure 3.6), which also exhibited generally lower alkalinity, TDS an DOC than the tributaries examined.

Figure 3.5 Results of principal component analysis (PCA) on dissolved metal concentrations in the Athabasca River mainstem and tributaries, September 2003.



A. Specific dissolved metals correlated with Athabasca River & tributaries Dissolved Metals PC1 and PC2

	Negative Correlations		Positive Correlations	
	Moderate (-0.5 > r > -0.75)	Strong (r < -0.75)	Moderate (0.5 < r < 0.75)	Strong (r > 0.75)
PC1	-	-	Nickel, thorium, lithium, lead, bismuth, chlorine, cobalt, chromium, boron, thallium	Strontium
PC2	Iron, calcium, lithium, boron	Manganese	-	Molybdenum

Note: Analytes that were correlated with both principal components in the same direction (i.e., +/+ or -/-) were excluded.

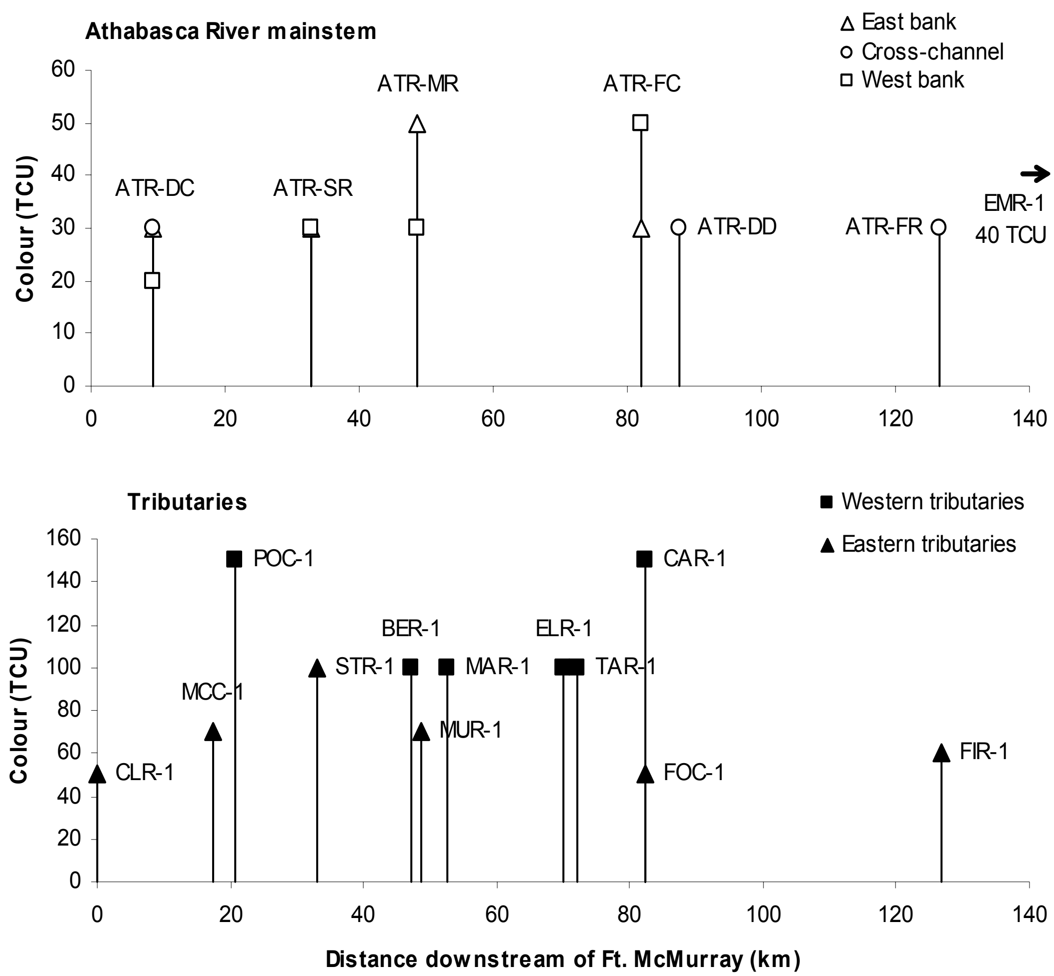
B. Conventional WQ variables correlated with Athabasca River & tributaries Dissolved Metals PC1 and PC2[1]

	Negative Correlations		Positive Correlations	
	Moderate (-0.5 > r > -0.75)	Strong (r < -0.75)	Moderate (0.5 < r_s < 0.75)	Strong (r_s > 0.75)
PC1	-	-	Conductivity	-
PC2	DO, TKN, TDS, pH, colour, dissolved phosphorus, alkalinity, bicarbonate, DOC	TOC	-	-

[1] Variables assessed included hardness, alkalinity, bicarbonate, conductivity, TDS, TSS, DOC, TOC, colour, total phosphorous, dissolved phosphorous, temperature, Kjeldahl nitrogen (TKN), ammonia, pH, and dissolved oxygen.

Athabasca River station ATR-DC-E (upstream of Donald Creek, east bank) did not group closely with other ATR stations, but instead closely with lower Clearwater River station CLR-1. Similar water quality at these two stations (e.g., Figure 3.3, Figure 3.4 and Figure 3.6), and consistent differences in water quality between east and west banks at ATR-DC suggests that water from the Clearwater River had not mixed fully into the main river flow by this point, approximately 9.2 km downstream of its confluence. Water quality at ATR-SR-E (upstream of the Steepbank River), over 30 km downstream of the Clearwater confluence, also exhibits similarities to CLR-1 and ATR-DC-E, such as elevated dissolved chlorine along its east bank relative to its west bank (Figure 3.3).

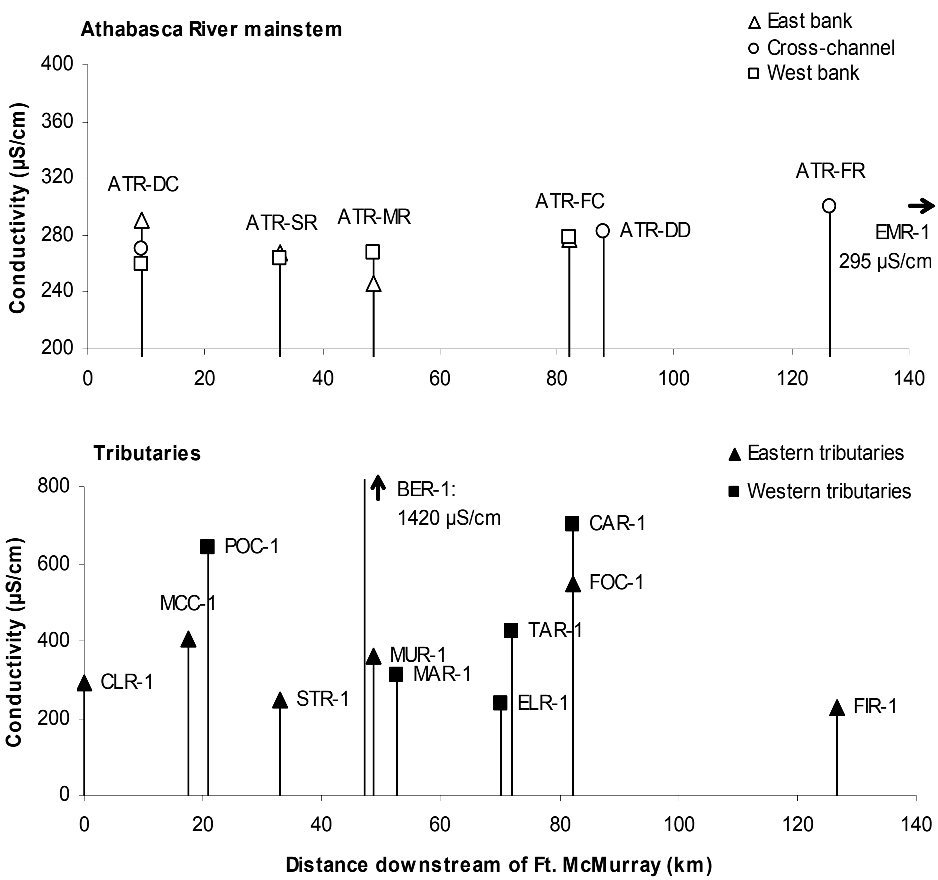
Figure 3.6 Measured colour of the Athabasca River and its tributaries downstream of Fort McMurray, September 2003.



Downstream Athabasca River mainstem station EMR-1 (Embarras River) also did not group with other ATR stations in the dissolved metals PCA for the mainstem, delta and tributaries, consistent with results of the PCA of Athabasca River mainstem stations only (Figure 3.2). Dissolved nickel concentrations, moderately correlated with PC1, were much higher at EMR-1 than at other stations sampled in the Athabasca River or any tributary outlets (i.e., 0.0145 mg/L, compared with <0.0001 to 0.0015 mg/L at all ATR-# and tributary outlet stations).

Amongst tributaries, eastern tributaries generally scored negatively on PC1 (i.e., PC1 < 0) while western tributaries scored positively (i.e., PC1 > 0) (Figure 3.5). Most western tributaries, particularly Beaver River (BER-1), Calumet River (CAR-1), Tar River (TAR-1) and Poplar Creek (POC-1) exhibited higher values for water quality variables correlated positively with PC1, such as conductivity (Figure 3.7), dissolved boron (Figure 3.8) and other dissolved metals, and DOC (Figure 3.9), relative to eastern tributaries.

Figure 3.7 Conductivity in the Athabasca River and its tributaries downstream of Fort McMurray, September 2003.



Highest conductivity was observed at Beaver River (BER-1, 1,420 μS), much higher than the second- and third-most conductive waters at the Calumet River (CAR-1) and Poplar Creek (POC-1), at 702 μS/cm and 642 μS/cm respectively. These three stations scored highest on PC1, consistent with this PC's positive correlation with conductivity, with BER-1 exhibiting the highest PC1 score. Conversely, Firebag River (FIR-1), exhibited both the lowest PC1 score and the lowest conductivity (i.e., 227 μS/cm) of all stations, including stations on the Athabasca River mainstem.

Figure 3.8 Total boron in the Athabasca River and its tributaries downstream of Fort McMurray, September 2003.

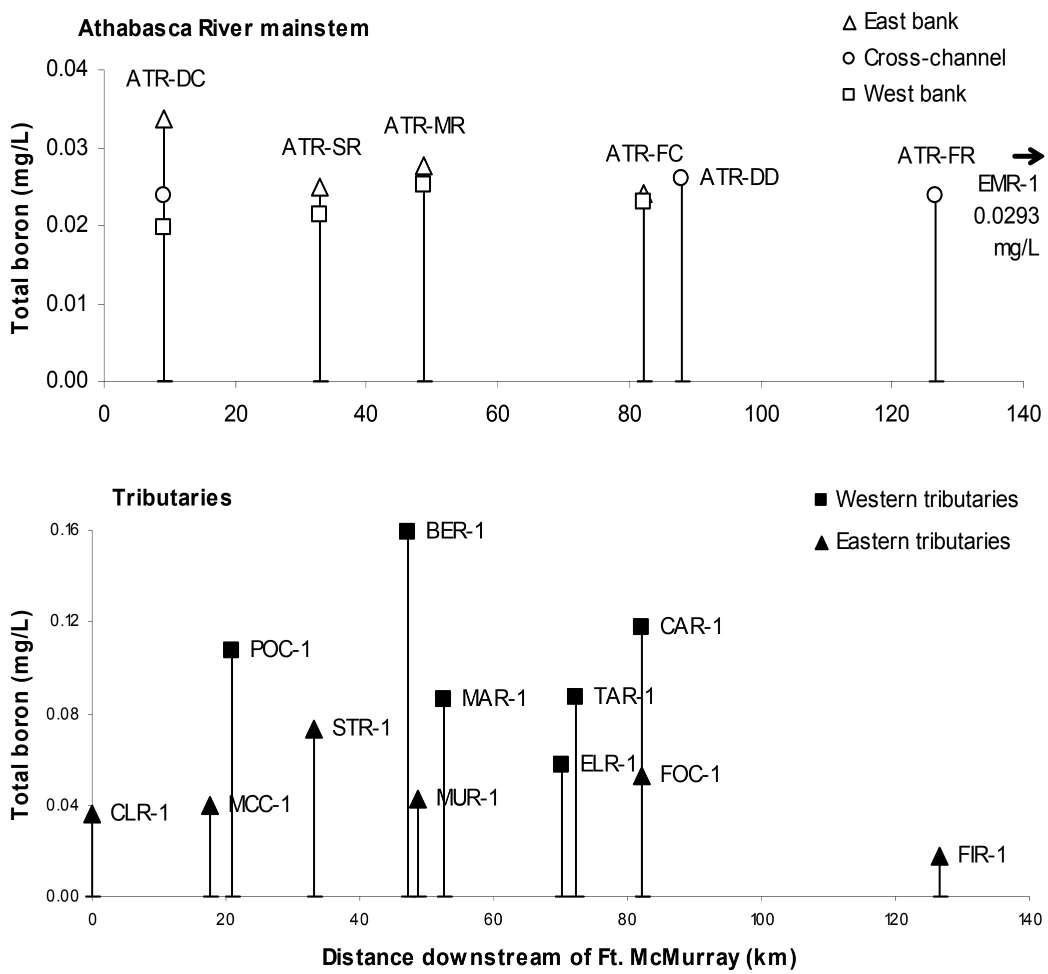
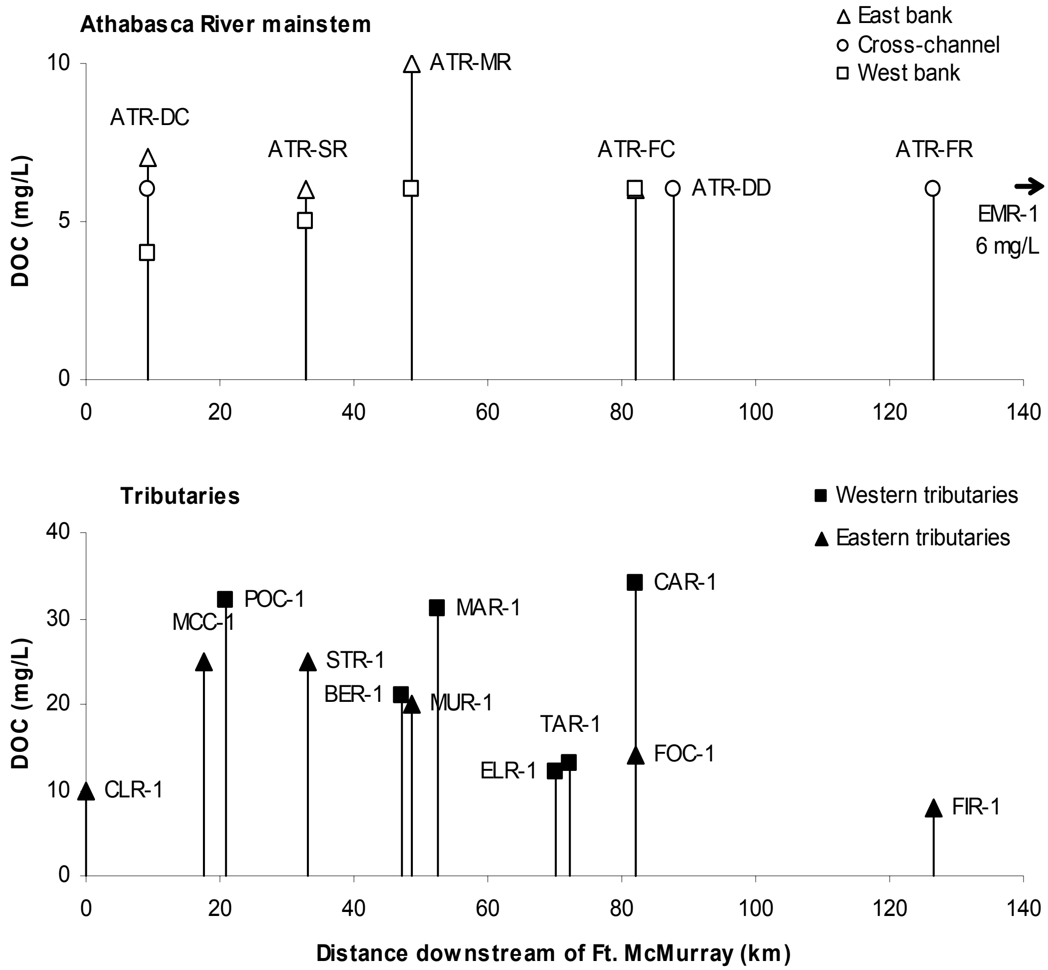


Figure 3.9 Dissolved organic carbon (DOC) in the Athabasca River and its tributaries downstream of Fort McMurray, September 2003.

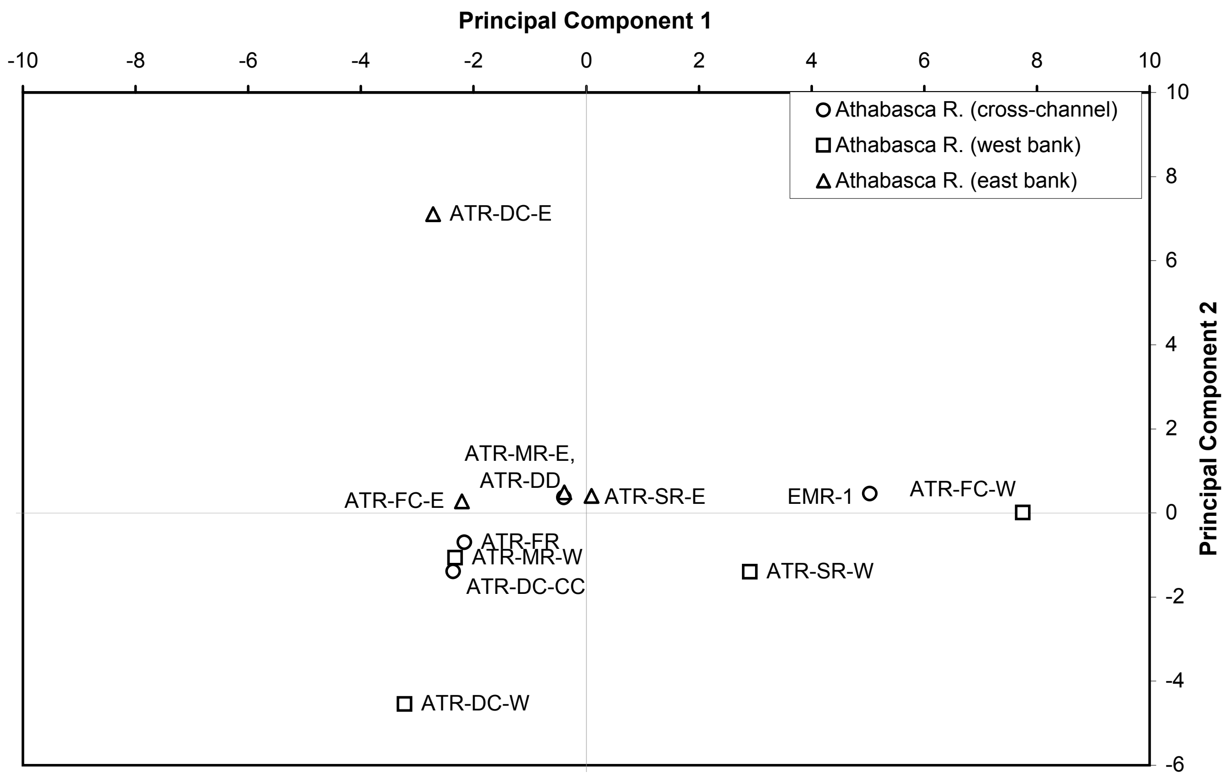


3.3.1.3 Total Metals

Athabasca River Mainstem

Six PCs were formed from analyses of the total metals data set. The first two PCs accounted for 43.0% and 25.2% respectively (68.2% combined) of total variance in the data set. Several metals, including total cobalt, manganese, lead, vanadium, aluminum, titanium, iron, arsenic, mercury, thorium, nickel, and chromium, were strongly, positively correlated with PC1 (r = 0.76 to 0.92). Total barium, lithium, copper, thallium, and bismuth were moderately correlated with this PC.

Figure 3.10 Results of principal component analysis (PCA) on total metal concentrations in the Athabasca River mainstem, September 2003.



A. Specific total metals correlated with Athabasca River Total Metals PC1 and PC2

	Negative Correlations		Positive Correlations	
	Moderate (-0.5 > r > -0.75)	Strong (r < -0.75)	Moderate (0.5 < r < 0.75)	Strong (r > 0.75)
PC1	-	-	Copper, bismuth, barium	Cobalt, manganese, lead, vanadium, aluminum, iron titanium, arsenic, mercury, throrium, nickel, chromium
PC2	Barium, antimony	Uranium, strontium, calcium, molybdenum	Selenium	Boron, chlorine

Note: Analytes that were correlated with both principal components in the same direction (i.e., +/+ or -/-) were excluded.

B. Conventional WQ variables correlated with Athabasca River Total Metals PC1 and PC2[1]

	Negative Correlations		Positive Correlations	
	Moderate (-0.5 > r > -0.75)	Strong (r < -0.75)	Moderate (0.5 < r_s < 0.75)	Strong (r_s > 0.75)
PC1	-	-	Colour	TSS
PC2	-	pH	-	DOC

[1] Variables assessed included hardness, alkalinity, bicarbonate, conductivity, TDS, TSS, DOC, TOC, colour, total phosphorous, dissolved phosphorous, temperature, Kjeldahl nitrogen (TKN), ammonia, pH, and dissolved oxygen.

Total chlorine, boron, selenium, and lithium were positively correlated, strongly or moderately, with PC2. Total molybdenum, uranium, calcium, and strontium were strongly, negatively correlated (r = –0.55 to –0.81) and antimony and barium were moderately, negatively correlated (r = -0.52) with PC2. Other analytes including total lithium and thallium did not separate well between the two PCs.

Of conventional water quality variables examined, total suspended solids (TSS) were strongly, positively correlated with PC1 (r_s = 0.83) while colour was moderately positively associated with the PC (r_s = 0.73). DOC was strongly and positively associated with PC2 (r_s = 0.832), while pH was strongly negatively associated (r_s = -0.76).

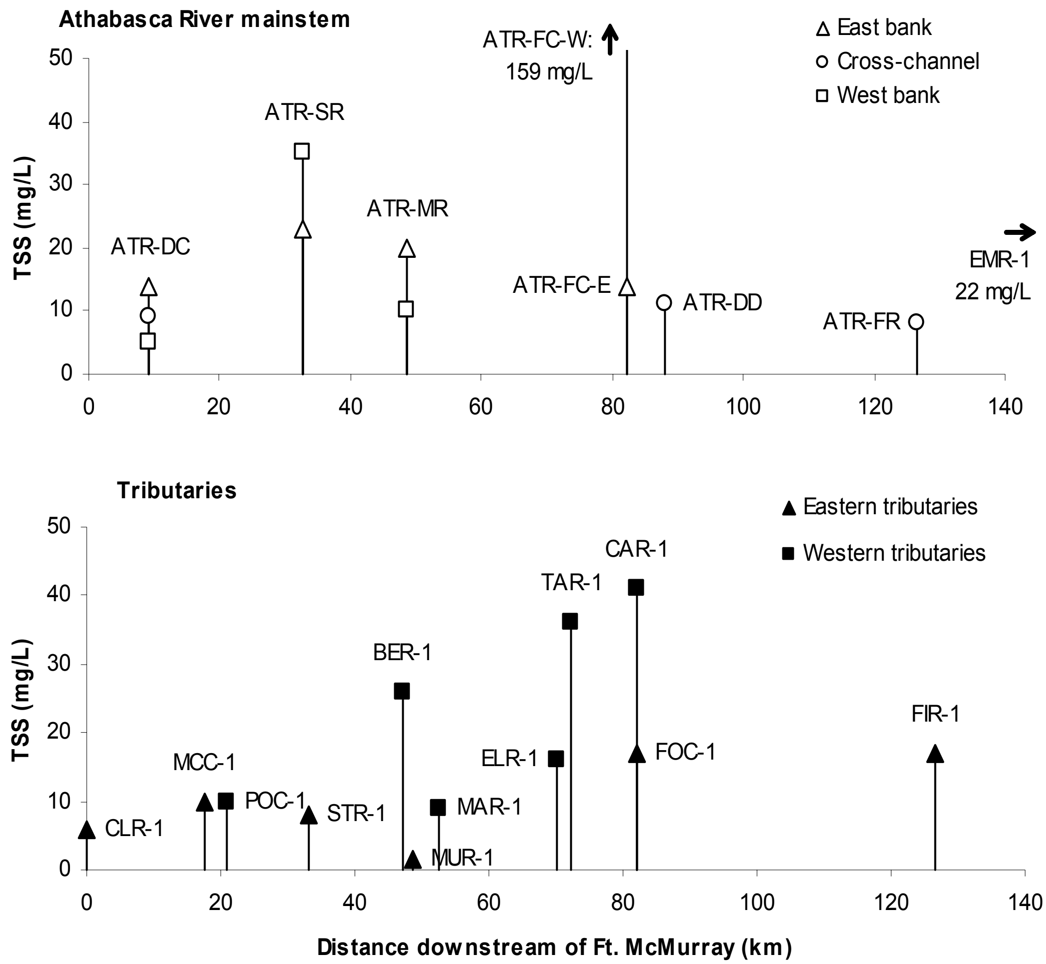
The scatterplot of total metals PC1 against PC2 (Figure 3.10) suggests two groupings of stations and two stations that do not group. On PC1, most stations clustered together in a narrow range of values from approximately PC1 = -2 to 0. Three stations exhibited positive PC1 scores: ATR-FC-W (upstream of Fort Creek, west bank) exhibiting the highest PC1 score, followed by EMR-1 (Embarras River) and ATR-SR-W (upstream of Steepbank River, west bank).

ATR-FC-W and ATR-SR-W exhibited highest TSS concentrations of all ATR stations (Figure 3.11), consistent with the strong correlation of TSS with PC1 and with historical observations that most total metals concentrations are strongly associated with suspended sediments (Golder 2003b). Sampling at ATR-FR-W was undertaken during a day of particularly strong northerly (upstream) winds of greater than 40 km/h (measured in the field by observing the GPS-derived boat speed downwind at which there was no effective wind on the boat deck). Wind-driven mixing of river water and mobilization of near-shore sediments may have contributed to this high TSS value relative to other ATR stations, including ATR-FC-E, immediately across the river from ATR-FC-W. This west bank station was sampled the following day during calm conditions.

Station EMR-1 scored higher on PC1 than ATR-SR-W, which exhibited similar TSS values (22 and 23 mg/L, respectively), perhaps due to its much higher total nickel concentration (i.e., 0.0154 mg/L relative to 0.0003 mg/L).

All stations except ATR-DC-E and ATR-DC-W (upstream of Donald Creek, east and west banks, respectively) exhibited little separation on PC2. This PC was strongly correlated with total chlorine, which was higher at ATR-DC along the east bank (i.e., 32.7 mg/L) than the west bank (3.12 mg/L).

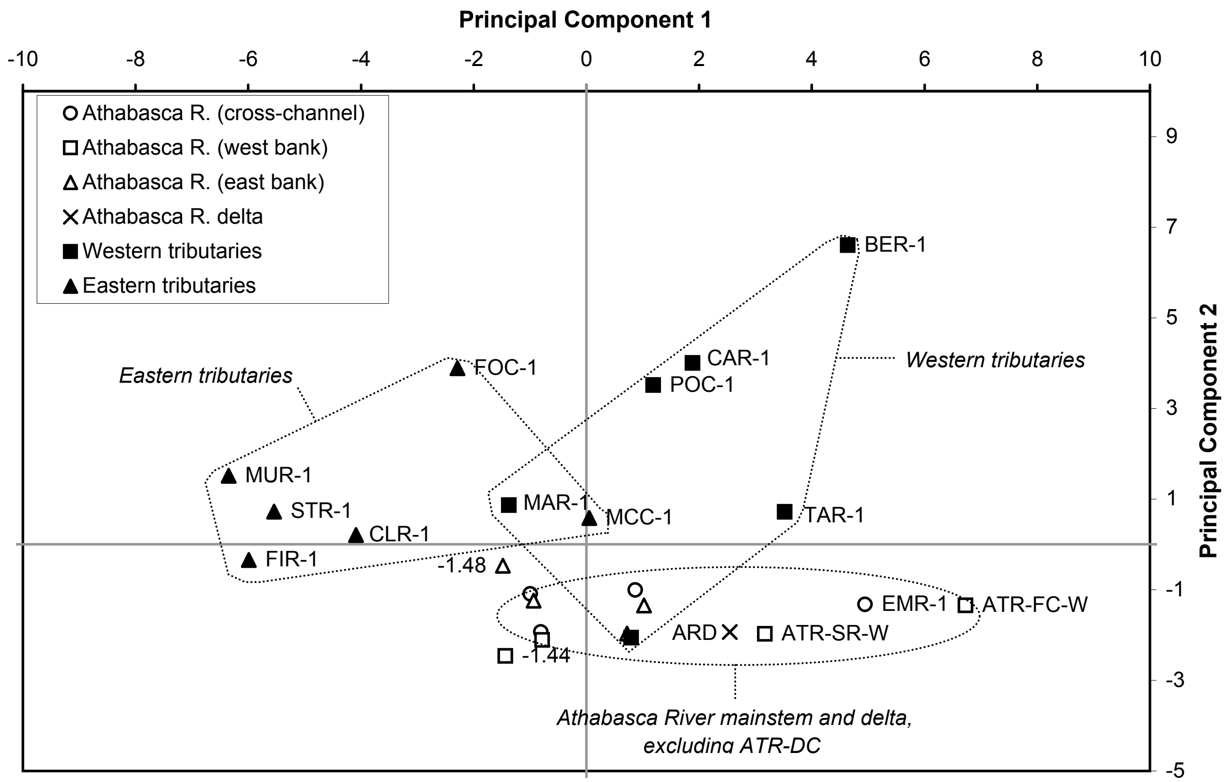
Figure 3.11 Total suspended solids (TSS) in the Athabasca River and its tributaries downstream of Fort McMurray, September 2003.



Athabasca River Mainstem, Delta and Tributaries

Five PCs were derived from PCA of the total metals data set for the Athabasca River mainstem, delta and tributaries. Respectively, PC1 and PC2 accounted for 39.6% and 19.5% (combined 59.1%) of total variance in the data set. Most metals were positively correlated with PC1, including cobalt, lead, thorium, nickel, vanadium, chromium, titanium and aluminum (strongly, r = 0.805 to 0.909), and arsenic, uranium, strontium, copper, molybdenum, zinc, antimony, mercury, barium and thallium (moderately). Total calcium, boron and lithium were strongly and positively correlated with PC2; total selenium correlated moderately and positively with this PC. Total molybdenum was moderately negatively correlated with PC2. Analytes including manganese and iron did not separate well between the two PCs.

Figure 3.12 Results of principal component analysis (PCA) on total metal concentrations in the Athabasca River mainstem and tributaries, September 2003.



A. Specific total metals correlated with Athabasca River & tributaries Total Metals PC1 and PC2

	Negative Correlations		Positive Correlations	
	Moderate (-0.5 > r > -0.75)	Strong (r < -0.75)	Moderate (0.5 < r < 0.75)	Strong (r > 0.75)
PC1	-	-	Arsenic, uranium, strontium, copper, molybdenum, zinc, antimony, mercury, barium, thallium	Cobalt, lead, thorium, nickel, vanadium, chromium, titanium, aluminum
PC2	Molybdenum	-	Selenium	Calcium, boron, lithium

Note: Analytes that were correlated with both principal components in the same direction (i.e., +/+ or -/-) were excluded.

B. Conventional WQ variables correlated with Athabasca River & tributaries Total Metals PC1 and PC2 [1]

	Negative Correlations		Positive Correlations	
	Moderate (-0.5 > r > -0.75)	Strong (r < -0.75)	Moderate (0.5 < r_s < 0.75)	Strong (r_s > 0.75)
PC1	-	-	-	TSS
PC2	-	-	Colour, TDS, bicarbonate, alkalinity, hardness, dissolved phosphorus	TOC, conductivity, DOC

[1] Variables assessed included hardness, alkalinity, bicarbonate, conductivity, TDS, TSS, DOC, TOC, colour, total phosphorous, dissolved phosphorous, temperature, Kjeldahl nitrogen (TKN), ammonia, pH, and dissolved oxygen.

TSS was strongly and positively correlated with PC1. No other conventional water quality variables were moderately or strongly correlated with this PC, positively or negatively. PC2 exhibited strong correlations with DOC, TOC and conductivity, and moderate correlations with colour, dissolved phosphorous, and several aggregate parameters related to dissolved ion concentrations, specifically total dissolved solids (TDS), alkalinity, bicarbonate, and hardness. Given these correlations, PC1 may be considered generally indicative of total metals concentrations that are related to suspended sediments (i.e., particulate or adsorbed metals), while PC2 may be considered related to the dissolved metal component of total metals.

Figure 3.12 illustrates the PC1 versus PC2 scatterplot for this PCA. Athabasca River mainstem stations exhibited a similar clustering when analyzed with the delta and tributary stations as when analyzed independently (*cf*. Figure 3.10 and Figure 3.12), with all stations grouping together near the origin of the plot except ATR-FC-W, EMR-1, and ATR-SR-W, which exhibited higher TSS concentrations relative to most other ATR stations. Athabasca delta station ARD-1 (Big Point Channel) exhibited a similar TSS value (i.e., 20 mg/L) to both EMR-1 and ATR-SR-E, and scored intermediately on PC1 between the main ATR group and this "elevated TSS" group.

East and west bank stations at ATR-DC (upstream of Donald Creek) scored lowest on PC1, with ATR-DC-E scoring higher on PC2 than ATR-DC-W. As was observed in other PCAs of mainstem, delta and tributary stations, ATR-DC-E scored intermediately between other ATR stations and Clearwater River (CLR-1).

All tributaries to the Athabasca River except ELR-1 (Ells River) scored higher on PC2 than any Athabasca River mainstem or delta station. Beaver River (BER-1) scored highest on PC2; highest concentrations of hardness, alkalinity, TDS, and conductivity, all positively correlated with PC2, were observed at this station. Conversely, stations FIR-1 (Firebag River) and ELR-1, stations exhibiting lowest conductivity, scored lowest on PC2 relative to other tributaries, and in the same range as Athabasca River mainstem stations.

Western tributaries generally scored higher on PC1 than eastern tributaries, with all western tributaries exhibiting positive PC1 scores except MacKay River (MAR-1). Eastern tributaries generally exhibited negative PC1 scores (Figure 3.12). Eastern tributaries CAR-1 (Calumet River), TAR-1 (Tar River) and BER-1 exhibited highest TSS of all tributary stations, also scoring highest of all tributaries on PC1. Eastern tributary MUR-1 (Muskeg River) scored lowest on PC1, and also exhibited lowest TSS (i.e., 1.5 mg/L) of all stations, including Athabasca mainstem stations.

3.3.1.4 Major Ions

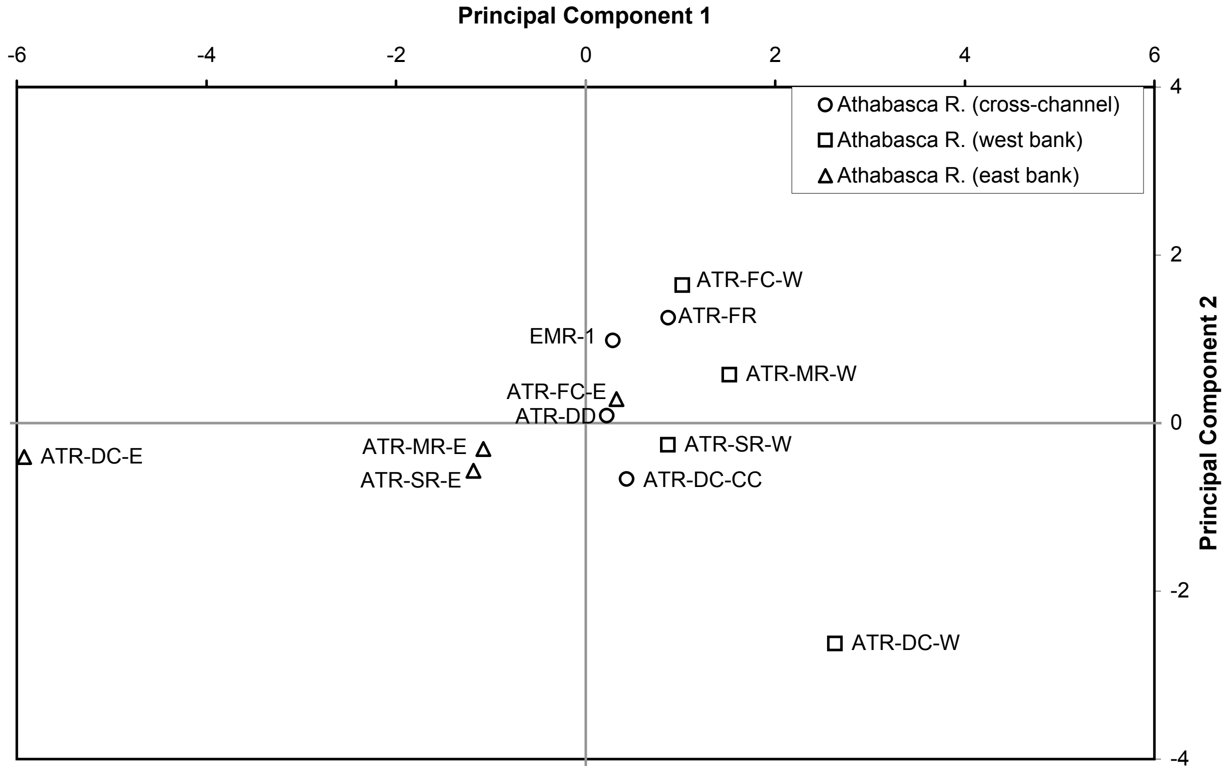
Athabasca River Mainstem

Two PCs were formed from the analyses of the major ions data set for Athabasca River mainstem stations. PC1 and PC2 accounted for 64.7% and 17.7% of the total variance in the data set, respectively (82.4% combined). PC1 was correlated with all ions except sulphide: sulphate, calcium, magnesium, and potassium were strongly, positively correlated while sodium and chloride were moderately, negatively correlated. PC2 was moderately, positively correlated with both sodium and chloride.

Conventional water quality variables associated with PC1 included: hardness was strongly, positively correlated; alkalinity and bicarbonate were moderately, positively correlated; and DOC was moderately, negatively correlated. PC2 was moderately, positively correlated with hardness and total dissolved solids, and moderately negatively correlated with ammonia.

Figure 3.13 presents a scatterplot of major ions PC1 and PC2 for the Athabasca River mainstem. Most stations cluster in a loose group near the centre of the plot. However, east and west bank stations upstream of Donald Creek (i.e., ATR-DC-E and ATR-DC-W) place distantly from this group, with ATR-DC-E scoring very low on PC1 compared with other stations, and ATR-DC-W scoring higher on PC1 and lower on PC2 than all other stations. The cross-channel composite sample from this location (i.e., ATR-DC-CC) scored generally near the main cluster of ATR stations.

Figure 3.13 Results of principal component analysis (PCA) on major ion concentrations in the Athabasca River mainstem, September 2003.



A. Specific major ions correlated with Athabasca River Major Ions PC1 and PC2

	Negative Correlations		Positive Correlations	
	Moderate (0.5 < r < 0.75)	Strong (r > 0.75)	Moderate (0.5 < r < 0.75)	Strong (r > 0.75)
PC1	Chloride, sodium	-	-	Sulphate, calcium, magnesium, potassium
PC2	-	-	Chloride, sodium	-

Note: Analytes that were correlated with both principal components in the same direction (i.e., +/+ or -/-) were excluded.

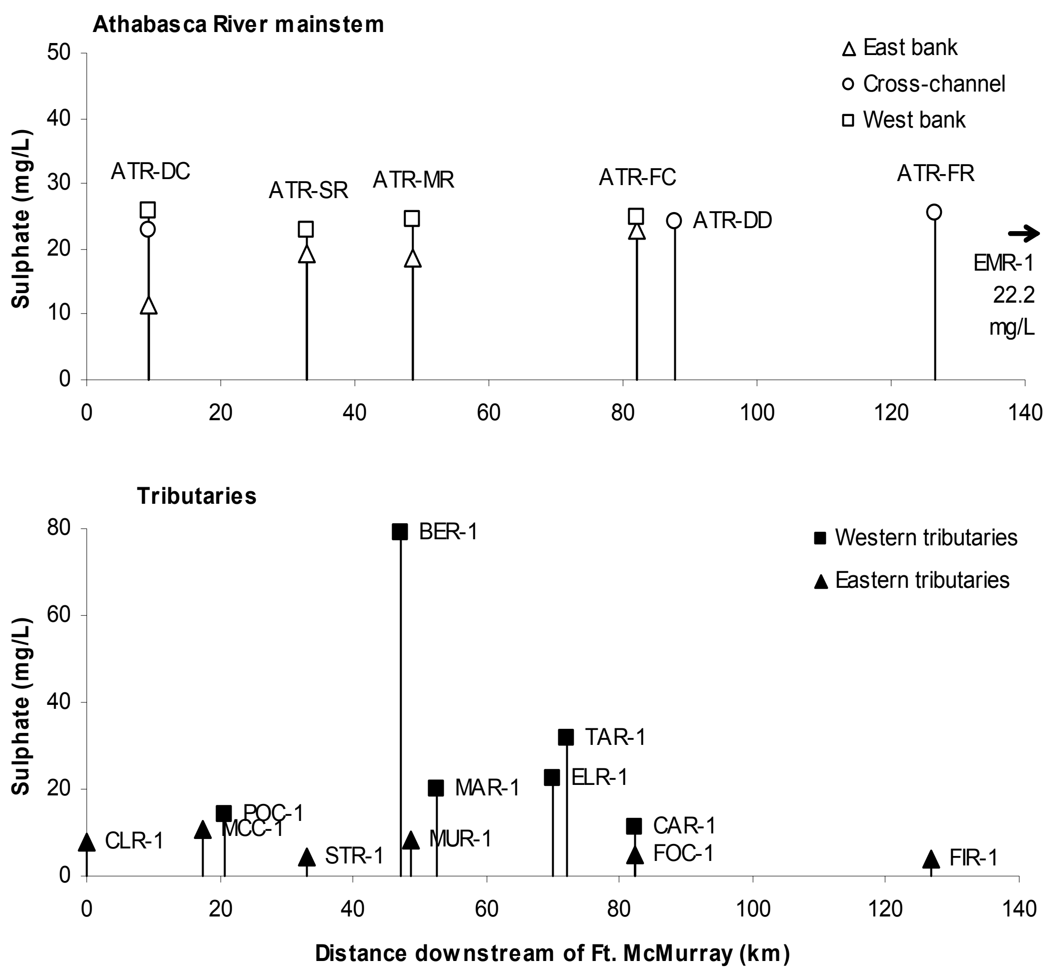
B. Conventional WQ variables correlated with Athabasca River Major Ions PC1 and PC2[1]

	Negative Correlations		Positive Correlations	
	Moderate (0.5 < r_s < 0.75)	Strong (r_s > 0.75)	Moderate (0.5 < r_s < 0.75)	Strong (r_s > 0.75)
PC1	DOC	-	Alkalinity, bicarbonate	Hardness
PC2	Ammonia	-	hardness, TDS	-

[1] Variables assessed included hardness, alkalinity, bicarbonate, conductivity, TDS, TSS, DOC, TOC, colour, total phosphorous, dissolved phosphorous, temperature, Kjeldahl nitrogen (TKN), ammonia, pH, and dissolved oxygen.

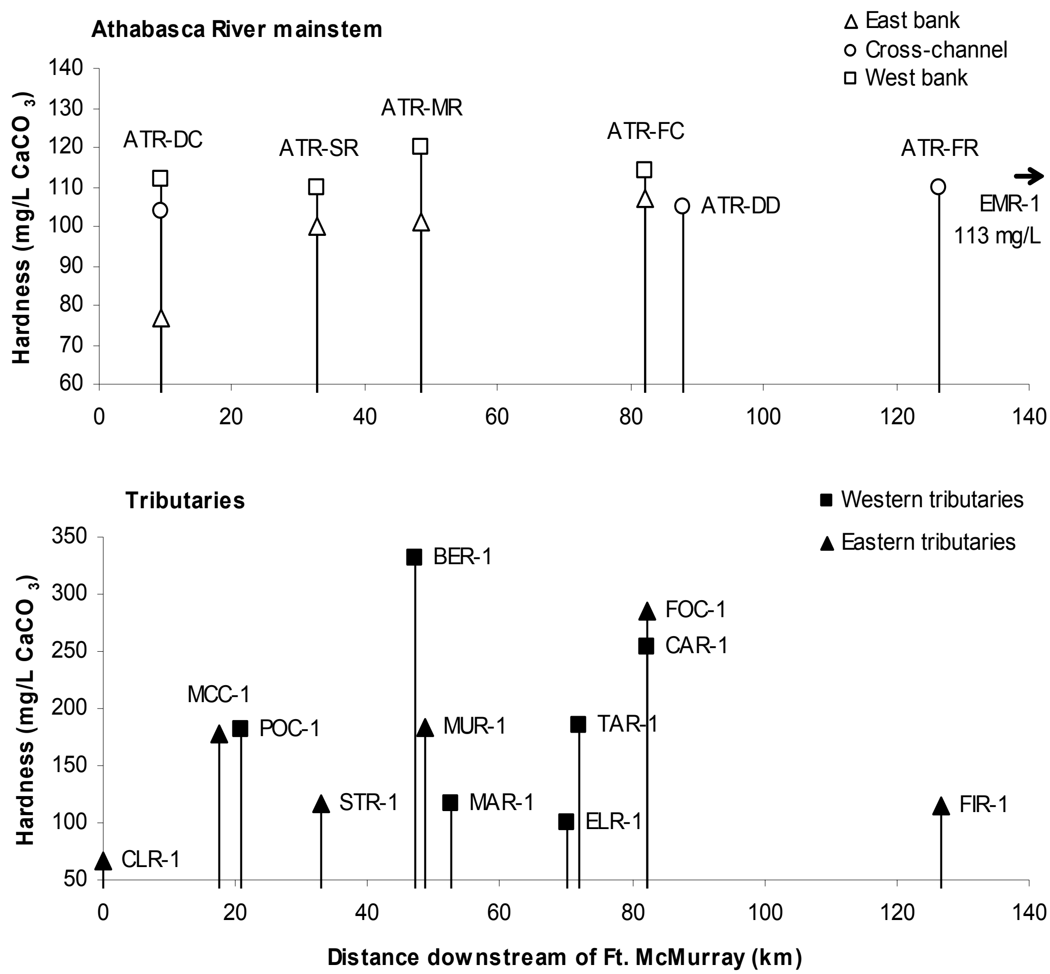
Relative to other stations, ATR-DC-W exhibited low chloride (i.e., 2/mg/L) while ATR-DC-E exhibited high chloride (i.e., 36 mg/L) (Figure 3.3) [dissolved chlorine; correlation of dissolved chlorine with chloride for all September 2003 data: r_s = 1.0). Concentrations of sulphate were also low at ATR-DC-E relative to all other stations (Figure 3.14).

Figure 3.14 Sulphate concentrations in the Athabasca River and its tributaries downstream of Fort McMurray, September 2003.



Generally, east bank stations between Fort McMurray and the Muskeg River (i.e., ATR-DC-E, ATR-SR-E and ATR-MR-E) exhibited higher chloride and lower sulphate and hardness (Figure 3.15) than west bank stations at these locations (i.e., ATR-DC-W, ATR-SR-W and ATR-MR-W).

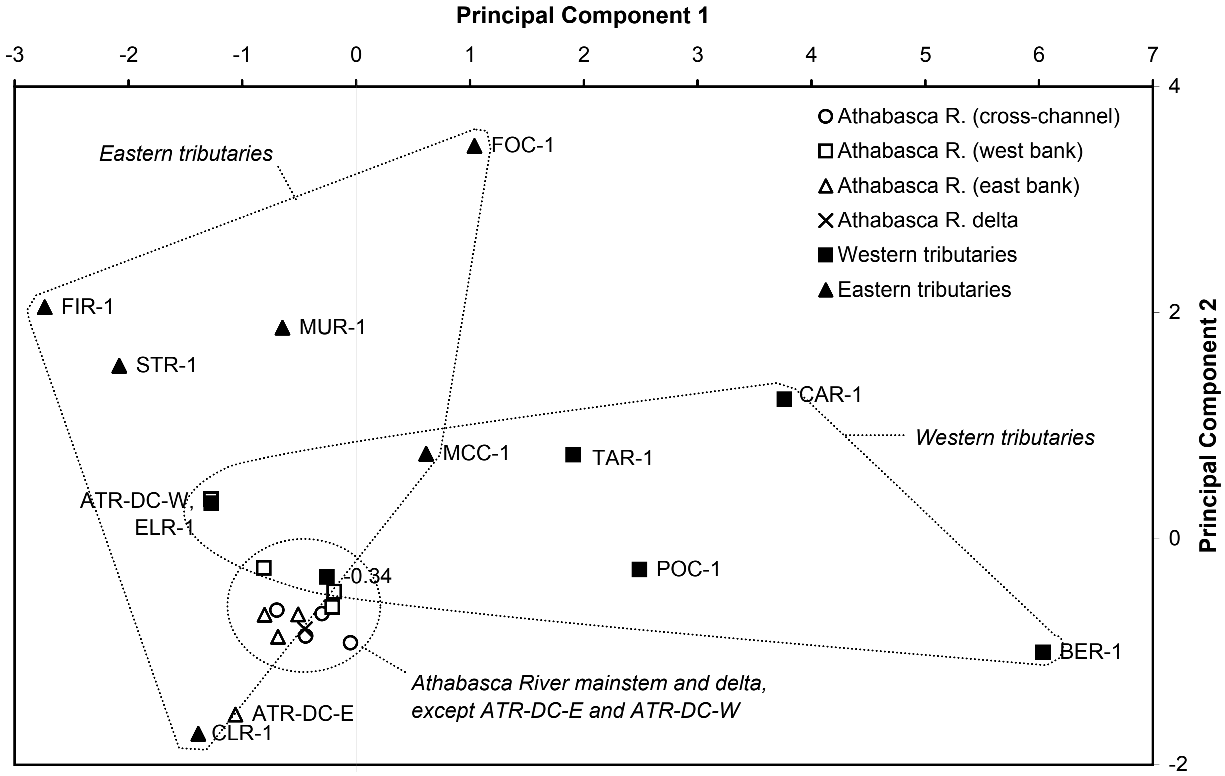
Figure 3.15 Hardness of waters in the Athabasca River and its tributaries downstream of Fort McMurray, September 2003.



Athabasca River Mainstem, Delta and Tributaries

Three PCs were formed from the analyses of the combined major ions data set for the Athabasca River mainstem, delta and tributaries. These PCs accounted for 49.7% and 22.7% (71.7% combined) of the total variance in the data set. PC1 was strongly, positively correlated with potassium, magnesium and sodium, and moderately, positively associated with chloride. PC2 was moderately negatively correlated with chloride and sulphate, and moderately positively correlated with magnesium.

Figure 3.16 Results of principal component analysis (PCA) on major ion concentrations in the Athabasca River mainstem and mouth of tributaries, September 2003.



A. Specific major ions correlated with Athabasca River & tributaries Major Ions PC1 and PC2

	Negative Correlations		Positive Correlations	
	Moderate (0.5 < r < 0.75)	Strong (r > 0.75)	Moderate (0.5 < r < 0.75)	Strong (r > 0.75)
PC1	-	-	Chloride	Magnesium, potassium, sodium
PC2	Sulphate, chloride	-	Magnesium	-

Note: Analytes that were correlated with both principal components in the same direction (i.e., +/+ or -/-) were excluded.

B. Conventional WQ variables correlated with Athabasca River & tributaries Major Ions PC1 and PC2 [1]

	Negative Correlations		Positive Correlations	
	Moderate (0.5 < r_s < 0.75)	Strong (r_s > 0.75)	Moderate (0.5 < r_s < 0.75)	Strong (r_s > 0.75)
PC1	-	-	pH, alkalinity, TDS bicarbonate, hardness	Conductivity
PC2	-	-	Alkalinity, bicarbonate, hardness, pH, temperature	

[1] Variables assessed included hardness, alkalinity, bicarbonate, conductivity, TDS, TSS, DOC, TOC, colour, total phosphorous, dissolved phosphorous, temperature, Kjeldahl nitrogen (TKN), ammonia, pH, and dissolved oxygen.

PC1 correlated with several water quality variables generally related to ion concentration, including conductivity (strong, positive correlation), alkalinity, TDS, bicarbonate, hardness and pH (moderate, positive correlations). PC2 similarly was moderately, positively associated with alkalinity, bicarbonate, hardness, pH and temperature.

Most Athabasca River mainstem stations clustered together with slightly negative scores on both PC1 and PC2, with the exception of west and east bank stations upstream of Donald Creek (ATR-DC), which scored differently, predominantly on PC2. Station ATR-DC-E (east bank) scored closely with Clearwater River (CLR-1), consistent with results of the dissolved and total metals PCAs, while ATR-DC-W scored higher than the main ATR group to a similar degree that ATR-DC-E scored lower. The cross-channel composite sample collected at this station (ATR-DC-CC) placed within the main ATR group, suggesting that major ion concentrations at ATR-DC generally were consistent with other ATR samples, but not homogeneous across the river at this location.

Western tributary stations generally separated widely along PC1, with less variation on PC2. Station BER-1 (Beaver River), which exhibited very high conductivity, sulphate and chlorate concentrations relative to all other stations, scored highest on PC1. CAR-1 (Calumet River), POC-1 (Poplar Creek) and TAR-1 (Tar River), which also exhibited relatively high conductivity, sulphate, and hardness or alkalinity compared with other stations, also scored high on PC1. Conversely, western tributary stations MAR-1 (MacKay River) and ELR-1 (Ells River), which exhibited lowest alkalinity and hardness of all western tributaries, scored negatively on PC1.

Most eastern tributaries generally scored negatively on PC1 and positively on PC2. Stations FOC-1 (Fort Creek), MUR-1 (Muskeg River), STR-1 (Steepbank River) and FIR-1 (Firebag River), which all scored high on PC2, all exhibited low concentrations of sulphate and chloride relative to western tributaries and the Athabasca River mainstem and delta. CLR-1 (Clearwater River), exhibiting the highest chloride and lowest alkalinity of all stations surveyed, scored most negatively on PC2, clustering with ATR-DC-E.

3.3.1.5 Inter-correlation of Water Quality Variables

Athabasca River Mainstem

Table 3.10 summarizes moderate and strong correlations observed among the thirteen water quality indicators described in Section 3.2.7.2 and summary variables from principal component analyses of Athabasca River mainstem stations only.

Many conventional variables and nutrients were positively correlated with phosphorus, major ions, and metals, with the exception of pH, which was negatively correlated with phosphorus, metals, and DOC. DOC was positively correlated with dissolved metals and dissolved phosphorus, while alkalinity, TDS, and sulphate were inter-correlated and positively correlated with major ions.

TSS was positively correlated with total metals, total phosphorous and total aluminum, but not correlated with dissolved metals, dissolved phosphorous or dissolved aluminum. TKN was not correlated with any of the variables examined.

Many individual metals and metals PCs were inter-correlated. Dissolved Metal PC1 was positively correlated with alkalinity and negatively correlated with DOC; while Dissolved Metal PC2 was negatively correlated with pH. Dissolved aluminum was not correlated with any variables.

Table 3.10 Rank correlations among key water quality indicators and dissolved metals, total metals, and major ions principal components for the Athabasca River mainstem, September 2003.

	Negative Correlations		Positive Correlations	
	Moderate	Strong	Moderate	Strong
Variable	- 0.5 > r_s > - 0.75	r_s < - 0.75	0.5 < r_s < 0.75	r_s > 0.75
DOC	Sulphate, Ion PC1, Diss Met PC1,	pH	Dissolved P	Total boron, Tot Met PC2
pH	Dissolved P, Diss Met PC2	DOC, Total boron, Tot Met PC 2	-	-
Alkalinity	-	-	Sulphate, Ion PC1 Diss Met PC1,	-
TDS	-	-	Ion PC2	-
TSS	-	-	Total P, Cr, Al	Tot Met PC1
Sulphate	Dissolved P, DOC Tot Met PC2	-	Alkalinity	Ion PC1
TKN	-	-	-	-
Dissolved Phosphorus	pH, sulphate	-	Total P, DOC, Total boron	-
Total Phosphorus	-	-	Total Cr, TSS, dissolved P	-
Total Boron	-	pH	Tot Met PC2, Dissolved P	DOC
Total Chromium	-	-	Tot Met PC1, Total P, Total Al	TSS

Table 3.10 (cont'd).

Variable	Negative Correlations Moderate $-0.5 > r_s > -0.75$	Negative Correlations Strong $r_s < -0.75$	Positive Correlations Moderate $0.5 < r_s < 0.75$	Positive Correlations Strong $r_s > 0.75$
Dissolved Aluminum	-	-	-	-
Total Aluminum	-	-	TSS, Total Cr	Tot Met PC1
Dissolved metals PC1	DOC	-	Alkalinity	-
Dissolved metal PC2	pH	-	Tot Met PC2	-
Total Metals PC1	-	-	Total Cr	TSS, Total Al
Total Metals PC2	Sulphate	pH, Ion PC1	Total boron, Diss Met PC2	DOC
Major Ions PC1	DOC	Tot Met PC2	Alkalinity	Sulphate
Major Ions PC2	-	-	TDS	-

Athabasca River Mainstem, Delta, and Tributaries

Table 3.11 summarizes moderate and strong correlations observed among the thirteen water quality indicators described in Section 3.2.7.2 and summary variables generated by principal component analyses for water quality measurements for the Athabasca River, its delta and tributaries.

Table 3.11 Rank correlations among key water quality indicators and dissolved metals, total metals, and major ions principal components for the Athabasca River Mainstem, delta and mouths of tributaries, September 2003.

Variable	Negative Correlations Moderate $-0.5 > r_s > -0.75$	Negative Correlations Strong $r_s < -0.75$	Positive Correlations Moderate $0.5 < r_s < 0.75$	Positive Correlations Strong $r_s > 0.75$
DOC	Total aluminum	Diss Met PC2	alkalinity, TDS, TKN	Dissolved P, Total boron, Tot Met PC2
pH	-	-	Ion PC2	-
Alkalinity	Diss Met PC2	-	DOC, TDS, TKN, Total boron, Tot Met PC2, Ion PC1 & PC2	-
TDS	Diss Met PC2	-	DOC, Alkalinity, Total boron, Tot Met PC2, Ion PC1	-
TSS	-	-	Total P, Cr, Al	Tot Met PC1

Table 3.11 (cont'd).

Variable	Negative Correlations Moderate $-0.5 > r_s > -0.75$	Negative Correlations Strong $r_s < -0.75$	Positive Correlations Moderate $0.5 < r_s < 0.75$	Positive Correlations Strong $r_s > 0.75$
Sulphate	Dissolved P	-	Diss Met PC2, Tot Met PC1, Total Al	-
Total Kjeldahl Nitrogen (TKN)	Diss Met PC2	-	DOC, Alkalinity, Total boron	-
Dissolved Phosphorus	Sulphate, Total Al, Diss Met PC2	-	Total P, boron, Tot Met PC2	DOC
Total Phosphorus	-	-	TSS, Dissolved P	-
Total Boron	Diss Met PC2	-	TKN, TDS, dissolved P, Alkalinity, Tot Met PC2, Ion PC2	DOC
Total Chromium	-	-	TSS	Tot Met PC1, total Al
Dissolved Aluminum	Tot Met PC2	-	-	-
Total Aluminum	DOC, dissolved P, Tot Met PC2	-	Sulphate, TSS, Diss Met PC2	Total Cr, Tot Met PC1
Diss Met PC1			Ion PC1, Tot Met PC1	-
Diss Met PC2	Alkalinity, TDS, Total boron, dissolved P, TKN	DOC, Tot Met PC2	Sulphate, Total Al	-
Tot Met PC1	-	-	TSS, Sulphate, Diss Met PC1, Ion PC1	Total Cr, Total Al
Tot Met PC2	Total Al, Dissolved Al	Diss Met PC2	Alkalinity, TDS, Dissolved P, Total boron	DOC
Ion PC1	-	-	Alkalinity, TDS, Total boron, Diss Met PC1, Tot Met PC1	-
Ion PC2	-	-	Alkalinity, Bicarbonate Hardness, pH, Temperature	-

Several variables, including DOC, alkalinity, total boron, dissolved P and TKN, correlated negatively with Dissolved Metal PC2; this PC was negatively associated with low iron, manganese, calcium, lithium and boron, and also negatively correlated with water colour. All of these variables were also positively correlated with Total Metals PC2 (which itself was strongly negatively correlated with Dissolved Metals PC2), suggesting that these PCs may describe similar water characteristics.

Sulphate was positively correlated with dissolved and total metals (including total aluminum) and negatively correlated with dissolved phosphorus. Both TKN and dissolved phosphorus, the most bioavailable forms of N and P nutrients, were positively correlated with DOC and negatively correlated with Dissolved Metals PC2. TSS was positively correlated with total metals concentrations generally (i.e., Total Metals PC1) as well as with total aluminum, chromium, and phosphorous, but not with any dissolved metals. pH was not correlated with any of the variables examined.

Most individual metals and metals PCs were inter-correlated and positively correlated with TSS, TDS, DOC, or phosphorus. However, total aluminum was negatively correlated with dissolved phosphorus and DOC. Major ion PC1 was correlated with alkalinity, TDS and total boron. Dissolved aluminum was not correlated with any of the variables examined.

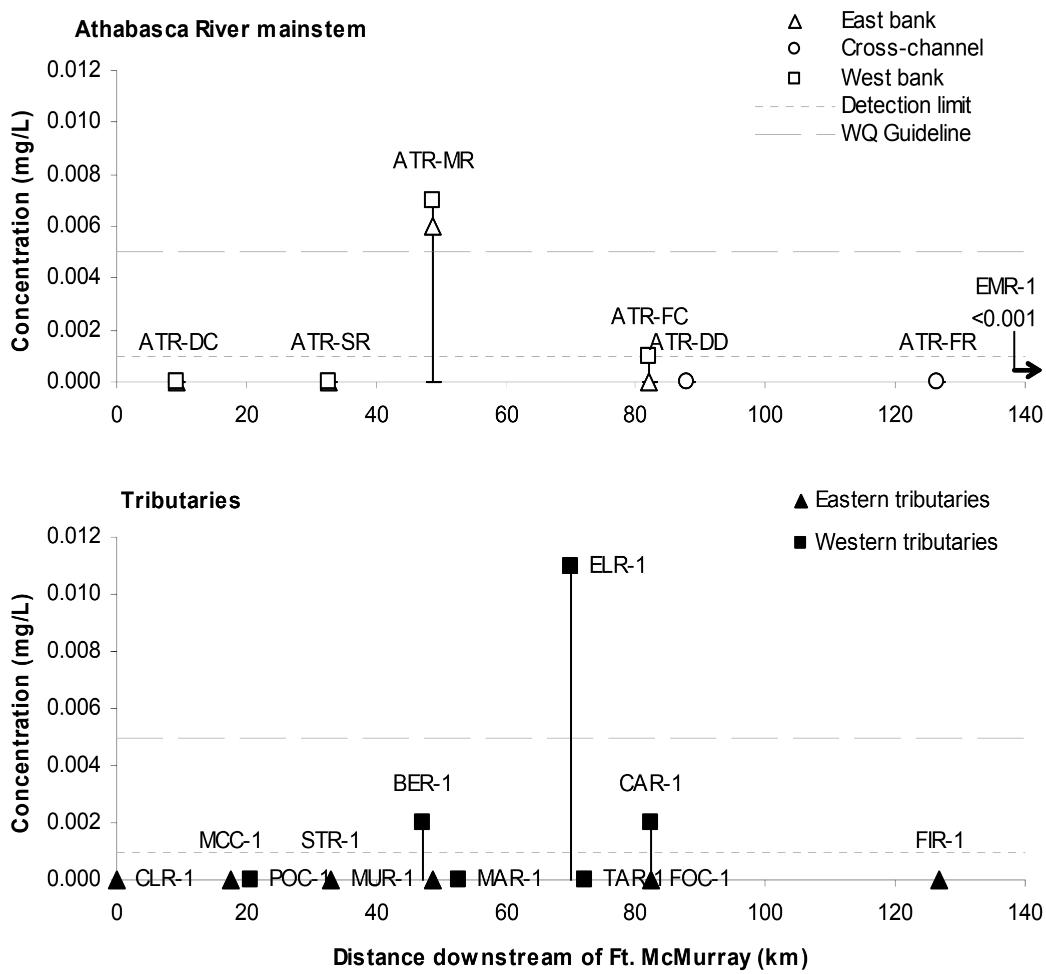
3.3.1.6 Organic Compounds and Hydrocarbons

Halogenated organic compounds measured by RAMP included total recoverable hydrocarbons (TRH), naphthenic acids, phenols, and polyaromatic hydrocarbons (PAHs).

Total recoverable hydrocarbons were not detected in water samples from any station during any seasonal sampling during 2003.

Total phenolic compounds (total phenols) were observed at several Athabasca River mainstem and tributary stations in September 2003 (Figure 3.17). Values exceeding the Alberta guideline for the protection of aquatic life of 0.05 mg/L were observed at the Athabasca River upstream of the Muskeg River along both east and west banks (ATR-MR-E and –W, 0.006 and 0.007 mg/L, respectively) and at ELR-1 (Ells River, 0.011 mg/L). Phenols were also detected in the Ells River during spring sampling at the detection limit of 0.001 mg/L; phenols were not detected at any other Athabasca River mainstem, delta or tributary mouth station during winter, spring or summer sampling during 2003.

Figure 3.17 Total phenol concentrations in the Athabasca River mainstem and its tributaries downstream of Fort McMurray, September 2003.



Naphthenic acids were not detected at any station during winter and spring sampling. In summer, they were measured at BER-1 (Beaver River) at a concentration of 2 mg/L, twice the analytical detection limit (ADL). In September 2003, naphthenic acids were observed at several stations at the detection limit of 1 mg/L, including FIR-1 (Firebag River), FOC-1 (Fort Creek), ELR-1 (Ells River), MCC-1 (McLean Creek) and POC-1 (Poplar Creek). Concentrations of 3 mg/L and 2 mg/L were observed at BER-1 (Beaver River) and CAR-1 (Calumet River), respectively. Naphthenic acids were not detected in any water samples from the Athabasca River mainstem or delta.

No PAHs were detected at any station sampled except ATR-DD (Athabasca River, downstream of development, near the outlet of Susan Lake), where naphthalene and methyl naphthalene were measured at 0.00005 mg/L (ADL = 0.00004 mg/L) and 0.00004 mg/L (ADL = 0.00004 mg/L), respectively.

3.3.1.7 Temporal Trends

Seasonal Variations in Water Quality

Most water quality variables exhibited clear differences in concentration with season. Generally, water quality variables occurring primarily in dissolved form, including major ions such as sodium, magnesium and sulphate and various metals, exhibited highest seasonal concentrations in winter (e.g., Figure 3.18: total dissolved solids, and Figure 3.19: total boron). Additionally, pH at all stations surveyed was lowest in winter (Figure 3.18), as was dissolved oxygen, which fell below minimum guidelines for the protection of aquatic life at several stations in winter (Section 3.3.5). Nitrate+nitrite was measured, near its detection limit, at all sampling stations except one during winter, but was not detected during any other season.

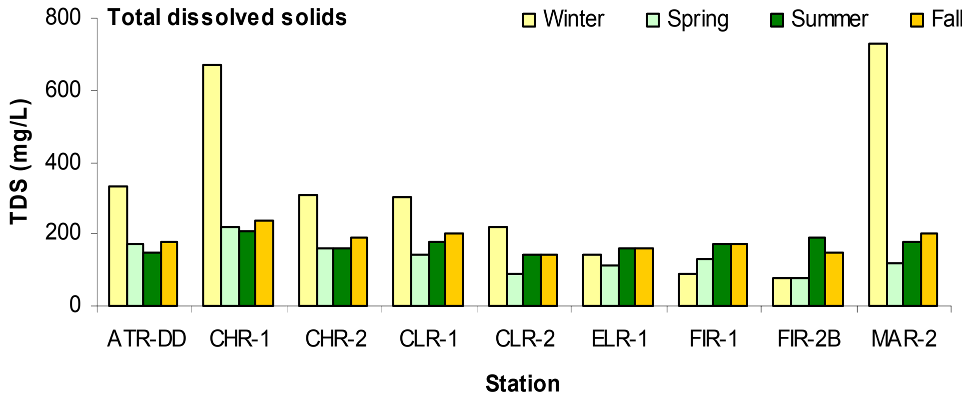
Conversely, highest total suspended solids generally were observed in spring or summer (Figure 3.18); concentrations of compounds associated with TSS, such as total aluminum (Figure 3.19) were similarly highest in spring or summer. Values in fall generally were intermediate between winter and summer observations for both dissolved and particulate-associated water quality variables. However, concentrations of total phenols were highest in fall at all stations where this variable was observed above its analytical detection limit in 2003.

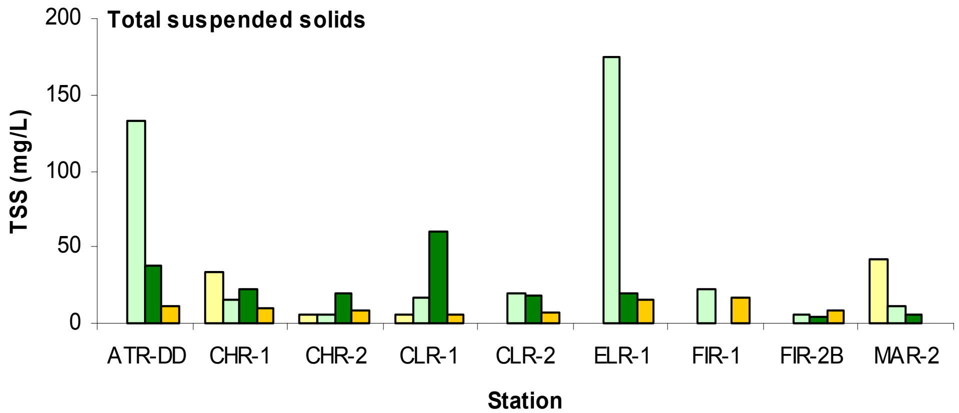
These general seasonal trends were consistent at all stations regardless of stream order or relative flow. However, some compounds exhibited different or more complex seasonal trends, such as total mercury (Figure 3.19), which generally, but not consistently, exhibited highest values in summer, which may be related to mobilization of mercury through methylation, which, as a biologically-mediated process, is temperature-dependent (Heyes *et al.* 2000).

Annual Variation in Water Quality

The RAMP 5-year report (Golder 2003a) assessed temporal trends in water quality in the Athabasca River mainstem, based on long-term data sets at Old Fort (ATR-OF) and upstream of Fort McMurray (ATR-UFM) collected by AENV. Similar long-term data sets have not yet been compiled by RAMP, precluding statistical trend analysis of RAMP-collected water quality data for the Athabasca River mainstem. Readers are referred to the 5-year report for further discussion of long-terms trends in the Athabasca River.

Figure 3.18 Seasonal variation in total dissolved solids, total suspended solids, and pH at water quality stations monitored in all four seasons in 2003.





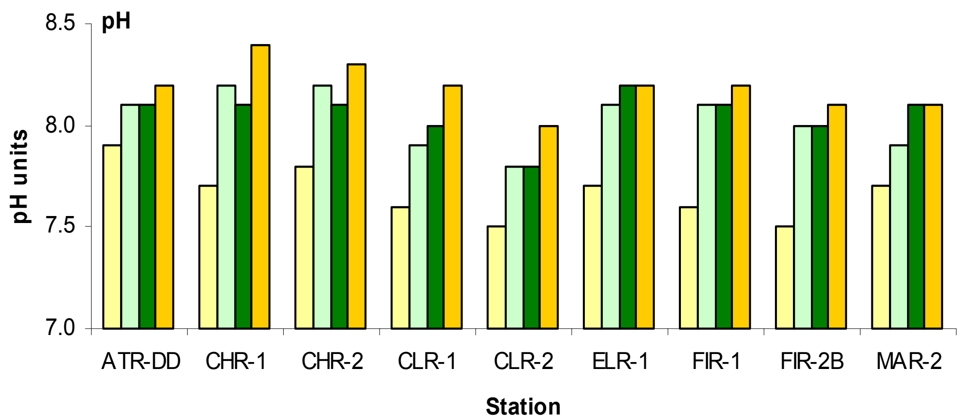
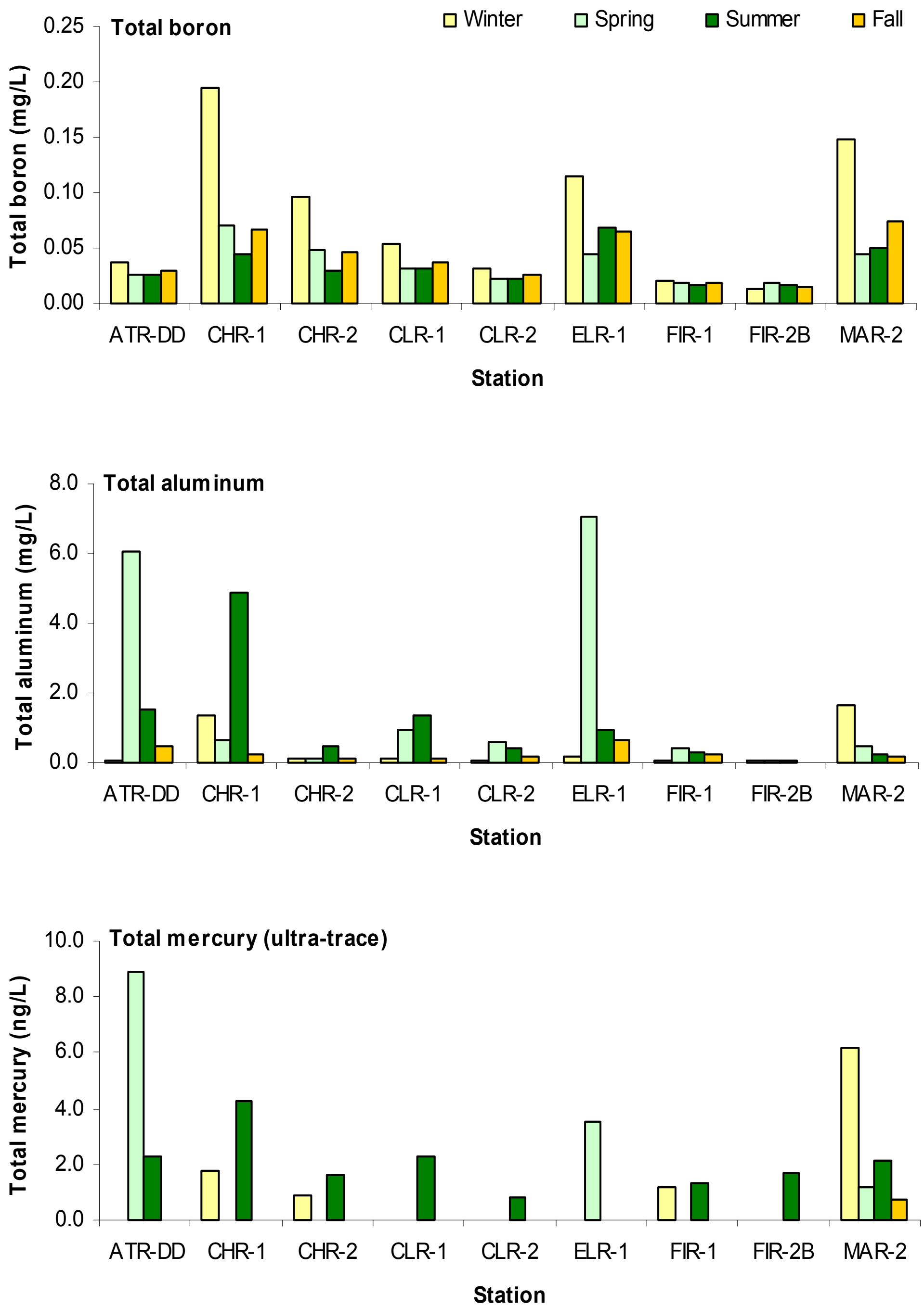


Figure 3.19 Seasonal variation in selected metals at water quality stations monitored in all four seasons in 2003.



3.3.2 Muskeg River Watershed

The Muskeg River has been a focus of oil sands development activities in recent years, and supports the largest number of RAMP sampling stations of any regional watershed excluding the Athabasca River mainstem.

Water quality at sampling stations in the Muskeg River watershed was within historical ranges at all stations surveyed, except Muskeg Creek (MUC-1), where total phenols concentrations were higher than previously recorded, and Stanley Creek (STC-1), where numerous water quality variables exhibited historical highs.

Temporal trends in variables highlighted by Golder (2003a) as key indicators of water quality in the oil sands region are presented for upper Muskeg River station MUR-6 and the Muskeg River mouth (MUR-1) in Figure 3.20, Figure 3.21 and Figure 3.22. These graphs also provide a qualitative comparison of upstream and downstream water quality in the Muskeg River drainage, with which to assess potential effects of local oil sands developments on Muskeg River water quality.

Statistical assessment of temporal trends in these variables at the mouth of the Muskeg River (MUR-1) indicated significant declining trends in total suspended solids (Kendall's τ = -0.84) and total aluminum (τ = -0.90). Due to the low number of observations in the test (i.e., n=7), the critical value of τ required for a trend to be statistically significant was high (i.e., $\tau > 0.71$). Concentrations of total aluminum were shown by RAMP (2003a) and through correlation analysis of water quality data collected by RAMP for September 2003 (Section 3.3.1.5) to correlate with suspended sediment load in regional rivers. However, visual inspection of trends in these variables since 1997 at MUR-1 (Figure 3.21 and Figure 3.22) indicates that TSS and total aluminum values have remained relatively consistent and low since 1998, following high observed values in 1997. This single high observation in 1997 may explain the significance of these observed trends. Higher sulphate concentrations from 1998 to 2000 relative to more recent years may relate to discharges from the Alsands Drain (now decommissioned), as discussed in the RAMP 5-year report (Golder 2003a).

Other water quality variables at MUR-1 exhibiting trends which were not statistically significant but correlated at values of $\tau > |0.5|$ included dissolved aluminum (negative trend, τ = -0.68) and total boron (positive trend, τ = 0.52).

No statistically significant trends in water quality at MUR-6 were observed (n = 6, critical τ = 0.87), although correlations of $\tau > |0.5|$ were returned for TSS and total aluminum (decreasing trends, τ = -0.69 and -0.60 respectively) and pH (increasing trend, τ = 0.73).

Figure 3.20 pH, alkalinity and sulphate concentration in the Muskeg River near its mouth (MUR-1) and upstream of development (MUR-6), 1997 to 2003.

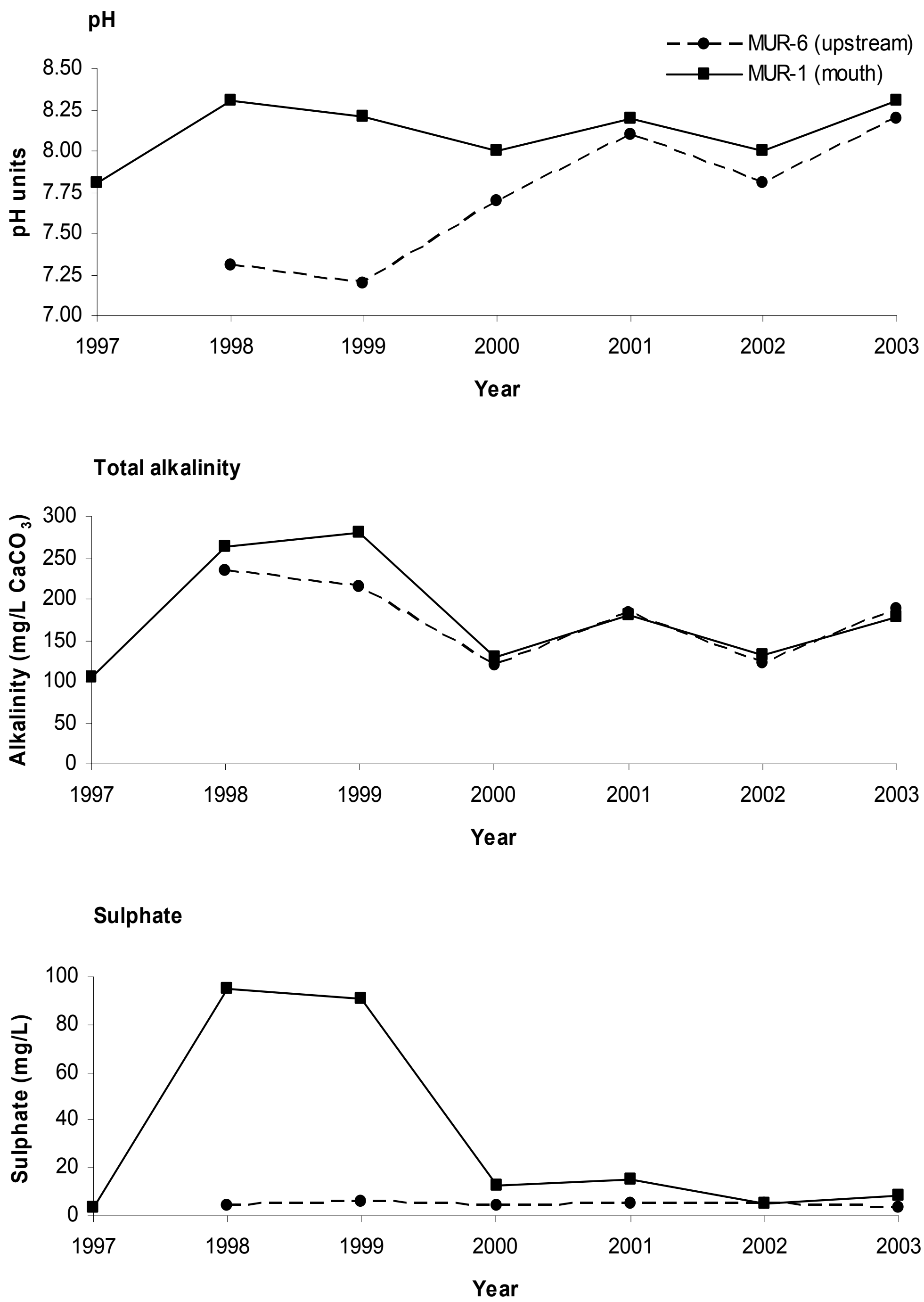


Figure 3.21 Total Kjeldahl nitrogen, total phosphorous and total suspended solids in the Muskeg River near its mouth (MUR-1) and upstream of development (MUR-6), 1997 to 2003.

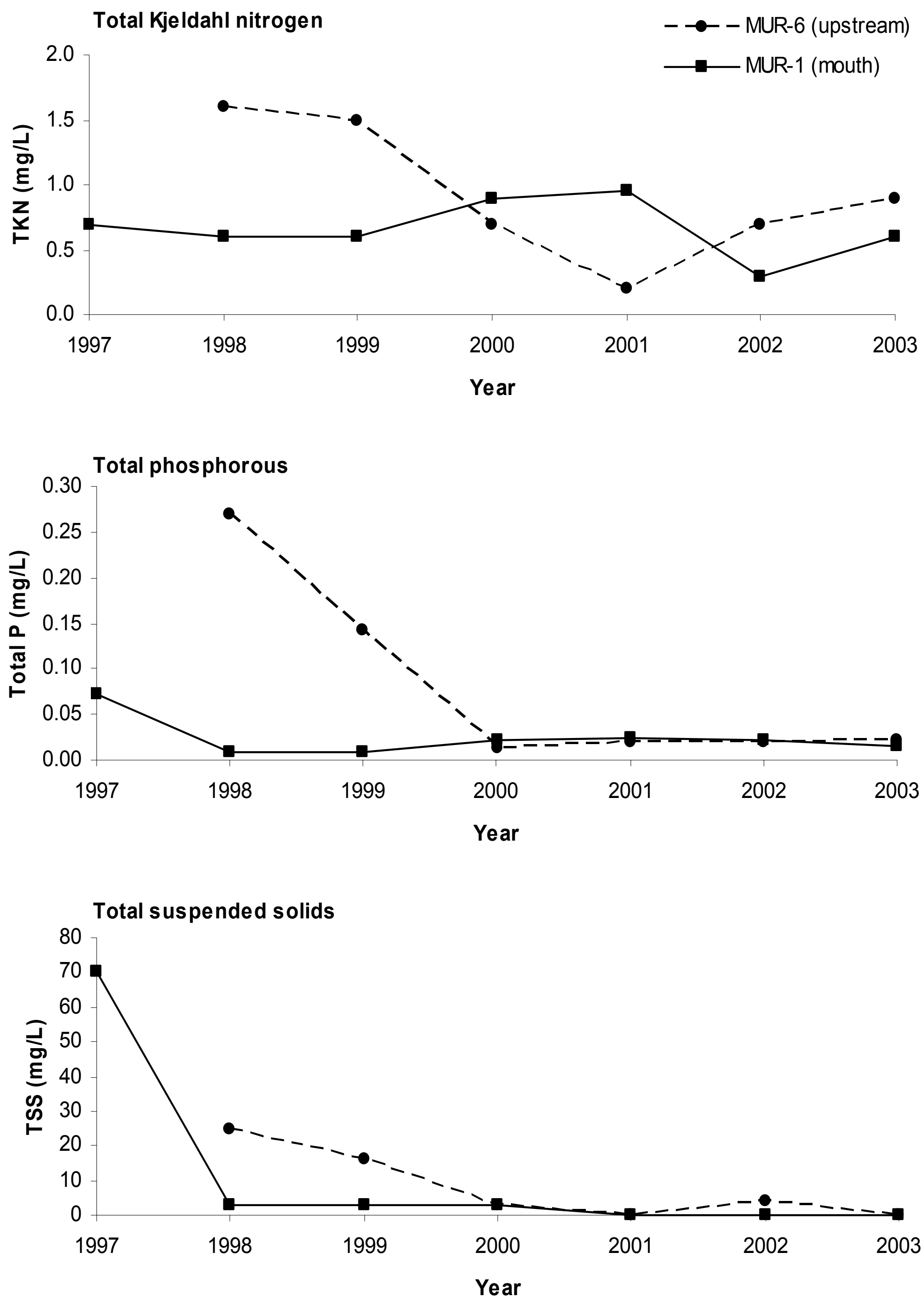
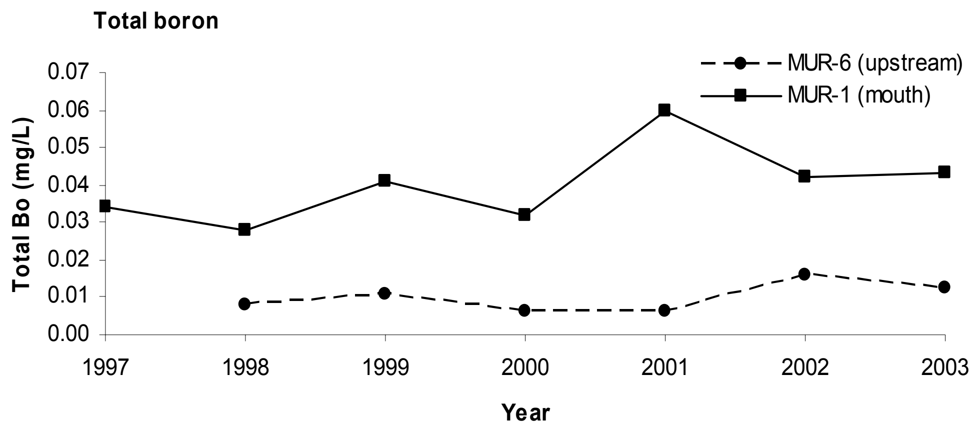
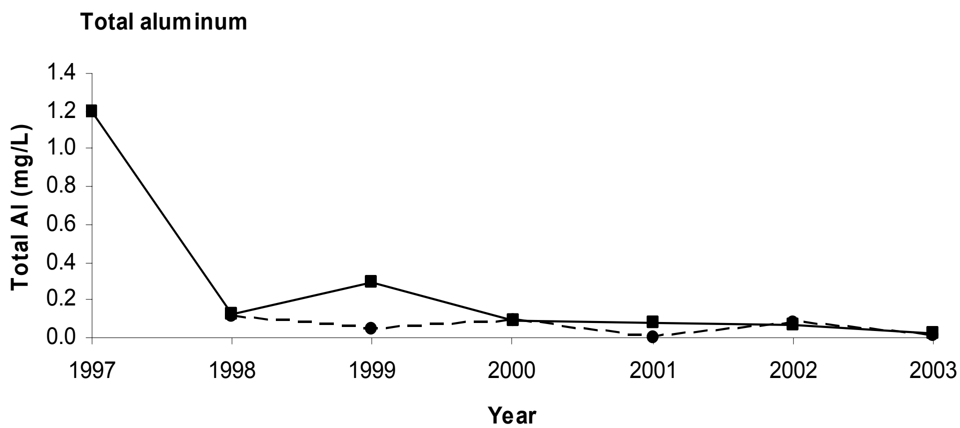


Figure 3.22 Selected total metal concentrations in the Muskeg River near its mouth (MUR-1) and upstream of development (MUR-6), 1997 to 2003.





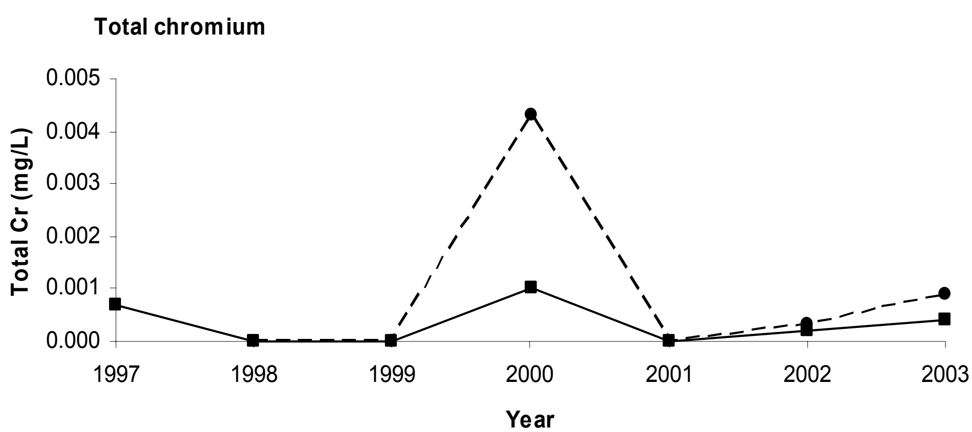
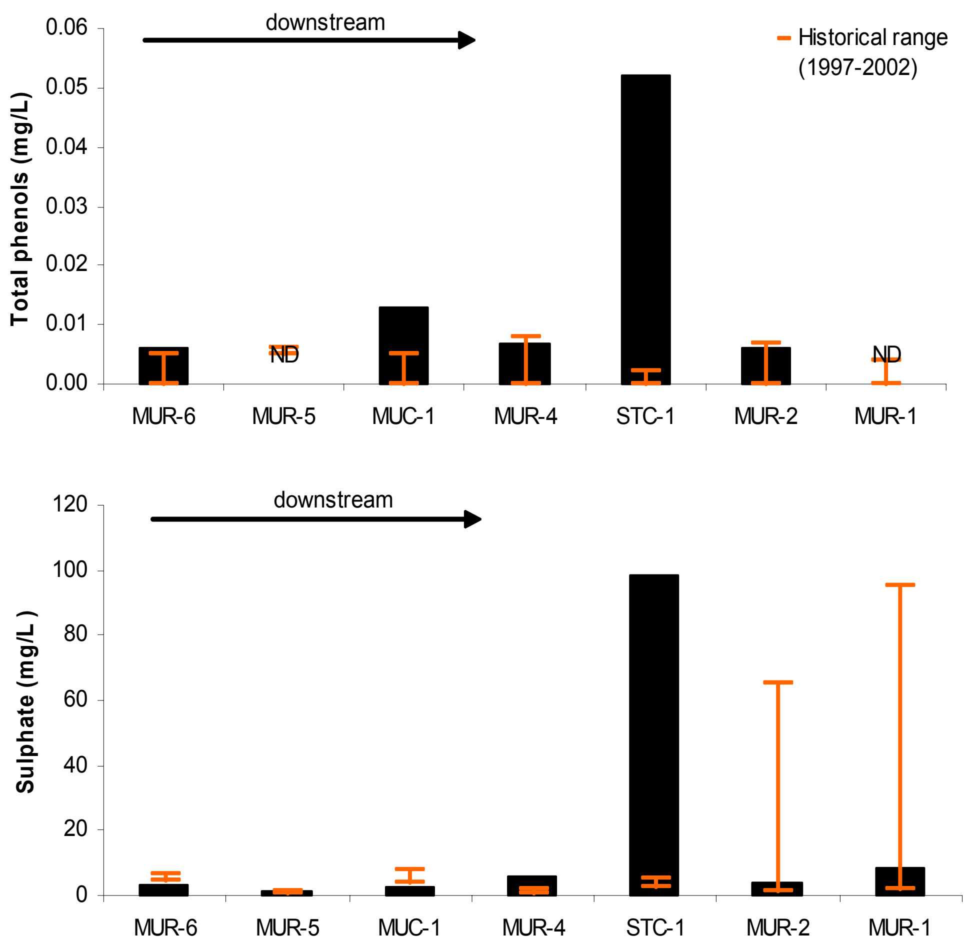


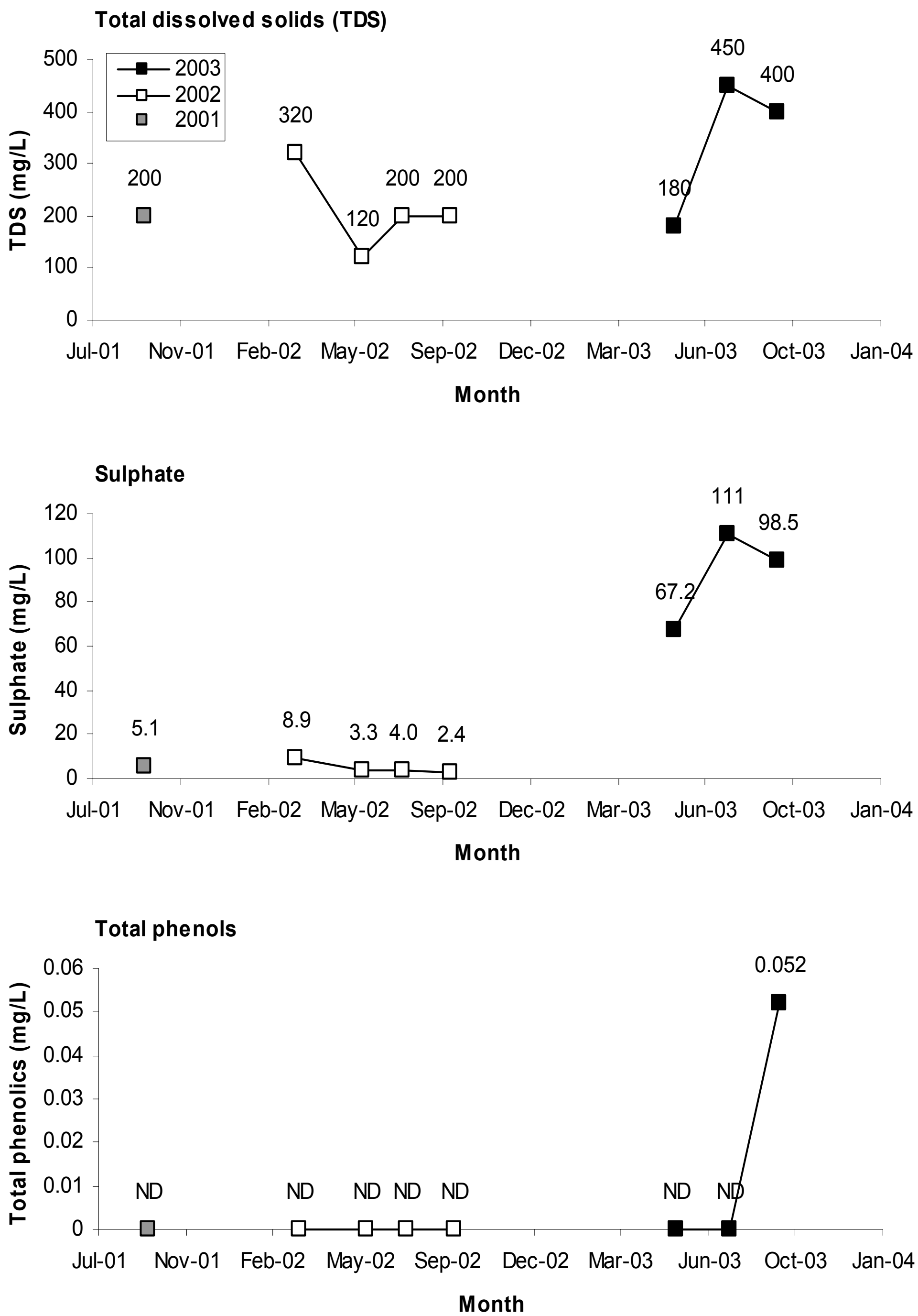
Figure 3.23 presents concentrations of total phenol and sulphate at RAMP and industry water quality monitoring stations in the Muskeg River in September 2003. Historical ranges of these variables in fall at each location are reported for comparison.

Figure 3.23 Total phenol and sulphate concentrations at RAMP and industry sampling stations in the Muskeg River watershed, September 2003



Water quality in Stanley Creek (STC-1) in 2003 differed substantially from previous years. Figure 3.24 presents concentrations of total dissolved solids, sulphate and total phenols in Stanley Creek measured by RAMP from 2001 to 2003. This change in water quality likely has occurred following commencement of clean water discharge (CWD) into Stanley Creek by Syncrude Canada Ltd. on May 18, 2003. The quality and quantity of this water release is discussed further in Section 3.4.2. Despite changes in water quality of Stanley Creek, water quality in the Muskeg River downstream of Stanley Creek (i.e., MUR-2 and MUR-1) in 2003 was consistent with historical observations.

Figure 3.24 Concentrations of total dissolved solids, sulphate, and total phenols at Stanley Creek, 2001 to 2003.



3.3.3 Other Watersheds

Various watersheds sampled in addition to the Muskeg River are monitored by RAMP not only at their confluence with the Athabasca River mainstem but also at upstream stations that offer information regarding changes in environmental quality within these watersheds. For the RAMP water quality program, these watersheds include the Clearwater River (CLR-#) and its tributary the Christina River (CHR-#), the Steepbank River (STR-#), the MacKay River (MAR-#) and the Firebag River (FIR-#). Temporal and spatial trends in water quality in these watersheds are presented below.

3.3.3.1 Clearwater and Christina Rivers

The watershed of the Clearwater River, the largest tributary to the Athabasca River in the oil sands region, includes areas east of Fort McMurray to beyond the Saskatchewan border, as well as areas south of Fort McMurray where various oil sands developments are being planned or implemented. These southern areas are drained by the Christina River, which joins the Clearwater River several km upstream of Fort McMurray.

The Clearwater River at station CLR-1 (upstream of Fort McMurray) is a large, sinuous river flowing over shifting sand substrate. At CLR-2 (upstream of Christina River confluence), the river is more channelized, faster flowing and flows across substrates of predominantly gravel, cobble and boulder. The Christina River near its mouth (CHR-1) also is generally fast flowing with mixed substrates, although at the specific location sampled a depositional bar exists at mid-channel. The upper Christina River at CHR-2 flows more slowly than CHR-1, its channel is more sinuous, and substrates are finer.

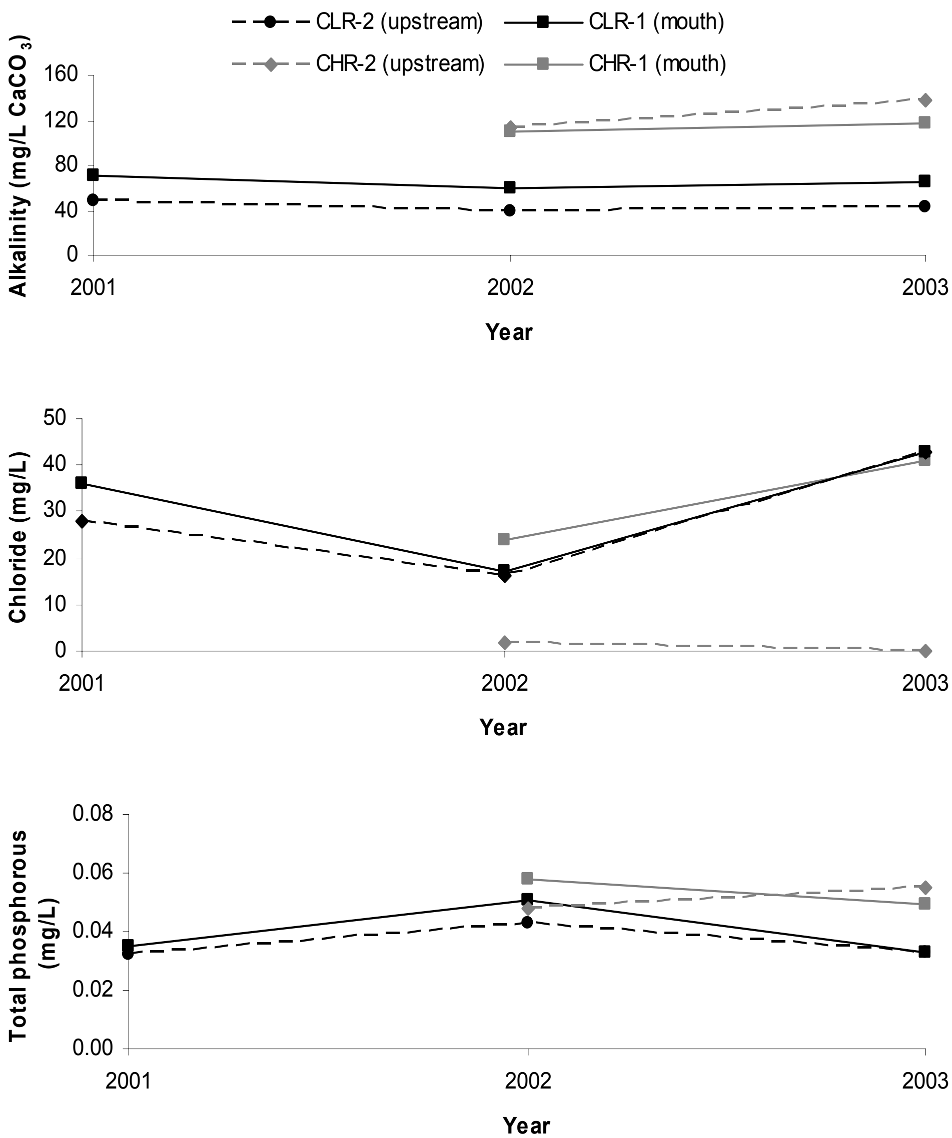
Figure 3.25 presents temporal trends in selected water quality variables for stations in the Clearwater and Christina rivers for fall 2001 to 2003, the period of record over which RAMP has collected data in this watershed. These graphs also provide a qualitative comparison of upstream and downstream water quality.

Generally, water quality variables at all Clearwater and Christina river stations have varied consistently over this period. The Christina River generally exhibits higher alkalinity, conductivity, and concentrations of dissolved ions, metals and nutrients than the Clearwater River. Chloride ion concentrations, high in the Clearwater River relative to the Athabasca River mainstem and its other tributaries, occurs in similar concentrations at upstream and downstream locations on the Clearwater and the Christina River at its mouth (CHR-1). However, at CHR-2 (upstream of Janvier), chloride occurs at very low concentrations (Figure 3.25), indicating chloride concentrations in the Christina River increase from near-detection to regionally high levels between Janvier and its confluence with the Clearwater River.

Total phenols were detected in water from the upper Christina River (CHR-2) in fall 2003 at a concentration of 0.019 mg/L, above Alberta guidelines of 0.005 mg/L. Phenols were not detected at CHR-2 during any other season or at any other Clearwater watershed station in any season.

No statistical assessment of trends in the Clearwater River was undertaken due to the small number of observations available from the RAMP program (i.e., n = 3).

Figure 3.25 Selected water quality variables for the Clearwater and Christina Rivers over the RAMP period of record, 2001 to 2003.



3.3.3.2 Steepbank River

The Steepbank River at its mouth (STR-1) is channelized and relatively fast-flowing; surficial, exposed bitumen occurs in several areas along the river at this location. Water quality at STR-1 was characterized by relatively high colour (100 TCU), total iron (0.834 mg/L) and DOC (25 mg/L) relative to other Athabasca River tributaries sampled in September 2003. Upstream station STR-2 exhibits similar water quality, with higher colour and iron, but concentrations of major ions and related measures (i.e., alkalinity, TDS, hardness and conductivity) were approximately half of STR-1. Station NSR-1, on the North Steepbank River, exhibited similar ion concentrations to STR-2, but lower colour and total iron than either STR-2 or STR-1. Total phenols were observed at both STR-2 and NSR-1 in September 2003 (at 0.007 mg/L and 0.008 mg/L, respectively), but not at STR-1 at the river's mouth.

The mouth of the Steepbank River has been monitored by RAMP since 1997; stations STR-2 and NSR-1 have been monitored only since 2002. Figure 3.26 presents temporal trends in selected variables highlighted by Golder (2003a,b) as key indicators of water quality Steepbank and North Steepbank river stations from fall 1997 to 2003, the period of record over which RAMP has collected data in this watershed. Data has only been collected at STR-2 and NSR-1 since 2002. These graphs also provide a qualitative comparison of upstream and downstream water quality.

Statistical assessment of temporal trends in these variables at the Steepbank River mouth (STR-1) indicated no significant trends ($n = 6$, $\tau_c = 0.87$). Water quality variables exhibiting trends that were not statistically significant but correlated at values of $\tau > |0.5|$ included dissolved aluminum (negative trend, $\tau = -0.60$) and dissolved organic carbon (positive trend, $\tau = 0.55$).

3.3.3.3 MacKay River

The MacKay River flows into the Athabasca River along its western shore just south of the community of Fort McKay. It is wide and very shallow at its mouth (MAR-1), no more than 0.1 m across its width when sampled in September 2003. The upper MacKay River (MAR-2) station is narrower and somewhat faster flowing, but still relatively shallow.

Water quality in the MacKay River has been monitored at its mouth since 1998, and at the upper MacKay since 2002. MAR-1 is monitored annually in fall, while MAR-2 was monitored in all four seasons of 2003. Figure 3.27 presents temporal trends in selected variables for stations in the MacKay River at its mouth and upstream over this period of record. These graphs also provide a qualitative comparison of upstream and downstream water quality.

The MacKay River exhibited relatively high nutrient concentrations (i.e., nitrogen and phosphorous), with values for total nitrogen (calculated as TKN+[NO_3+NO_2]) exceeding the water quality guideline of 1.0 mg/L at MAR-2 in winter (2.3 mg/L) and at MAR-1 in fall (2.9 mg/L). Total phosphorous also exceeded the guideline of 0.05 mg/L at MAR-2 in spring (0.008 mg/L). These values were similar to previous years' data and generally varied consistently among stations between years (Figure 3.27).

Dissolved oxygen at the upper MacKay River in winter 2003 were very low, at 0.8 mg/L. Concentrations of several dissolved ions and metals at MAR-2 were very high in winter relative to other seasons, including chloride (winter: 149 mg/L; spring: 2 mg/L), manganese (winter: 4.03 mg/L total; spring: 0.00432 mg/L total), strontium (winter: 0.419 mg/L total; spring: 0.0766 mg/L total), and boron (winter: 0.149 mg/L total; spring: 0.0441 mg/L total).

No statistical assessment of trends in the MacKay River was undertaken due to the small number of observations available from the RAMP program (i.e., n = 5).

Figure 3.26 Selected water quality variables for the Steepbank River over the RAMP period of record, 1997 to 2003.

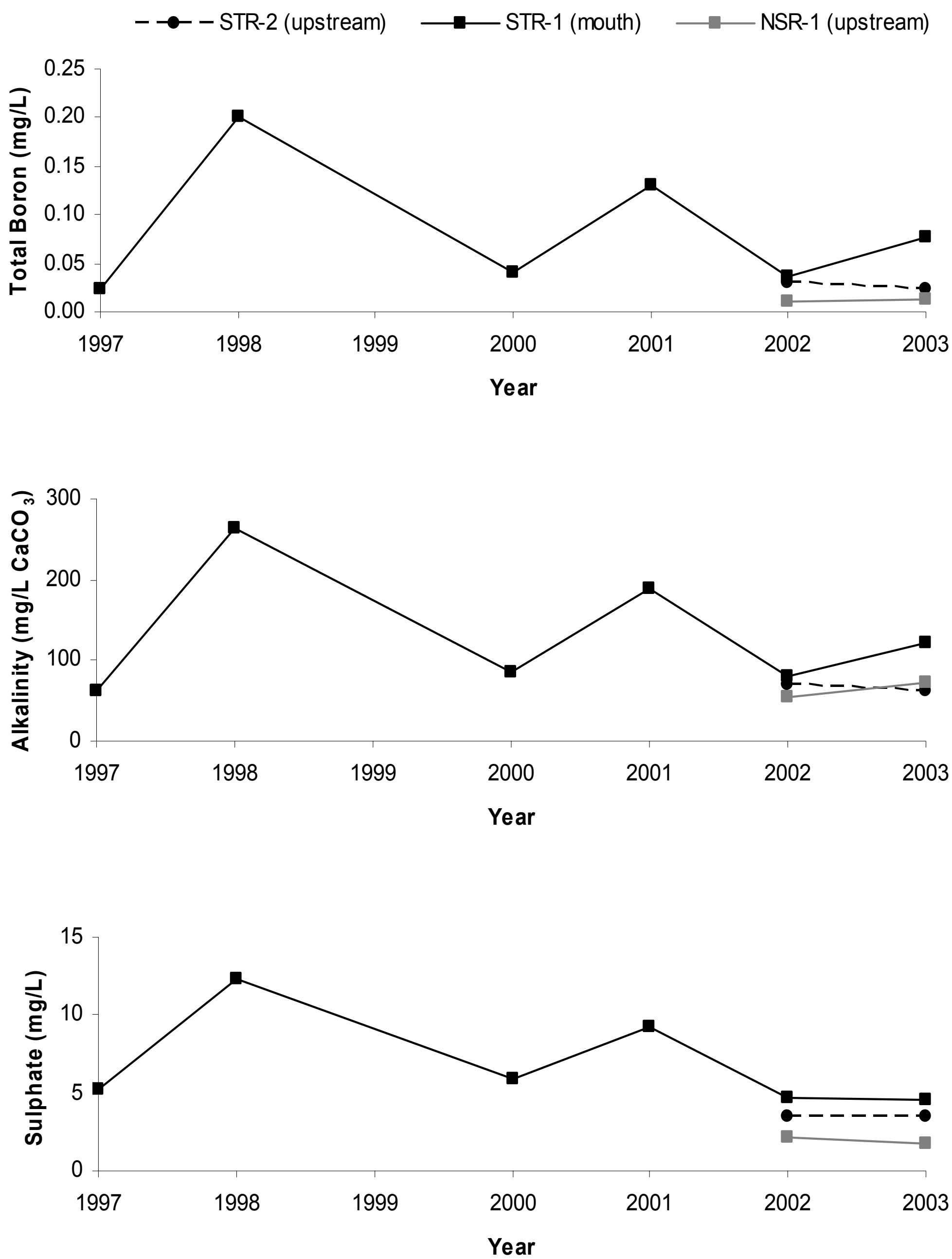
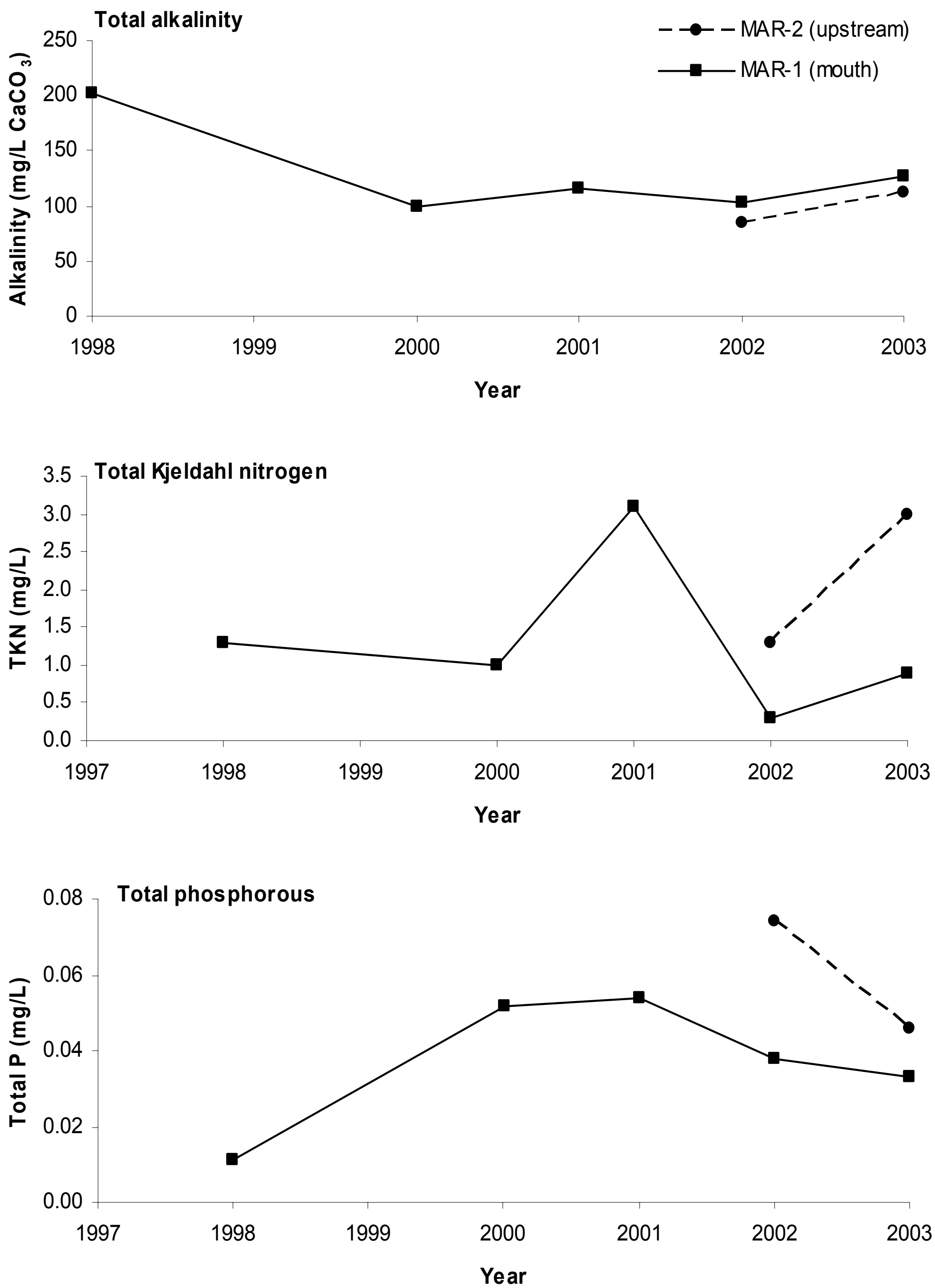


Figure 3.27 Selected water quality variables for the MacKay River over the RAMP period of record, 2001 to 2003.



3.3.3.4 Firebag River

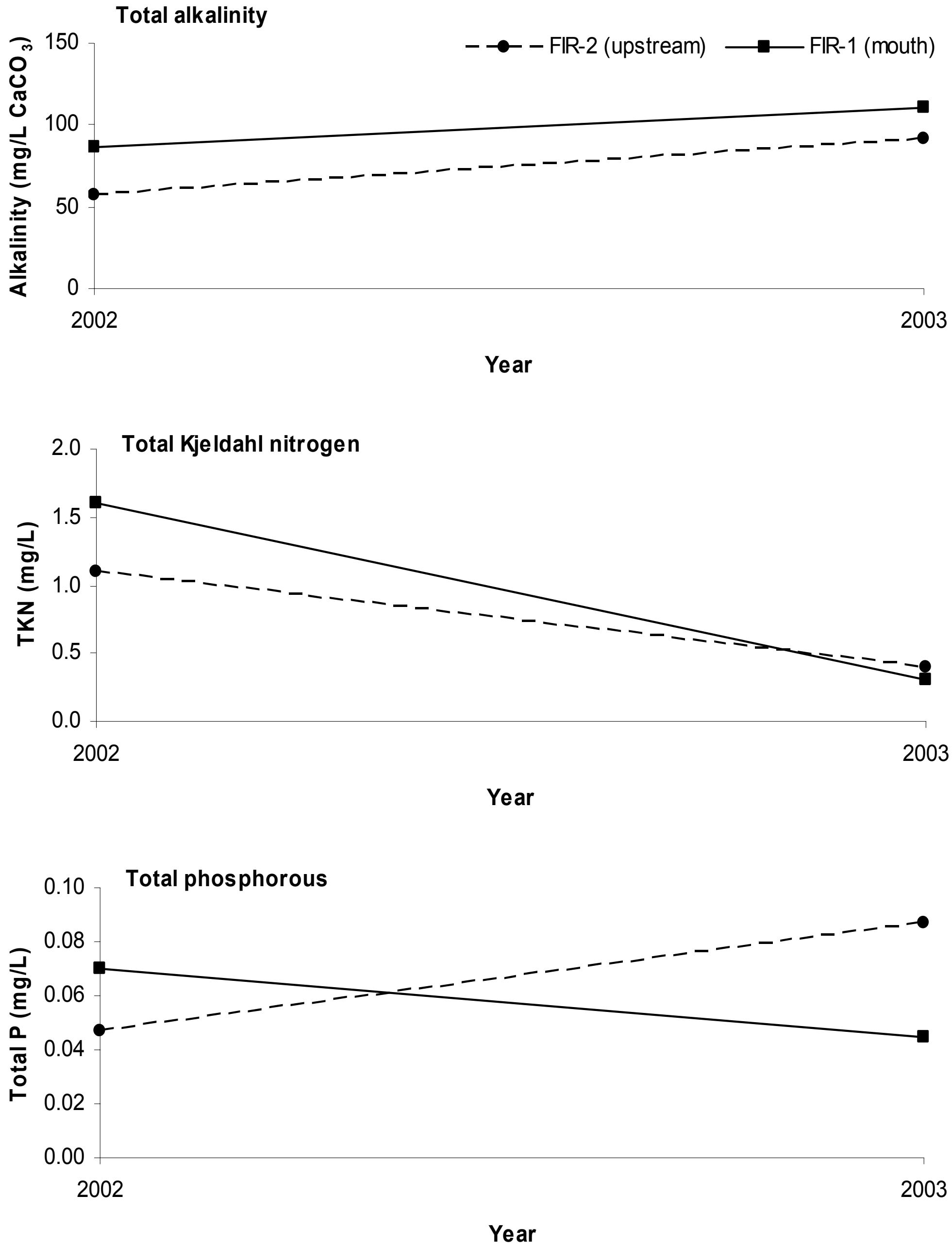
The Firebag River, which joins the Athabasca River mainstem approximately 130 km downstream of Fort McMurray, is the second largest tributary to the Athabasca River in the RAMP study area after the Clearwater and drains a large catchment east of the Athabasca extending into Saskatchewan. The river near its mouth exhibits moderate flow, with a mix of sand and larger substrates.

Water quality in the Firebag River has been monitored at its mouth (FIR-1) since 2002. Water quality monitoring in the upper Firebag River (FIR-2) was initiated in 2002, but moved to a more appropriate location (FIR-2B) in 2003 (see Section 3.2.6). Figure 3.28 presents temporal trends in selected variables for Firebag River stations FIR-1 and FIR-2/2B. These graphs also provide a qualitative comparison of upstream and downstream water quality, although such spatial and temporal comparisons may be confounded by the change in location of the upper Firebag River station in 2003.

Relative to other Athabasca River tributaries, the Firebag River exhibited lower alkalinity, colour, conductivity and dissolved and total metals, and higher phosphorous and nitrogen (Figure 3.28).

No statistical assessment of trends in the Firebag River was undertaken due to the small number of observations available from the RAMP program (i.e., n = 2).

Figure 3.28 Selected water quality variables for the Firebag River over the RAMP period of record, 2002 to 2003.



3.3.4 Lakes

Table 3.12 summarizes water quality of Kearl Lake, Shipyard Lake and McClelland Lake, monitored by RAMP in 2003.

Table 3.12 Selected water quality variables measured in lakes sampled by RAMP in 2003.

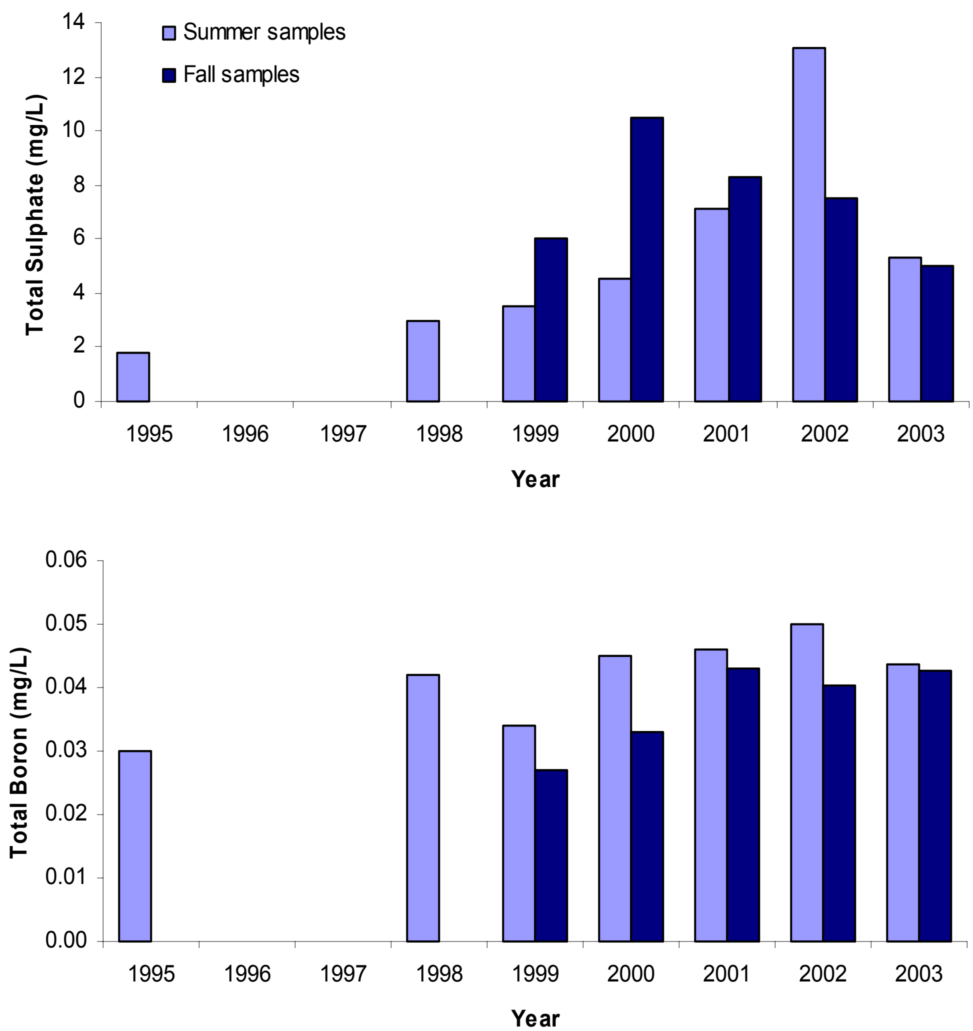
	Kearl Lake (KEL-1)		**Shipyard Lake (SHL-1)**		**McClelland L. (MCL-1)**
Variable (mg/L)	Winter	Fall	Summer	Fall	Fall
Dissolved Oxygen	**0.24**	10	7.95	**2.8**	9.8
Temperature (C)	1.7	10	20.3	8.5	14
pH	7.8	8	8	8.1	8.5
Color, True (TCU)	150	50	60	50	10
Alkalinity, Total (CaCO3)	181	79	166	175	123
Hardness (CaCO3)	161	72	166	175	122
Conductivity (EC)	354	165	356	360	233
Total Dissolved Solids	280	140	250	270	160
Dissolved Organic Carbon	40	21	18	19	11
Total Organic Carbon	42	26	18	21	12
Total Suspended Solids	3	15	3	3	<3
Tot. Rec. Hydrocarbons	<0.5	<0.5	<0.5	<0.5	<0.5
Naphthenic Acids	<1	1	<1	1	<1
Phenols (4AAP)	<0.001	0.005	0.002	**0.006**	0.003
Sulfate (SO4)	10.6	4.7	5.3	5	1
Boron (B)	0.0697	0.0493	0.0437	0.0426	0.0513
Chromium (Cr)	0.0003	0.0005	0.0007	0.0004	0.0004
Copper (Cu)	**0.0077**	0.0003	0.0002	0.0003	0.0004
Iron (Fe)	**1.51**	0.13	**0.543**	**0.771**	0.0685
Manganese (Mn)	0.26	0.0167	0.0291	0.0138	0.0165
Mercury (Hg), ultra-trace	2.6	<0.6	<0.6	<0.6	<0.6
Ammonia-N	2.01	0.43	<0.05	<0.05	<0.05
Total Kjeldahl Nitrogen	3.5	1.7	0.6	<0.2	0.9
Nitrate + Nitrite	<0.1	<0.1	<0.1	<0.1	<0.1
Total Nitrogen	**3.5**	**1.7**	0.6	<0.2	0.9
Phosphorus, Dissolved	0.008	0.008	0.006	0.009	0.005
Phosphorus, Total	0.015	0.023	0.013	0.015	0.014

Bold values indicate value exceeds relevant AENV or CCME water quality guideline.

Shipyard Lake

The RAMP 2002 technical report identified statistically-significant temporal trends in concentrations of sulphate and total boron in samples of Shipyard Lake water collected in summer from 1995 to 2002 (Golder 2003b). Figure 3.29 presents these temporal data sets with data collected in summer 2003, as well as samples collected by RAMP in fall from 1999 to 2003. Sulphate concentrations observed in Shipyard Lake in summer and fall 2003 were well below those observed in summer and fall 2002, and similar to concentrations measured in 1999 or 2000. Concentration of total boron in fall 2003 was higher than fall 2002, and similar to the fall historical high observed in 2001. Total boron concentration in summer 2003 was lower than has been recorded since 1999.

Figure 3.29 Concentrations of sulphate and boron in Shipyard Lake, 1995 to 2003.



Statistical assessment of temporal trends in water quality in Shipyard Lake from 1995 to 2003 (fall data) indicated no significant trends (n = 6, τ_c = 0.867). Water quality variables exhibiting trends that were not statistically significant but correlated at values of $\tau > |0.5|$ included sulphate (positive trend, τ = 0.733), dissolved organic carbon (positive trend, τ = 0.645), total chromium (positive trend, τ = 0.602) and dissolved aluminum (negative trend, τ = -0.600). A weak, positive trend in total boron concentrations was observed (τ = 0.467).

Water quality in Shipyard Lake was similar in summer and fall 2003, with the notable exception of dissolved oxygen levels in fall (2.8 mg/L), which were below the observed summer value and below Alberta and CCME minimum guidelines. Total phenols were observed in Shipyard Lake in both summer (0.002 mg/L) and fall (0.006 mg/L).

Kearl Lake

Seasonal differences in water quality at Kearl Lake between winter and fall included generally higher concentrations of metals in winter, including values exceeding water quality guidelines for total copper (0.0077 mg/L) and dissolved selenium (0.0012 mg/L, compared with the total selenium guideline of 0.001 mg/L). Dissolved oxygen concentrations in winter were very low (i.e., 0.24 mg/L) in this shallow lake.

Total nitrogen concentrations in Kearl Lake exceeded water quality guidelines in both winter and fall.

McClelland Lake

McClelland Lake was sampled by RAMP for the first time in 2003. Relative to Shipyard and Kearl Lake, McClelland Lake exhibits low colour (10 TCU) and metals concentrations.

3.3.5 Values Exceeding Water Quality Guidelines

Table 3.13 lists water quality values that exceeded environmental quality guidelines for all stations sampled by RAMP in 2003, including the Athabasca River mainstem, its delta, its tributaries, any upstream stations on these tributaries, and lakes, are reported, with the exception of values exceeding guidelines for total aluminum and total iron.

Total aluminum concentrations measured at RAMP stations regularly exceeded the water quality standard of 0.1 mg/L. In fall 2003, this guideline was exceeded at all Athabasca River mainstem and delta stations and tributary stations CLR-1, CLR-2, CHR-1, STR-1, STR-2, BER-1, CAR-1, ELR-1, MAR-1, MAR-2, MCC-1, POC-1 and TAR-1. Similar incidences of exceeding the guideline were observed in summer, with values exceeding guideline at 12 of 16 stations sampled, including ATR-DD, FIR-1, CLR-1, CLR-2, CHR-1, CHR-2, NSR-1, BER-1, CAR-1, ELR-1, MAR-2, and TAR-1. No values over guideline were measured in winter or spring.

The RAMP 5-year report demonstrated that total aluminum concentrations in the Athabasca River were closely correlated with total suspended solids concentrations, which suggested that total aluminum values represent predominantly particulate or particle-adsorbed aluminum. In contrast to Alberta and CCME guidelines, the government of British Columbia recommends a dissolved aluminum guideline for the protection of aquatic life of 0.05 mg/L (Butcher 2001), given dissolved aluminum represents most species of bioavailable aluminum that are likely to cause toxicity to aquatic organisms. Among all RAMP water quality stations sampled in 2003, only the Ells River (ELR-1) exhibited concentrations of dissolved aluminum exceeding this guideline, specifically 0.0682 mg/L in spring 2003

Table 3.13 Water quality observations exceeding water quality guidelines for the protection of aquatic life, with the exception of total aluminum and total iron values.

Parameter	Station	Observed value	Guideline Alberta[1] Acute	Guideline Alberta[1] Chronic	Guideline CCME[2] CGWQ
Winter (March 2003)					
Dissolved oxygen (mg/L)	FIR-1	4.4	>5.5	>6.5	>6.5
	FIR-2B	0.8			
	KEL-1	0.24			
	CHR-1	4.2			
	ELR-1	4.1			
	MAR-2	0.8			
Total copper (mg/L)[3]	ATR-DD	0.0052	0.027	0.007	0.003
	FIR-1	0.0033	0.021	0.007	0.003
	FIR-2B	0.0045	0.017	0.007	0.002
	KEL-1	0.0077	0.025	0.007	0.003
	CHR-1	0.0048	0.034	0.007	0.004
	CLR-1	0.0036	0.016	0.007	0.002
	CLR-2	0.004	0.010	0.007	0.002
	ELR-1	0.0032	0.022	0.007	0.003
	MAR-2	0.0087	0.049	0.007	0.004
Dissolved seleniuim (mg/L)	KEL-1	0.0012	-	-	0.001
	MAR-2	0.0013			

Table 3.13 (cont'd).

Parameter	Station	Observed value	Guideline		
			Alberta[1]		CCME[2]
			Acute	Chronic	CGWQ
Spring (May 2003)					
Total seleniuim (mg/L)	MAR-2	0.0012	-	-	0.001
Total phosphorous (mg/L)	FIR-2B	0.109	-	0.005	-
Total nitrogen (mg/L)	KEL-1	3.4	-	-	1.0
	CHR-1	1.1			
	MAR-2	2.3			
Summer (July 2003)					
Total mercury (ng/L)	ATR-DD	8.9	13	5	100
	TAR-1	9.6			
Total phosphorous (mg/L)	ATR-DD	0.083	-	0.005	-
	FIR-2B	0.051			
	CHR-2	0.052			
	CAR-1	0.083			
	MAR-2	0.06			
	TAR-1	0.113			
	CHR-2	0.092			
	CLR-1	0.092			
	CAR-1	0.096			
	MAR-2	0.068			
	TAR-1	0.112			
Fall (September 2003)					
Total seleniuim (mg/L)	BER-1	0.0012	-	-	0.001
Total phenols (mg/L)	ATR-MR-E	0.006	-	0.005	-
	ATR-MR-W	0.007			
	FIR-2B	0.012			
	SHL-1	0.006			
	JAC-1	0.014			
	MUC-1	0.013			
	MUR-6	0.006			
	STC-1	0.052			
	CHR-2	0.019			
	STR-2	0.007			
	NSR-1	0.008			
	ELR-1	0.011			
	MAR-2	0.006			
Total phosphorous (mg/L)	ATR-FC-W	0.102	-	0.005	-
	FIR-2B	0.087			
	CHR-2	0.055			
	CAR-1	0.099			
	TAR-1	0.057			

Table 3.13 (cont'd).

Parameter	Station	Observed value	Guideline Alberta[1] Acute	Guideline Alberta[1] Chronic	CCME[2] CGWQ
Total nitrogen (mg/L)	ATR-MR-E	1.2	-	-	1.0
	KEL-1	1.6			
	MAR-1	2.9			

[1] AENV (1999); [2] CCME (2002); [3] Total copper guidelines vary with hardness of water.

As with total aluminum, total iron values in the RAMP study area regularly exceeded the guideline of 0.3 mg/L. In 2003, total iron observations at all stations in every season exceeded this guideline except MUC-1 (Muskeg River mouth), MUR-6 (Muskeg River upstream of Wapasu Creek), KEL-1 (Kearl Lake), and MCL-1 (McClelland Lake) in September 2003. Concentrations of dissolved iron exceeded the 0.3 mg/L total iron guideline at approximately half of sampling stations sampled, although not at any stations in the Athabasca River mainstem or delta or the Muskeg River watershed.

3.3.6 Chronic Toxicity Assessment

Results of chronic toxicity assessment of ambient river water from the Tar River (TAR-1), Ells River (ELR-1) and the Calumet River (CAR-1) appear in Table 3.14 below. No samples exhibited effects on invertebrate survival or reproduction, algal growth, or growth of larval fathead minnows. However, reduced survival of fathead minnows was observed in samples of water from the Ells and Tar rivers.

Table 3.14 Results of chronic toxicity assessment of Tar, Ells and Calumet rivers.

Test (Organism)	Endpoint	Statistic	CAR-1	ELR-1	TAR-1
Fish early life-stage survival and growth (fathead minnow, *Pimephales promelas)*	Survival	IC25	>100	50	78
		IC50	>100	>100	>100
		NOEC	100	25	50
		LOEC	>100	50	100
	Growth	IC25	>100	>100	>100
		IC50	>100	>100	>100
		NOEC	100	100	100
		LOEC	>100	>100	>100

Table 3.14 (cont'd).

Test (Organism)	Endpoint	Statistic	CAR-1	ELR-1	TAR-1
Invertebrate reproduction (*Ceriodaphnia dubia*)	Survival	IC25	>100	>100	>100
		IC50	>100	>100	>100
		NOEC	100	100	100
		LOEC	>100	>100	>100
	Reproduction	IC25	>100	>100	>100
		IC50	>100	>100	>100
		NOEC	100	100	100
		LOEC	>100	>100	>100
Algal growth (*Selanastrum capricornutum*)	Growth	IC25	>100	>100	>100
		IC50	>100	>100	>100
		NOEC	100	100	100
		LOEC	>100	>100	>100

Underlined values indicate that test was invalid because the control group did not pass the minimum requirements for reproduction.

Results of chronic toxicity testing using *Ceriodaphnia dubia* and fathead minnows provided by industry to RAMP for stations in the Muskeg River (i.e., MUR-2, MUR-4 and MUR-5) indicated no toxicity in 2003.

3.4 DISCUSSION

3.4.1 Water Quality in the RAMP Study Area

Athabasca River Mainstem

In 2003, water quality in the Athabasca River downstream of Fort McMurray was generally consistent with previous years. Results of principal components analyses indicate that water quality is similar at all stations along the river from upstream of Donald Creek to the Athabsasca River delta, suggesting that inputs from tributaries in the oil sands region, regardless of human activities on them, do not clearly affect water quality in the river mainstem. This may be due to the large flow of the Athabasca River relative to its tributaries, particularly in fall, when flow in most tributaries is extremely low. However, some variables, including chloride and conductivity, do appear to increase in concentration with increasing distance downstream, likely due to tributary inputs.

Cross-channel mixing in the river is extremely poor, with different water quality characteristics along each bank persisting over tens of kilometers. Water along the east bank of the river near Donald Creek, nearly 10 km downstream from the Clearwater River confluence, was more similar in quality to the Clearwater River than to water at the river bank immediately opposite. Lower ion concentrations (particularly chloride, sulphate and alkalinity) were evident along the Athabasca River's west bank relative to its east bank upstream of the Steepbank and Muskeg river as well, suggesting that Clearwater River water may not have completely mixed into the Athabasca River flow even as far downstream as the Muskeg River, approximately 50 km downstream.

Previous RAMP studies have determined that a clear relationship exists between suspended sediment concentrations and total metals, with particular reference to total aluminum, as well as total phosphorous. However, total suspended solids are not correlated with concentrations of dissolved metals, represented broadly by Dissolved Metals PC scores and correlation analyses of specific metals of interest, such as dissolved boron and aluminum. Similarly, TSS was not correlated with dissolved phosphorous, the most biologically reactive form of phosphorous as a nutrient.

Particulate-bound phosphorous and metals, particularly aluminum, likely represent mineral compounds that are not biologically available to aquatic organisms. Although most water quality guidelines are based on total metals, metal toxicity to many aquatic organisms occurs primarily through their dissolved forms (e.g., uptake of dissolved copper, nickel and zinc across the gills of fishes). Further, environmental assessments have of oil sands development have postulated potential effects of oil sands development on (dissolved) metals concentrations through muskeg dewatering and groundwater seepage (e.g., Shell Canada Ltd. 2002). Therefore, an explicit focus on concentrations and trends in dissolved metals in addition to total metals in the RAMP program is suggested. Explicit examination of dissolved metals is particularly relevant during open water months when suspended materials in rivers, particularly the Athabasca River, may contribute to total metals concentrations in ways that mask trends in dissolved metals and phosphorous that may be important to aquatic ecosystem function.

Table 3.15 presents a summary of all metals measured by RAMP in 2003 at stations where four seasons of sampling were undertaken, segregated into metals that were predominantly measured in dissolved or particular form. Metals predominantly in dissolved form were defined generally as metals where, averaged over all four seasons, dissolved metal concentration was over 80% of total metal concentration for each sample; those predominantly in particulate form were defined generally as those whose dissolved metal concentrations were less than 20% of total metals concentrations.

Table 3.15 Proportion of dissolved relative to total values for metals measured in water samples collected by RAMP at stations sampled in all four seasons in 2003.

Metals Typically Occurring in Dissolved Form (Dissolved/Total Metal > 80%)	**Metals Typically Associated with Particulates** (Dissolved/Total Metal < 20%)	**Metals Not Consistently Associated with Particulates or in Dissolved Form** (80% < Dissolved/Total Metal > 20%)
Athabasca River mainstem		
Beryllium, Boron, Calcium, Chlorine, Molybdenum, Selenium, Silver, Strontium, Thallium	Aluminum, Iron, Thorium, Titanium	Antimony, Arsenic, Barium, Bismuth, Cadmium, Chromium, Cobalt, Copper, Lead, Lithium Manganese, Nickel, Uranium, Vanadium, Zinc
Athabasca River tributaries		
Beryllium, Bismuth, Boron, Cadmium, Calcium, Chlorine, Lithium, Molybdenum, Selenium, Strontium, Thallium	Aluminum	Arsenic, Chromium, Cobalt, Copper, Iron, Lead, Manganese, Nickel, Silver, Thorium, Titanium, Uranium, Vanadium, Zinc

Athabasca RiverTributaries

Principal components analysis combined with correlation analysis was highly effective at describing water chemistry in tributaries of the Athabasca River and distinguishing them from the Athabasca River mainstem. Tributaries generally exhibited higher colour, alkalinity, conductivity, concentrations of most dissolved ions and metals, dissolved organic carbon, and lower suspended solids than the Athabasca River. Additionally, differences in water quality between eastern and western tributaries were observed, with most western tributaries generally exhibiting higher concentrations of metals than eastern tributaries, as well as higher colour, conductivity and alkalinity.

Tributaries with water quality characteristics of note include:

- *Beaver River (BER-1):* This stream, near the Syncrude Mildred Lake facility, exhibited concentrations of several key water quality variables, including sulphate, conductivity, chloride, and several dissolved metals, that were outside the range of natural variability of other tributaries sampled, suggesting a potential effect of human activities in this watercourse.

- *Poplar Creek (POC-1)*: This stream exhibited high chloride, alkalinity, colour and dissolved metals (but similar sulphate concentrations) relative to other tributaries which may suggest effects of human activities on this watercourse.

- *Calumet River (CAR-1)*: This stream, which had almost no flow during September 2003 sampling, exhibited the highest dissolved organic carbon, colour and alkalinity of all tributaries sampled. The Calumet River has yet to experience major development in its watershed.

- *Tar (TAR-1) and Ells (ELR-1) rivers*: These rivers, located close to one another north of Fort McKay in an area yet to experience major development, exhibited a moderate chronic effect on fathead minnow survival (IC25 = 78% and 50%, respectively). Water quality at these stations was broadly similar to other tributary stations, although the Ells River exhibited the highest total phenol concentrations of any tributary. Sediment collected from the mouth of the Ells River also exhibited high PAHs relative to other stations in fall 2003 (Chapter 4).

Tributaries experiencing oil sands development in their watersheds, including the Muskeg, the MacKay, the Clearwater/Christina, and the Steepbank rivers, clustered within broad groups of similar tributaries in principal component analyses, suggesting that water quality in these tributaries is generally typical of regional water quality.

Muskeg River watershed

Within the Muskeg River watershed specifically, water quality was similar to previous years at all stations, with the exception of Stanley Creek (STC-1), where large increases in concentrations of sulphate, phenol, alkalinity, conductivity and other variables were observed. This may be associated with the commencement of Syncrude's Clean Water Discharge to Stanley Creek in late May 2003. From June to December 2003, these water releases to Stanley Creek ranged from 92,130 m^3 in November to 481,000 m^3 in July, corresponding to an average daily flow rate of approximately 10,500 m^3/day or 10.5 L/s (M. Lyons, Syncrude Canada Ltd., *pers. comm.*).

Despite these changes in Stanley Creek water quality, water quality at the mouth of the Muskeg River was consistent with previous years. Temporal trend analysis found significant declines in concentrations of total suspended solids and total aluminum at this station between 1997 and 2003. However, this trend analysis likely was strongly influenced by high values for these variables measured in 1997; concentrations of TSS and total aluminum, which has been demonstrated to be closely related to TSS, have been consistently low since 1998.

Other Tributary Watersheds with Upstream Development

Comparison of water quality at upstream and downstream locations in the Clearwater River, MacKay River, Steepbank River and Firebag River watersheds suggested that water quality generally was consistent year-to-year, with inter-annual variations reflected at both upstream and downstream locations. No temporal trends were observed that suggested impacts from human activities over the period of record. Specific observations of note for upstream stations in these watersheds include the following:

- *Christina River (CHR-1 and CHR-2):* Chloride concentrations increase from near the detection limit at upper Christina River station CHR-2 to relatively high concentrations at its mouth (CHR-1), suggesting a source or sources of chloride in this reach of the Christina River.

- *Upper MacKay River (MAR-2):* This station exhibited very high concentrations of several dissolved metals and ions during winter, including strontium, manganese, chloride and conductivity.

Lakes

The RAMP 2002 annual report (Golder 2003b) found statistically significant increases in concentrations of total boron and sulphate in Shipyard Lake in summer samples collected from 1995 to 2003. Reassessment of these temporal trends following collection of an additional year of data, as well as consideration of fall data from 1998 to 2003, indicates that this trend is not significant. Concentrations of sulphate and total boron in Shipyard Lake in summer and fall 2003 were similar to those observed in 1999.

Seasonality

Generally, concentrations of dissolved ions (including alkalinity and conductivity) and dissolved metals were higher in winter at all stations relative to open water seasons. For aquatic resources in tributaries to the Athabasca River, availability of overwintering habitats may be a limiting factor, given most tributaries scheduled for winter sampling in winter by RAMP in both 2003 and 2002 could not be sampled as they were frozen to depth. However, in tributaries with available overwintering habitats that do not freeze to depth, water quality may be an important concern, given concentrations of copper and other dissolved metals exceeded water quality guidelines at several stations in winter, and particularly that dissolved oxygen concentrations were very low in several locations, particularly in upper reaches of watersheds and in Kearl Lake, the only lake sampled in winter 2003. Concentrations of metal anions in winter may be counterbalanced by the high hardness of waters also observed in winter, as high concentrations of calcium ions, a key component of hardness, are known to ameliorate potential toxic effects of metals such as copper and zinc (Welsh *et al.* 2000).

Winter also may be an important season for assessing effects of groundwater quality on river water quality, as most smaller rivers likely are ground-fed at this time. Water quality in some smaller streams, such as the upper MacKay River (MAR-2), varied markedly between winter and open water seasons.

Differences among spring, summer and fall sampling seasons were observed; such variations generally were smaller than differences between winter and any open water season. Concentrations of total phenolic compounds were highest in fall, indicating that this season is the most effective time to analyze for this variable.

3.4.2 RAMP Water Quality Component

Based on results of the 2003 RAMP water quality program and annual programs preceding it, the following suggestions are made regarding this RAMP component:

- Consider reducing or eliminating measurements of PAHs in the Athabasca River mainstem, given only two PAHs were detected in water from stations monitored in Fall 2003, at or near their detection limits;

- Any increased efforts in sampling PAHs in water should be focused on specific tributaries where hydrocarbon concentrations have been or may be expected to be high (e.g., the Ells River);

- Given cross-channel composite samples in the Athabasca River provided representative data regarding cross-channel water quality in each river reach monitored, consider collection and analysis of cross-channel composite samples only along the Athabasca River mainstem rather than east bank, west bank, and cross-channel composites at these stations;

- Consider moving water quality sampling immediately upstream of the Athabasca River delta from station EMR-1 to current sediment quality station ATR-ER, given the Embarras River is not actually a tributary to the Athabasca River (it is the Athabasca River), and given the proximity of ATR-ER shortly upstream.

- Consider sampling a second Athabasca River mainstem station in winter, such as ATR-DC-CC (upstream of Donald Creek, cross-channel composite), to provide further concurrent data to assess with results from ATR-DD;

- For internal consistency and consistency with other RAMP components, rename delta station ARD-1 to ARD-BPC, in concert with renaming sediment quality stations BPC (Big Point Channel), GIC (Goose Island Channel) and FLC (Fletcher Channel) to ARD-BPC, ARD-GIC, and ARD-FLC.

4.0 SEDIMENT QUALITY

4.1 OVERVIEW OF 2003 PROGRAM

Sediment quality was sampled by RAMP at 36 stations throughout the lower Athabasca River watershed in September 2003, including:

- 14 stations on the Athabasca River mainstem from upstream of Fort McMurray to the Athabasca River delta, including stations along both banks of the river;
- Three stations in channels of the Athabasca River delta;
- Eight stations in the Muskeg River watershed;
- Four stations in the Clearwater River watershed, including two along the Christina River;
- Two stations in the Firebag River;
- Three stations in other tributaries to the Athabasca River, including Ells River, Tar River, and the North Steepbank River; and
- Two regional lakes, including Shipyard Lake and McClelland Lake.

Samples from all stations were analyzed for the following variables:

- Physical variables (i.e., grain size and moisture)
- Carbon content, including organic and inorganic carbon;
- Concentrations of various metals;
- General measures of petroleum hydrocarbons, including total recoverable hydrocarbons, total extractable hydrocarbons, and total volatile hydrocarbons; and
- A suite of various polycyclic aromatic hydrocarbons, including target (parent) PAHs and alkylated PAHs.

Additionally, chronic toxicity of sediment was assessed at 28 of the 36 stations sampled, through 10 day exposures of the three organisms to collected sediments, including the amphipod *Hyallela azteca*, larvae of the chironomid midge

Chironomus tentans, the earthworm *Lumbriculus variegatus*. Detailed methods and results of the 2003 water quality program appear below.

4.2 METHODS

Objectives of the 2003 RAMP sediment monitoring program included assessment of baseline sediment quality and identification of any potential effects related to oil sands development or other environmental factors in rivers and lakes in the RAMP study area.

Sediment quality monitoring stations were selected to provide data related to ongoing and anticipated developments in the oil sands region. Stations were located upstream, downstream, and in the vicinity of existing oil sands developments, to allow for comparisons of sediment quality between these areas. Sediments were also collected from waterbodies in areas under consideration for development to provide baseline sediment quality data, which would provide an indication of the background levels and natural variability of chemicals in sediments in undeveloped areas.

4.2.1 Station Locations

Sediment samples were collected by RAMP from 36 stations located along the Athabasca River and its major tributaries in the oil sands region, and from regionally important lakes and wetlands Figure 4.1. Stations sampled and variables analyzed at each station are summarized in Table 4.1.

Table 4.1 Summary of RAMP sediment quality program, September 2003.

Station identifier and location		Analytical package[A] / Season			
		W	S	S	F
Athabasca River mainstem					
ATR-UFM	Upstream of Fort McMurray (cross channel)	-	-	-	3
ATR-DC-W	Upstream of Donald Creek (west bank)	-	-	-	3
ATR-DC-E	Upstream of Donald Creek (east bank)	-	-	-	3
ATR-SR-W	Upstream of Steepbank River (west bank)	-	-	-	3
ATR-SR-E	Upstream of Steepbank River (east bank)	-	-	-	3
ATR-MR-W	Upstream of Muskeg River (west bank)	-	-	-	3
ATR-MR-E	Upstream of Muskeg River (east bank)	-	-	-	3
ATR-FC-W	Upstream of Fort Creek (west bank)	-	-	-	3
ATR-FC-E	Upstream of Fort Creek (east bank)	-	-	-	3
ATR-DD-W	Downstream of all development (west bank)	-	-	-	3
ATR-DD-E	Downstream of all development (east bank)	-	-	-	3
ATR-FR-W	Upstream of Firebag River (west bank)	-	-	-	3

Table 4.1 (cont'd).

Station identifier and location		Analytical package[A] / Season			
		W	S	S	F
ATR-FR-E	Upstream of Firebag River (east bank)	-	-	-	3
ATR-ER	Upstream of the Embarras River	-	-	-	3
Athabasca Delta / Lake Athabasca					
BPC	Big Point Channel	-	-	-	3
GIC	Goose Island Channel	-	-	-	3
FLC	Fletcher Channel	-	-	-	3
Athabasca River tributaries (south of Fort McMurray)					
CLR-1	Clearwater River (upstream of Fort McMurray)	-	-	-	3
CLR-2	Clearwater River (upstream of Christina River)	-	-	-	3
CHR-1	Christina River (mouth)	-	-	-	3
CHR-2	Christina River (upstream of Janvier)	-	-	-	3
Athabasca River tributaries (south of Fort McMurray)					
NSR-1	North Steepbank River (upstream of PC-Lewis)	-	-	-	3
ELR-1	Ells River (mouth)	-	-	-	3
TAR-1	Tar River (mouth)	-	-	-	3
FIR-1	Firebag River (mouth)	-	-	-	3
FIR-2	Firebag River (upstream of Suncor Firebag)	-	-	-	3
Muskeg River					
MUR-1	Muskeg River (mouth)	-	-	-	3
MUR-1B	1 km upstream of mouth	-	-	-	1
MUR-2	Upstream of Canterra Road Crossing	-	-	-	3
MUR-4	Upstream of Jackpine Creek	-	-	-	1
MUR-5	Upstream of Muskeg Creek	-	-	-	1
MUR-D2	Upstream of Stanley Creek	-	-	-	3
MUR-6	Upstream of Wapasu Creek	-	-	-	1
Muskeg River tributaries					
STC-1	Stanley Creek (mouth)	-	-	-	1
Wetlands					
SHL-1	Shipyard Lake (composite)	-	-	-	1
MCL-1	McClelland Lake (composite)	-	-	-	1
Additional sampling (Non-core programs)					
CAR-1	Calumet River (mouth)	-	-	-	-[B]
-	Potential TIE	-	-	-	-
Quality Assurance/Quality Control					
-	One split and one duplicate sample	-	-	-	1

[A] Legend to Analytical Packages:

1 = RAMP standard variables (carbon content, particle size, TRH, TEH, TVH, metals, PAHs, alkylated PAHs)

2 = Sediment toxicity (Chironomus tentans, Lumbriculus variegatus, Hyalella azteca).

3 = RAMP standard + toxicity

[B] Sediment not sampled at CAR-1 in September 2003 due to technical oversight.

4.2.1.1 Athabasca River Mainstem and Delta Stations

In the Athabasca River mainstem, sediment samples were collected from east and west bank locations (i.e., any location between the dry bank and 25% of the total cross-sectional wetted width), approximately 100 m upstream from the following tributaries:

- Donald Creek;
- Fort Creek;
- Steepbank River;
- Muskeg River;
- Firebag River; and
- Downstream of all development (near the outlet of Susan Lake).

Cross-channel sediments were collected from the Athabasca River approximately 100 m upstream of the Highway 63 bridge crossing in Fort McMurray, and in the lower reaches of the Athabasca River upstream of the Embarras River. Cross-channel composites were also collected from the Athabasca delta in Big Point, Goose Island, and Fletcher channels.

4.2.1.2 Other Waterbodies

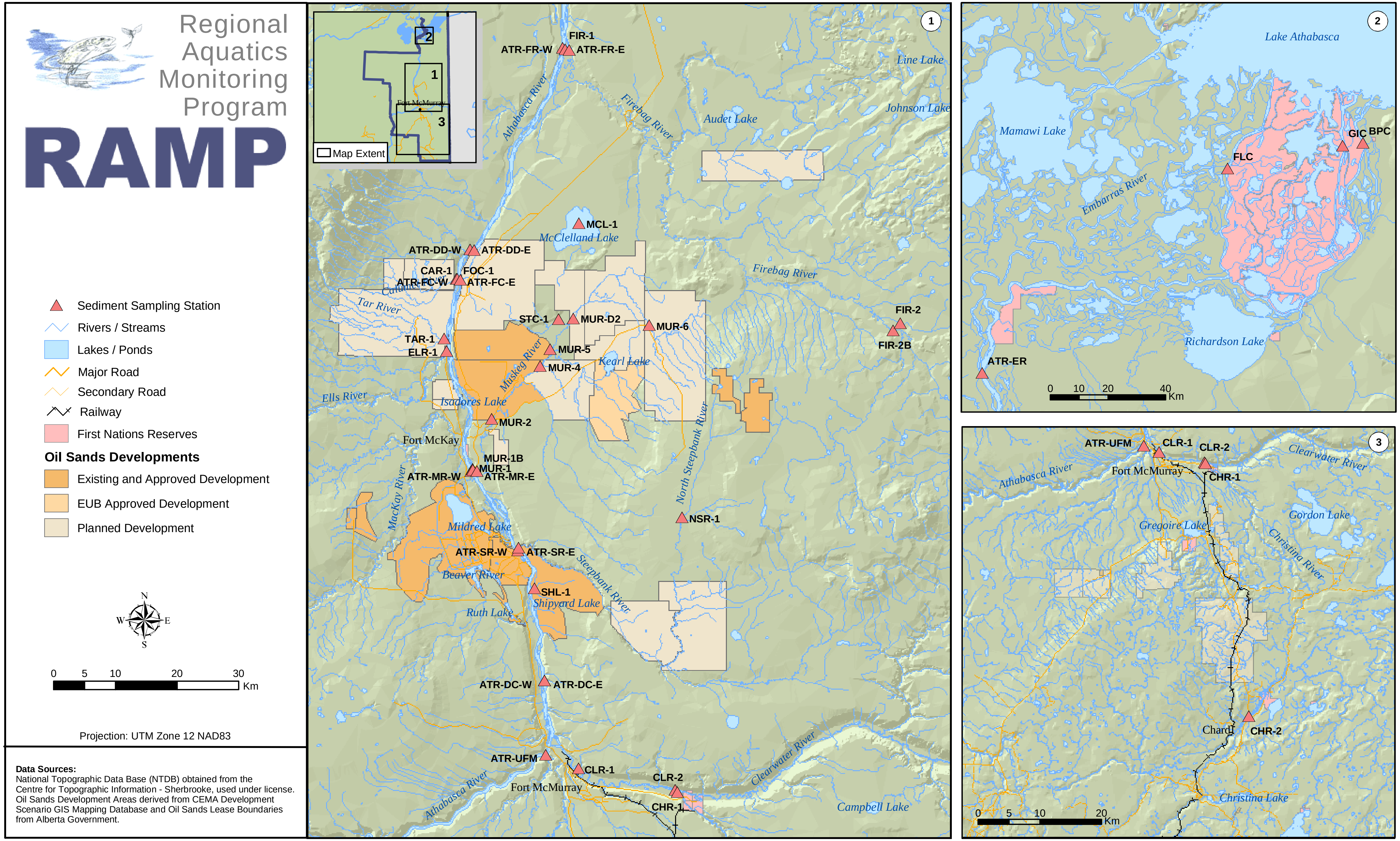
Sediment samples were collected from center channel locations of stations located along Athabasca River tributaries, where water depth and velocity allowed for safe sample collection. Stations located on the upper Clearwater and Christina Rivers and all Muskeg River stations (excluding the mouth) were either too deep or fast-flowing to allow for cross-channel samples to be collected; at these stations, individual grab samples were collected at regularly spaced intervals perpendicular to the bank.

Sediment samples also were collected from Shipyard and McClelland lakes.

4.2.2 Sampling Methods

The 2003 sediment quality field program was implemented from September 6 to September 22, concurrent with the fall water quality program described in Chapter 2. Sediment samples were collected from depositional zones at each station. At several sampling locations in tributaries to the Athabasca, substrates were predominantly erosional rather than depositional. At these locations, sampling was conducted where depositional sediments were found. Historical

Figure 4.1 RAMP Sediment Sampling Locations, 2003.



Mxd: G:\DATA\PROJECTS\RAMP1069\GIS\Fig4-1_Sediment2003.mxd
Last Modified: 2/17/2004 3:09:54 PM

sampling locations were identified using GPS coordinates and written descriptions from previous reports, and followed a general rule-of-thumb followed by the previous RAMP implementation team of sampling approximately 100 m upstream of river confluences. Stations were accessed by helicopter, jet boat, canoe or four-wheel drive vehicle.

At each station, 4 to 6 grabs were collected with a 6″ x 6″ Ekman dredge (0.023 m^2). Grab samples were transferred to a stainless steel pan; once sufficient sediment had been colleted for analysis, all samples were homogenized in the pan into a single composite sample with a stainless steel spoon. To minimize potential for sample contamination, pans, spoons, and the dredge were rinsed with hexane and acetone then triple-rinsed with ambient water at each station prior to sampling.

Homogenized samples were transferred into labeled, sterilized glass jars for chemical analyses, and/or to resealable plastic bags for toxicological analysis. All samples were stored on ice prior to and during shipment to analytical laboratories.

4.2.3 Sample Shipping and Analysis

Samples were shipped to analytical laboratories via Greyhound or through the ETL/MMRT collaborative drop depot in Fort McMurray. All chemical analyses of sediment were undertaken by Enviro-Test Laboratories Ltd. (ETL, Edmonton, AB) except polycyclic aromatic hydrocarbons (PAHs), which were analyzed by AXYS Analytical Services Ltd. (AXYS, Sidney, BC). Evaluation of sediment toxicity was undertaken by HydroQual Laboratories Ltd. (Calgary, AB).

Table 4.2 summarizes physical, chemical and toxicological variables assessed in the RAMP 2003 sediment program. Further information regarding analytical methods appears in Appendix A4.

Due to very high amounts of plant material in sediment collected from station STC-1 (Stanley Creek), particle size analysis was not possible at this station.

Table 4.2 RAMP sediment quality parameters analyzed in 2003.

Group	Sediment quality variable	
Physical variables	Percent sand	Percent clay
	Percent silt	Moisture content
Carbon content	Total inorganic carbon	
	Total organic carbon	
	Total carbon	
Total metals	Aluminum	Manganese
	Arsenic	Mercury
	Barium	Molybdenum
	Beryllium	Nickel
	Boron	Potassium
	Cadmium	Selenium
	Calcium	Silver
	Chromium	Sodium
	Cobalt	Strontium
	Copper	Thallium
	Iron	Uranium
	Lead	Vanadium
	Magnesium	Zinc
Organics	Total recoverable hydrocarbons	
	Total volatile hydrocarbons (C5-C10)	
	Total extractable hydrocarbons (C11-C30)	
Target PAHs	Acenaphthene	Dibenzo(a,h)anthracene
	Acenaphthylene	Dibenzothiophene
	Anthracene	Fluoranthene
	Benzo(a)anthracene/chrysene	Fluorene
	Benzo(a)pyrene	Indeno(c,d-123)pyrene
	Benzofluoranthenes	Naphthalene
	Benzo(g,h,i)perylene	Phenanthrene
	Biphenyl	Pyrene

Table 4.2 (cont'd).

Group	Sediment quality variable
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 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)[1]
Chronic toxicity testing	Survival and growth of the amphipod *Hyallela azteca*
	Survival and growth of *Chironomus tentans* midge larvae
	Survival and growth of the earthworm *Lumbriculus variegatus*

[1] Any summations of Total PAH did not include retene, as it is also accounted for in total C4-substituted phenanthrene/anthracene.

4.2.4 Changes from the 2002 Study

In 2003, key changes to the sampling program included removal and addition of several sampling stations and the expansion of the toxicity testing program. More specifically:

- Sediment toxicity testing was conducted for all 14 Athabasca River mainstem stations (toxicity testing was not conducted for these stations in 2002);

- Toxicity testing was not conducted on samples from Shipyard Lake;

- Sediments were not collected from the McLean, Fort and Poplar creeks, and the upstream and downstream stations on the Steepbank River mainstem and the MacKay River;

- Four historical stations including three Muskeg River stations (MUR-4; MUR-5; and MUR-6) and Stanley Creek (STC-1) were sampled (these stations were not sampled in 2002);

- The list of metals analyzed in sediment by the consulting analytical laboratory changed somewhat, with aluminum, boron, calcium, iron, magnesium, manganese, potassium, sodium and titanium not analyzed in 2003, and bismuth and tin added to 2003 analyses;

- Stainless steel sampling equipment was rinsed with the organic solvents hexane and acetone prior to sampling at each station, to reduce potential contamination of equipment (waste solvent was collected and disposed of appropriately following sampling); and

- Survival results for earthworm (*Lumbriculus variegatus*) toxicity tests were not analyzed, due to inaccuracies associated with this test result caused by organism breakage (see Sections 4.2.5.1 and 4.4).

An additional change was the relocation of the upper Firebag River station FIR-2. In early 2003, during the winter water sampling program, it was determined that the historical Upper Firebag station was incorrectly situated on a tributary of the Firebag (i.e., not on the mainstem). Consequently, in fall 2003, a new sediment and water quality monitoring station was established on the Firebag River mainstem. All other station locations were consistent with previous RAMP studies.

4.2.5 Data Analysis

4.2.5.1 Analytical Approach

Analysis of the RAMP 2003 sediment quality data set was based on the results of previous RAMP studies, particularly those describing the relationships between sediment toxicity and chemistry in the RAMP 2002 technical report (Golder 2003b). Relationships between toxicity endpoints and chemical variables were examined.

Analysis of this year's sediment quality data included the following components:

- Characterization of sediment quality in the Athabasca River mainstem, delta, tributaries, and in Shipyard and McClelland lakes;
- Examination of relationships between sediment quality variables at individual stations;
- Examination of temporal trends for select metals and PAHs in sediments for individual stations;
- Assessment of relationships between sediment chemistry and toxicity; and
- Identification of any downstream changes or other spatial trends in sediment quality that may be related to oil sands development or other environmental factors.

4.2.5.2 Statistical Analyses

Relationships between Sediment Chemistry Variables

Correlations were used to assess relationships between sediment chemistry variables and similarity or differences in sediment chemistry among stations located in the Athabasca River mainstem, its delta, tributary watersheds to the Athabasca River, and Shipyard and McClelland lakes. This assessment was conducted using sediment quality data collected in fall 2003 only.

Prior to conducting correlation analyses, the sediment quality data set was reduced to a smaller number of variables using principal components analysis (PCA), as described below. All analyses were conducted using SYSTAT 10 (SPSS 2000).

Data Screening

Before any PCA or correlation analyses were conducted, data were screened to exclude any variables with concentrations below detection limits in over 70% of observations (i.e., stations) in each station group.

Data Reduction

PCA was used to reduce the sediment chemistry data set. PCA is a data reduction technique that reduces a large number of variables into a small number of summary variables called principal components (PCs). These summary variables, which are independent and orthogonal, are formed from linear combinations of the original variables. PCA is a useful technique because it can often reveal patterns or relationships that were not previously apparent, particularly when analyzing large data sets containing numerous variables.

Separate PCAs were conducted for the following chemical groups:

- Total metals; and
- PAHs.

Methods used for PCA were generally consistent with those described in the 5-year report (Golder 2003a) and the 2002 technical report (Golder 2003b). PCAs were conducted using both untransformed and $\log_{10}$-transformed data. The analysis that provided the best separation of the original variables with the summary variables (PCs) was used.

To identify differences and similarities in metal or PAH concentrations between stations, the primary PCs formed were plotted against each other. These plots were used to assess any spatial patterns related to metal or PAH concentrations. The resulting PCs also were used in subsequent correlation analyses as surrogates for the metals and PAHs.

Correlation Analyses

Relationships between the original variables and summary variables were evaluated using Pearson's correlations (r), to determine which individual variables (i.e., specific metals or PAHs used to create the PCs) were most strongly represented by the PCs. The direction of correlation was used to determine whether metals or PAHs increased or decreased as the factor scores (i.e., PCs) increased. Correlations (r) greater than $|0.50|$ but less than $|0.75|$ were described as moderate correlations; correlations of over $|0.75|$ were described as strong.

The degree and direction of these correlations may be used to interpret PC scores in subsequent analyses. For example, if a high Metals PC1 score was observed at a particular station, and through correlation analysis Metal PC1 is determined to be strongly correlated with increasing concentrations of copper and zinc, then this station likely exhibited high concentrations of copper and zinc. Analytes that were moderately positively or negatively correlated (i.e., in the same direction) with both PCs cannot be used to predict concentrations of the original variables.

Spearman's rank correlations (r_s) were used to assess relationships between the principal components and conventional sediment chemistry variables, including moisture, organic, inorganic, and total carbon, and grain size, total recoverable and extractable hydrocarbons, low molecular weight target PAHs, high molecular weight target PAHs, total debenzothiophenes, and retene, and sediment toxicity end-points.

Low molecular weight (LMW) PAHs include those with only two or three aromatic rings, including napthelene, biphenyl, fluorene, acenaphtene, acenaphtylene, phenanthrene, and anthracene. High molecular weight (HMW) PAHs include those with four, five or six aromatic rings, including fluoranthene, pyrene, benzo(a)pyrene, benzo(a)anthracene, chrysene, benzo(b/j/k)fluoranthene, dibenzo(ah)anthracene, indeno(1,2,3-cd)pyrene and benzo(ghi)perylene. Generally, HMW PAHs are less volatile, less soluble and more resistant to weathering than LMW PAHs (ATSDR 1995). Further, toxicity of PAHs generally increase with increasing molecular weight and alkylation (Eisler 1987a).

Dibenzothiophene and alkylated dibenzothiophenes were part of the PAH scan undertaken on sediment samples for this project. Dibenzothiophenes are sulfonated PAHs characteristic of coal and coal tar (Brewer *et al.* 1998) that were examined explicitly in analysis of the 2003 sediment data as potential indicators of a bitumen source of PAHs observed at each station. Retene, a C4-alkylated phenanthrene, is generally believed to be derived from anaerobic decomposition of abietic acid, a resin acid commonly found in wood of coniferous trees (Bouloubassi and Saliot 1991) or combustion of wood at low temperatures (Ramdahl 1983). Retene was examined explicitly as a potential indicator of decomposition of woody debris as a source for PAH concentrations observed.

Critical values of Spearman's rank correlation were used to determine whether a correlation was statistically significant. For all variables that were measured at all stations (excluding grain size and toxicity data), any correlations greater than $r_s = |0.33|$ were significant. Correlations with grain size (measured at 35 stations) were significant if the correlation was higher than $r_s = |0.34|$. Correlations with toxicity endpoints (measured at 29 stations), were significant if the correlation was higher than $r_s = |0.37|$. Qualitatively, correlations of $|0.50| < r_s < |0.75|$ were defined as moderate, while strong correlations were defined as $r_s > |0.75|$. Regardless of statistical significance, correlations of $r_s < |0.5|$ were defined as weak. All significance tests were conducted at a significance level of $\alpha = 0.05$.

Trend Analyses

Relationships between sediment quality variables, including conventional variables, chemical variables (including metal and PAH summary variables), and toxicological endpoints, were examined using correlation analysis. Results from correlation analyses were used to guide subsequent temporal and spatial trend analyses and to identify potential trends in sediment quality related to oil sands development or other human activities. Temporal and spatial trends were examined using qualitative and quantitative methods; the use of statistical methods to detect trends was largely limited by the sample sizes of the data sets.

Temporal trend analyses were conducted to evaluate whether concentrations of select contaminants in sediment have been decreasing or increasing since the RAMP program was initiated in 1997. Trend analyses in the RAMP 5-year report (Golder 2003a) for stations at the mouth of the Muskeg River (MUR-1) and the Athabasca River mainstem upstream of Fort Creek (ATR-FC-E and -W) and Donald Creek (ATR-DC-E and -W) determined that all metals and PAHs exhibited declining concentrations over the duration of sampling except five metals: beryllium, cadmium, uranium, thallium, and molybdenum. Using these five metals, trend analyses were conducted in 2003 to determine if concentrations of these contaminants have been decreasing or increasing over time. In addition to these metals, trends for a representative metal (i.e., copper) and two representative PAHs (i.e., napthelene [a low molecular weight PAH], and pyrene [a high molecular weight PAH]), and general indicators of petroleum hydrocarbons (i.e., total recoverable hydrocarbons or TRH) were also examined.

Kendall's rank correlations were applied to evaluate whether the concentrations of these analytes increased or decreased over time. Analyses were only conducted on data for the station located at the mouth of the Muskeg River (MUR-1), given this was the only station with greater than five years of sediment chemistry data (some RAMP stations on the Athabasca River mainstem have been sampled for 6 years, but early years tested cross-channel composite samples instead of individual samples from each bank).

Prior to analysis, all values below analytical detection limits were substituted with a value equal to one half of the detection limit. All analyses were conducted in SYSTAT 10 (SPSS 2000). The significance of the temporal trend for each analyte was determined by comparing correlation coefficients (τ) to a critical value; correlations were significant where $\tau > |0.87|$.

4.2.5.3 Descriptive Methods

In addition to statistical analyses of sediment quality data, various descriptive and/or qualitative approaches were used to examine the sediment quality data set:

- Screening of sediment quality data against Canadian Council of Ministers of the Environment (CCME) Interim Sediment Quality Guidelines (ISQG) and Predicted Effects Levels (PELs) (CCME 2002);

- Comparison of 2003 sediment quality data with those from previous years, to assess annual variability and consistency of sediment quality at specific stations;

- Qualitative comparison of sediment quality between upstream and downstream stations (in watersheds with upstream stations), where historical sample sizes prohibited a statistical approach to trend analysis; and

- Focus on specific sediment quality variables, stations, watersheds and/or historical trends previously identified by RAMP, particularly in the 5-year trend report (Golder 2003a) and the RAMP 2003 technical report (e.g., Golder 2003b).

4.2.5.4 Analysis of Sediment Toxicity Data

Raw survival data (i.e., number of surviving test organisms) were used in all analyses rather than survival relative to control, as was done in previous statistical analyses of RAMP sediment toxicity data (e.g., Golder 2003a,b). For each test, HydroQual tests one control population (i.e., organisms in clean sediment) for every four test populations (i.e., organisms in sediment provided from the RAMP study area). Each test begins with ten organisms. The number of organisms surviving at the end of the 10 day test represents the survival of organisms in each test (e.g., 8 of 10 organisms surviving = 80% survival). However, HydroQual reports results for each test both as survival (i.e., # organisms surviving) as survival relative to control (i.e., # surviving in test / # surviving in associated control). Given all organisms in control sediments may not survive, organism survival relative to control for tested sediments may be greater than 100% (e.g., 10 test organisms surviving / 8 control organisms surviving = 125% survival relative to control).

Given each test does not have its own control and control group survival is assumed not to be independent of test group survival (provided control group survival is sufficiently high as to not violate minimum QA/QC standards), number of surviving organisms was reported rather than survival relative to control, and used for any statistical comparisons of sediment toxicity with sediment chemistry.

Additionally, survival data for the *Lumbriculus variegatus* test were excluded from analysis, given this organism is fragile and routinely broke apart during take-down of test apparatus when tested in sandy sediments (J. Hatcher, HydroQual Laboratories, *pers. comm.*; J. Pickard, BC Research Ltd, *pers. comm.*). Because worm segments are very difficult to discriminate from whole organisms, these segments were counted as surviving individuals, resulting in values for surviving individuals well above the number of organisms originally placed in the test. For 2003 RAMP testing, numbers of worms reported to survive to the completion of the test exposure ranged from 14 to 26 (Appendix A4), greater than the 10 organisms originally placed in the test. Given this, only growth data for the *Lumbiculus* test was reported or analyzed.

4.3 RESULTS

The following section summarizes results of the RAMP 2003 sediment quality program. Complete sediment quality data collected by RAMP in 2003 and associated industry and AENV monitoring data, appear in Appendix A4.

4.3.1 Conventional Variables

4.3.1.1 Particle Size Distribution

Sediment at most stations sampled (i.e., 27 of 36) was comprised predominantly of sand (Figure 4.2), with several stations (i.e., Athabasca River mainstem stations ATR-DD-W, ATR-FR-W and ATR-FR-E and Firebag River mouth FIR-1) exhibiting sediment that was entirely composed of sand. Clay and silt content at the remaining nine stations comprised 55 to 96% of the particles (note: gravel was excluded from particle size analyses). Stations that exhibited greater than 50% clay and silt included three Athabasca River mainstem stations (ATR-MR-E, ATR-FC-E and W and ATR-ER), all delta stations, one Muskeg River station (MUR-4), and both lake stations.

4.3.1.2 Carbon Content

Total organic carbon (TOC) ranged from less than 0.1% of sediment at several Athabasca River mainstem stations (i.e., ATR-SR-E, ATR-DD-W and ATR-FC-E) and upstream and downstream stations on the Firebag River (i.e., FIR-1 and FIR-2B), to over 40% at Stanley Creek (STC-1) in the Muskeg River watershed (Figure 4.3). Generally, organic carbon was highest in stations in the upper Muskeg River watershed and in lakes, with TOC values over 10% observed at Muskeg River stations MUR-D2 (upstream of Stanley Creek), MUR-5 (upstream of Muskeg Creek) and MUR-4 (upstream of Jackpine Creek), and in both Shipyard Lake and McClelland lakes. Organic carbon content at other stations was lower, ranging from <0.1 to 4.5%.

Visual inspection of sediment samples during field collection indicated that sediment from several stations exhibited large amounts of plant materials (e.g., wood debris, aquatic plants and plant fragments, etc.), including Stanley Creek

(STC-1), Shipyard Lake (SHL-1), and McClelland Lake (MCL-1). Most carbon in sediment samples was organic, with inorganic carbon ranging from 0.03% (ATR-FC-W and CLR-2) to 1.3% (MUR-1B).

TOC and inorganic carbon were both moderately, positively correlated with fine sediment fractions (i.e., silt and clay) (r_s = 0.51 to 0.59); TOC was moderately, negatively correlated with sand content (r_s = -0.55).

4.3.2 Total Recoverable, Extractable, and Volatile Hydrocarbons

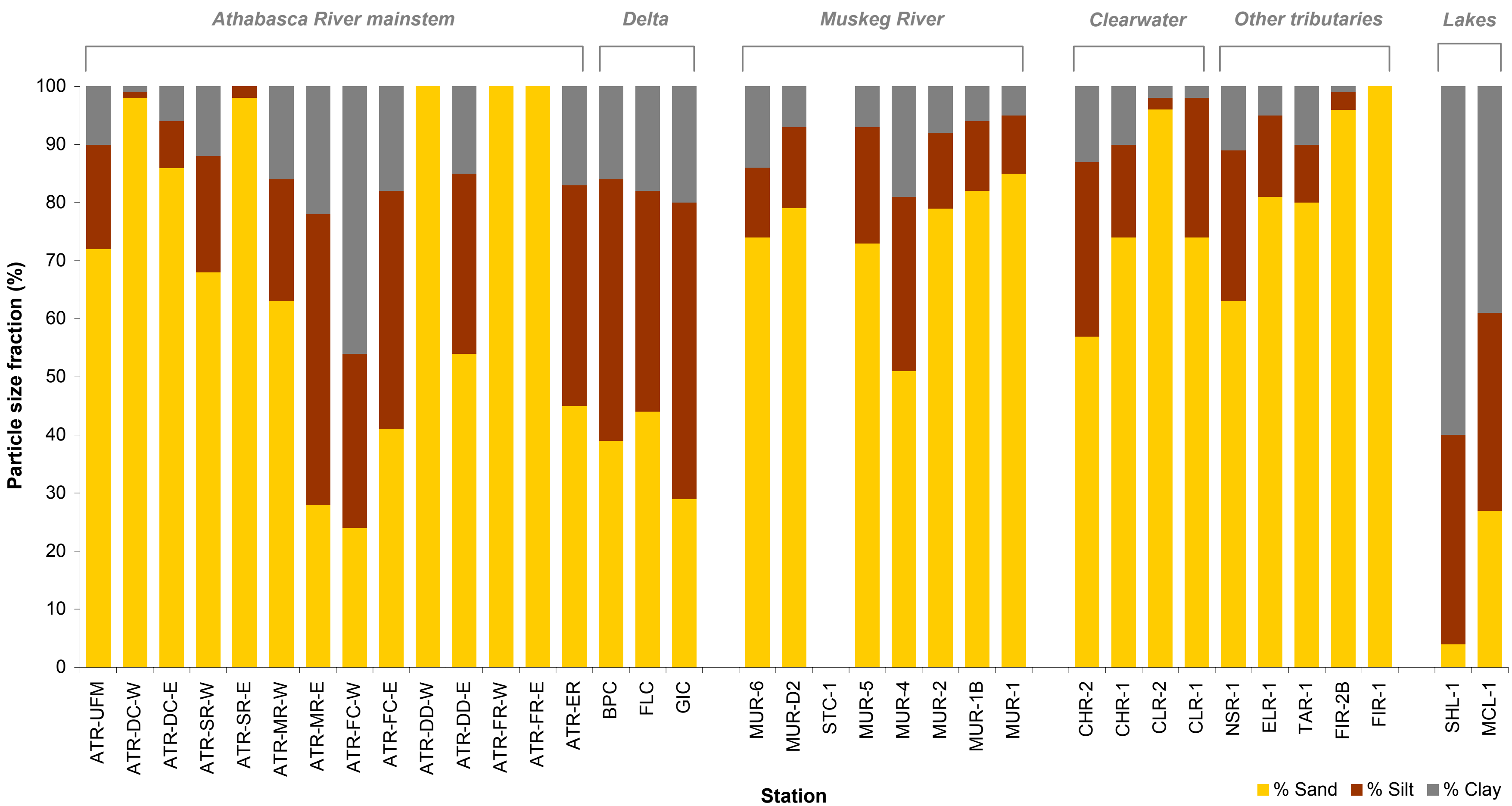
TRH is an aggregate measure of all non-polar hydrocarbons in a sample, consisting primarily of hydrocarbons with chains of greater than 10-12 carbon atoms. TEH is a measure of hydrocarbons ranging from C11 to C30. Therefore, when examined together, TEH may be considered a subset of TRH, with concentrations of (TRH minus TEH) generally indicative of higher-molecular weight hydrocarbons (i.e., > C32). Figure 4.4 illustrates concentrations of total recoverable hydrocarbons (TRH) and total extractable hydrocarbons (TEH) in sediments for each station, with TEH concentrations placed in front of TRH to indicate the possible proportion of C10-C32 hydrocarbons in the TRH value for each station.

TRH concentrations in sediment ranged from < 100 to 39,000 µg/g (Figure 4.4). Highest concentrations of TRH were observed at the east bank of the Athabasca River upstream of Donald Creek (ATR-DC-E, 39,900 µg/g), followed by Shipyard Lake (SHL-1, 26,800 µg/g) Stanley Creek in the Muskeg River watershed (STC-1, 25,200 µg/g). Generally, TRH concentrations were higher in the Muskeg River watershed and in Shipyard and McClelland lakes than in other areas, although the Ells River (ELR-1) exhibited higher TRH (i.e., 4,400 µg/g) than other tributaries, the Athabasca delta, or any Athabasca mainstem stations except ATR-DC-E.

TEH concentrations were moderately, positively correlated with TRH concentrations (r_s = 0.73), with highest values observed at ATR-DC-E (1,700 µg/g), MUR-2 (Muskeg River upstream of Canterra Road crossing, 1,600 µg/g) and the ELR-1 (Ells River, 1,500 µg/g).

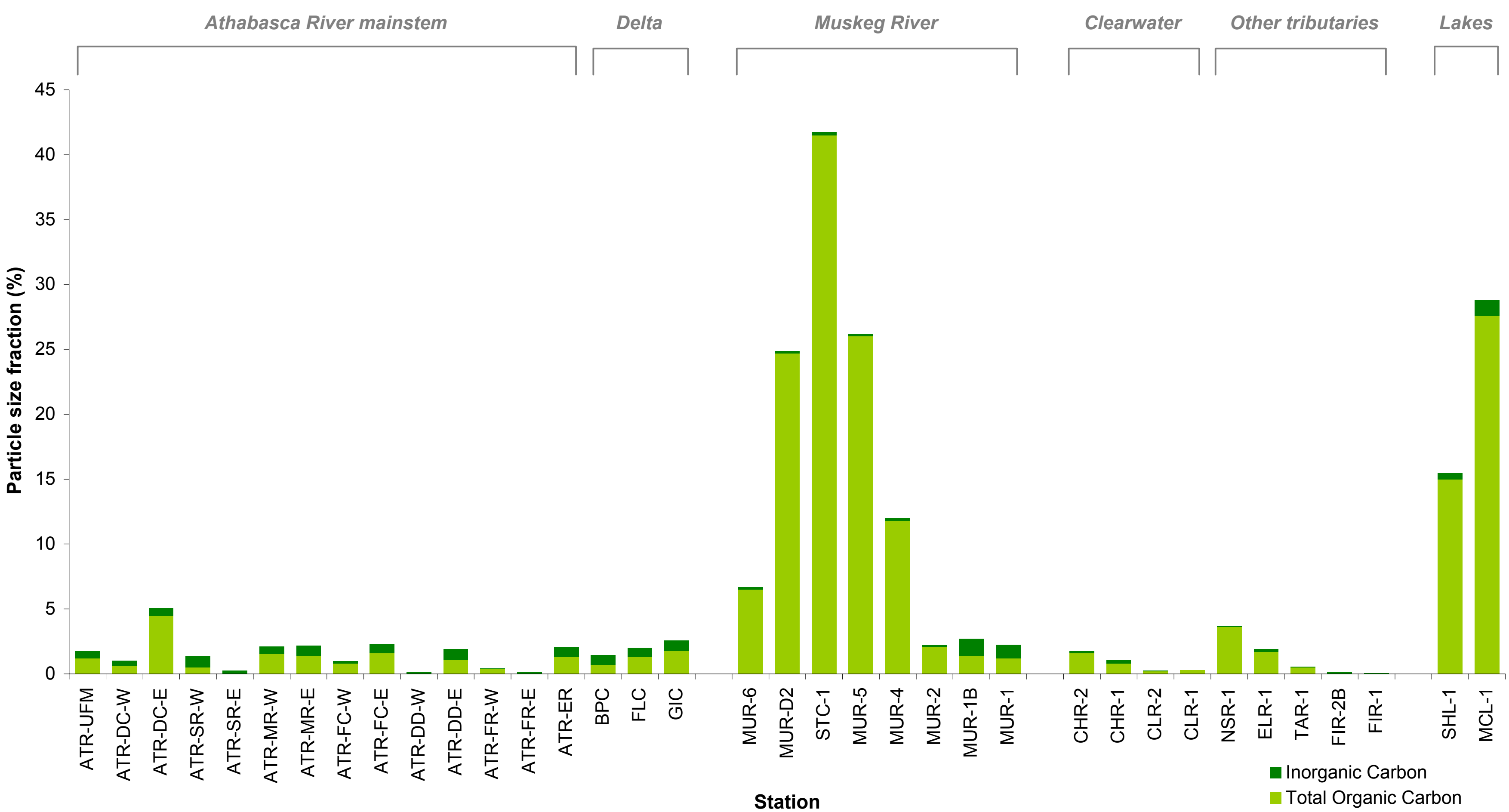
Both TRH and TEH were strongly, positively correlated with total organic carbon (r_s = 0.80 and 0.74), but weakly correlated with inorganic carbon. TRH was weakly, positively correlated with clay and silt fractions of sediment, while TEH was moderately, positively correlated with the clay fraction (r_s = 0.54) and weakly, negatively associated with the sand fraction (r_s = -0.47). Stations with sediment composed entirely of sand did not exhibit any TEH concentrations.

Figure 4.2 Particle size distribution of sediments collected by RAMP, September 2003.



Note: Particle size distribution could not be calculated for Stanley Creek due to a very high proportion of organic material to sediment in samples from this station.

Figure 4.3 Total organic and inorganic carbon in sediments collected by RAMP, September 2003.



Total volatile hydrocarbons (TVH) were non-detectable (<0.5 μg/g) at all but six stations, including three stations in the Clearwater watershed (i.e., CHR-1, Christina River mouth, 4.3 μg/g; CLR-2, Clearwater River upstream of Christina River, 1.6 μg/g; and CLR-1, Clearwater River upstream of Fort McMurray, 0.9 μg/g). TVH also was detected at stations on the Athabasca River upstream of the Firebag River (ATR-FR-W, 3.3 μg/g) and upstream of Fort McMurray (ATR-UFM, 1.0 μg/g), and on the upper Muskeg River (MUR-6, 2.8 μg/g).

4.3.3 Metals

4.3.3.1 Principal Components Analysis

Principal components analysis was conducted on the metals data set to reduce these chemical variables into a smaller set of summary variables.

Data Screening and Reduction

Total bismuth, mercury, silver, and tin were excluded from principal component analyses of the RAMP fall 2003 sediment quality data set, given over 70% of the values were non-detectable.

Results of Metals PCA

Two principal components (PCs) were derived from analyses of the metals data set, which was comprised of 16 metals. PC1 accounted for a majority of the variance in the data set (76.9%), while PC2 accounted for a much smaller fraction of the variance (6.9%). All metals exhibited positive correlations greater than 0.67 with PC1; 14 metals were strongly correlated with PC1 ($r = 0.77$ to 0.98) and the two remaining metals, selenium and molybdenum, exhibited moderate correlations ($r = 0.74$ and 0.67). All metals were weakly correlated with PC2 ($r = -0.00$ to 0.42), except selenium, which exhibited a moderate correlation ($r=-0.55$) with PC2. These results indicate that PC1 is an excellent summary variable for all metals in subsequent analyses. PC2 was not used in subsequent analyses given it explained a very small portion of the total variance and only one of the sixteen metals was moderately correlated with it.

A plot of metals principal component scores for each station is presented in Figure 4.5. Most stations exhibited low negative and positive PC scores, ranging from –4 to 4, suggesting that metals concentrations were not broadly different among these stations. A few stations exhibited metals scores (reflecting metal concentrations) that were above and below this range. Shipyard Lake (SHL-1) exhibited highest metal concentrations; stations located along the Clearwater River (CLR-1 and 2) and along the Firebag River exhibited the lowest concentrations of metals.

Figure 4.4 Total recoverable and total extractable hydrocarbons (TRH and TEH) in sediments collected by RAMP, September 2003.

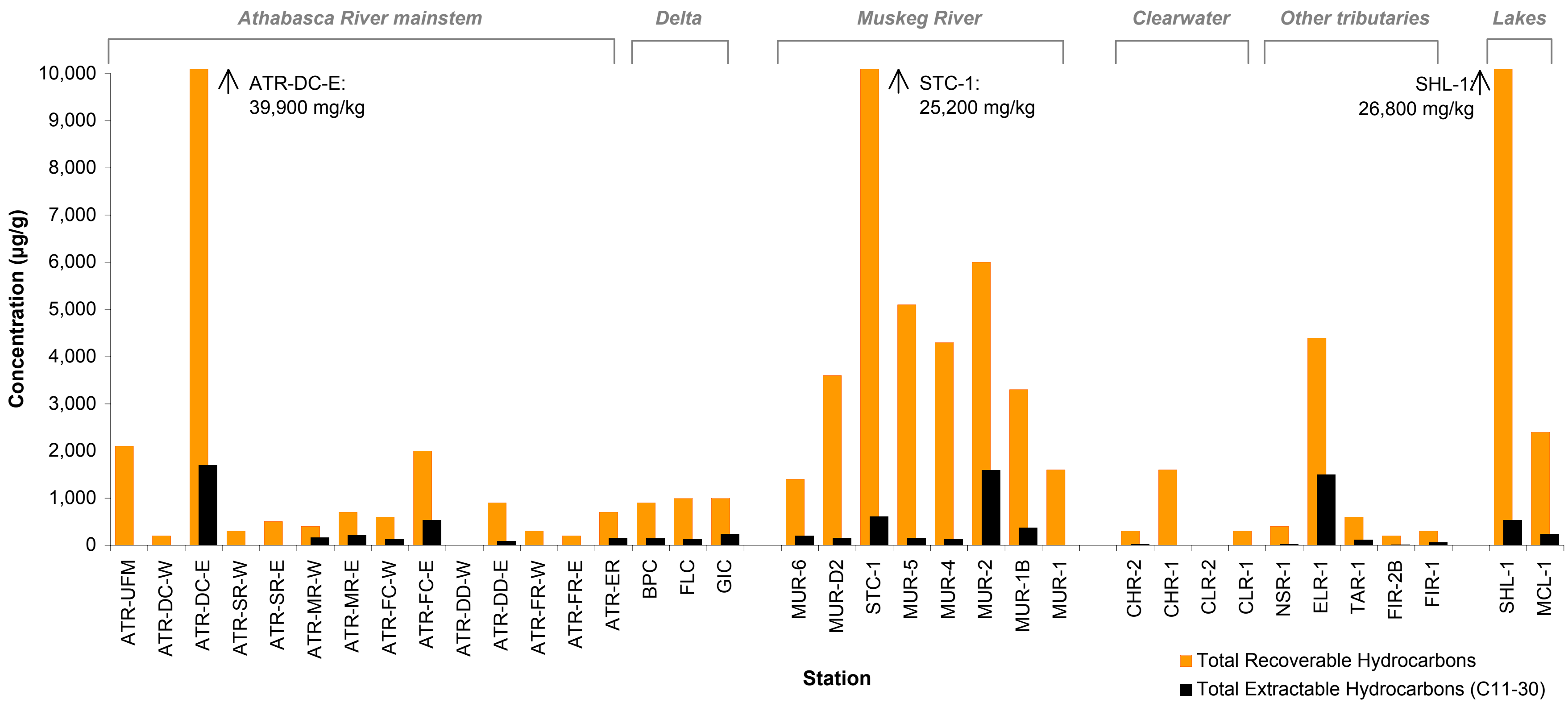
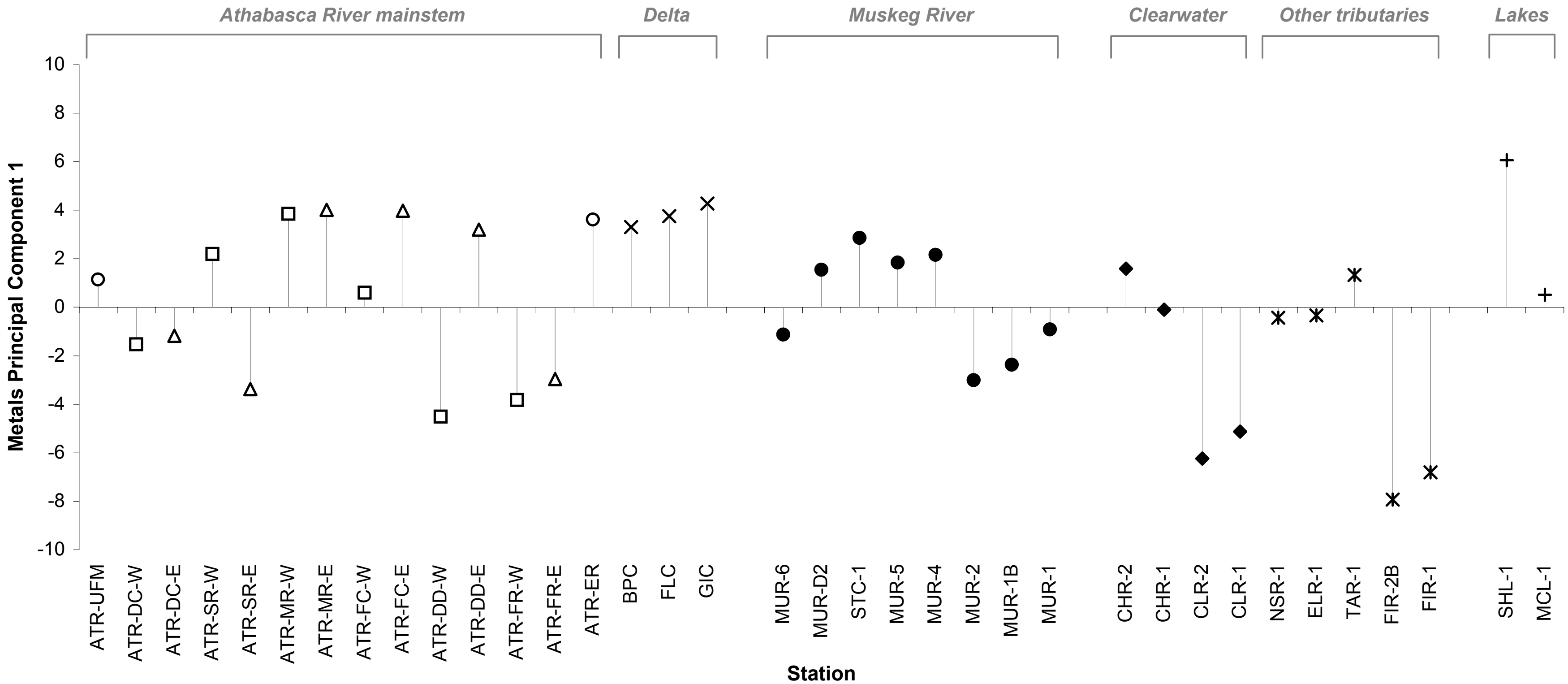


Figure 4.5 Results of Principal Component Analysis of total metals data set for sediments collected by RAMP, September 2003.



Chemical/physical sediment quality variables correlated with Metals PC1[1]

	Negative Correlations		Positive Correlations	
	Moderate	Strong	Moderate	Strong
PC1	PAH PC2	sand	Moisture, TOC, TIC, TC, PAH PC1	clay, silt

[1] Variables assessed included moisture, total, inorganic, and organic carbon, recoverable and extractable hydrocarbons, clay, silt, sand, and PAH PCs.

Toxicity endpoints correlated with Metals PC1[2]

	Negative Correlations		Positive Correlations	
	Moderate	Strong	Moderate	Strong
PC1	-	-	*Chironomus* growth	-

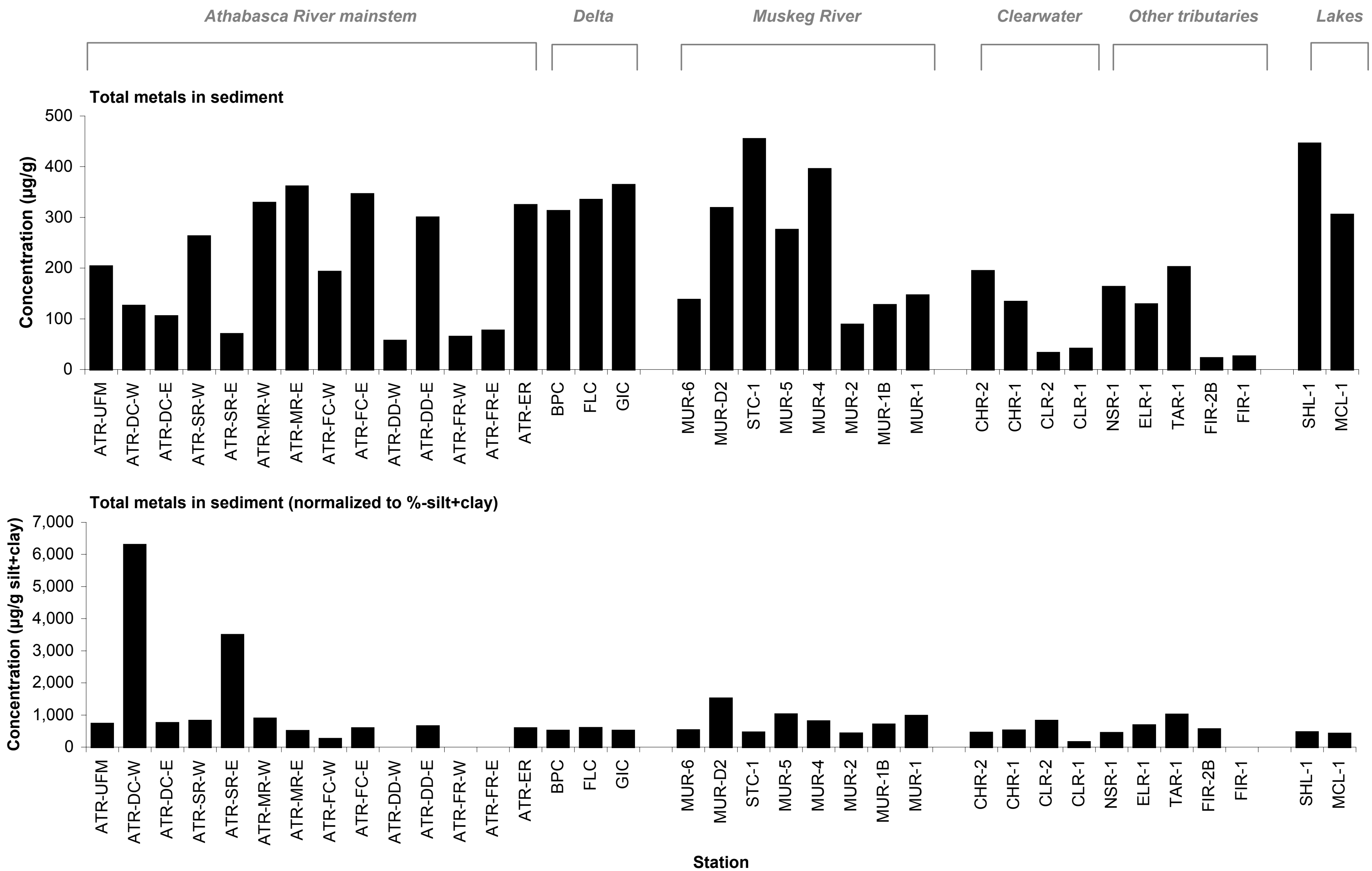
[2] Endpoints assessed included *Hyallela azteca* survival & growth, *Chironomus tentans* survival & growth, and *Lumbriculus variegatus* growth.

Stations within or near the Athabasca River delta (i.e., ATR-ER, BPC, GIC and FLC) generally exhibited higher metals concentrations than Athabasca River mainstem stations further upstream. Consistent differences in metal concentrations between west and east banks of the river mainstem were not observed. In the Muskeg River watershed, metal concentrations were highest in sediments from the middle reach of the river, from upstream of Stanley Creek (MUR-D2) to MUR-4 (upstream of Jackpine Creek); upstream station MUR-6 and stations near the river mouth (i.e., MUR-2, -1B and -1) generally exhibited lower concentrations of metals in sediment.

Metals concentrations in sediment, represented by Metals PC1, were strongly associated with increasing amounts of silt and clay fractions (r_s = 0.84 for both fractions) and strongly negatively associated with sand content (r_s = -0.83). Additionally, Metals PC1 was moderately, positively correlated with carbon content (organic, inorganic, and total).

Given the clear relationship between concentrations of many metals in sediment and sediment grain size (Brewer *et al.* 1998), comparisons of metals concentrations among stations also were undertaken with metal concentrations normalized to percent fine fractions (i.e., silt + clay) in each sample. Figure 4.6 illustrates total metal concentrations in sediments collected by RAMP in 2003, including concentrations of total metals normalized to proportions of fine sediments present at each station (i.e., µg/g of silt and clay). Unadjusted total metal concentrations were highest in Shipyard Lake (SHL-1), followed by several stations in the Athabasca River mainstem and the middle Muskeg River. Following adjustment for silt and clay content, metal concentrations among most stations were similar, with concentrations in sediments from the Athabasca River mainstem similar to those in tributary watersheds and lakes. Stations exhibiting highest adjusted metals concentrations included the Athabasca River upstream of Donald Creek (west bank), followed by the Athabasca River upstream of Steepbank River (east bank).

Figure 4.6 Total metals concentrations in sediments collected by RAMP, September 2003, including metals concentrations normalized to fine sediment fraction only (i.e., percent silt + clay).



4.3.4 Polycyclic Aromatic Hydrocarbons (PAHs)

4.3.4.1 Principal Components Analysis

Principal components analysis was conducted on the PAH data set to reduce these chemical variables into a smaller set of summary variables. Both target PAH compounds and alkylated PAH compounds were included in the PCA.

Data Screening and Reduction

Acenaphythlene and methyl acenaphthene were excluded from principal component analyses of the RAMP fall 2003 sediment quality data set, given over 70% of the values were non-detectable.

Results of PAH PCA

Three principal components (PCs) were generated from analyses of the PAH data set, which included 37 PAHs (Table 4.2). PC1 accounted for a majority of the variance in the data set (76.2%), while PC2 accounted for a smaller fraction of the variance (12.8%).

All PAHs exhibited positive correlations greater than 0.56 with PC1; 32 of the PAHs were strongly correlated with PC1 (r = 0.81 to 0.97), while the remaining five (i.e., anthracene, napthelene, C1-napthalenes, C2-napthelenes, biphenyl, methyl-biphenyl and retene) were moderately correlated (r = 0.55 to 0.72) with PC1. These results indicate that PC1 is an excellent summary variable for all PAHs included in the analyses.

Most PAHs that were not strongly correlated with PC1 were moderately, negatively correlated with PC2. Napthelene, biphenyl and C1-napthelene were strongly, negatively correlated with PC2, while methyl–biphenyl, C2-napthelene and fluorene were moderately, positively associated with PC2. Conversely, C3-substituted fluoranthenes/pyrenes were moderately, positively correlated with PC2. In a similar PC analysis undertaken for the RAMP 5-year report, napthelene and C1-napthelenes were similarly found to correlate differently than other PAHs with resultant PCs (Golder 2003a).

Generally, low molecular weight (LMW) PAHs – those with two or three benzene rings – correlated most negatively with PC2, with 2-ring compounds (target PAHs and single-alkylated derivatives) exhibiting strongest correlations (i.e., napthelene r_s = -0.78; biphenyl r_s = -0.77; C1-napthelene r_s = -0.75; methyl-biphenyl r_s = -0.77). Scores on PC2 generally were higher for higher molecular weight PAHs, and more highly substituted (i.e., alkylated) PAHs.

Therefore, PC1 likely is a good summary variable for total amounts of PAHs, while PC2 likely represents concentrations of higher molecular weight PAHs relative to lower molecular weight PAHs. Scores for PAH PC1 and PC2 appear in Figure 4.7 and illustrate the distribution of PAH concentrations across stations. Most stations scattered around the origin of the graph. Stations that scored high on PC1 exhibited higher concentrations of virtually all PAHs; those that scored low on this PC exhibit broadly lower concentrations of PAHs.

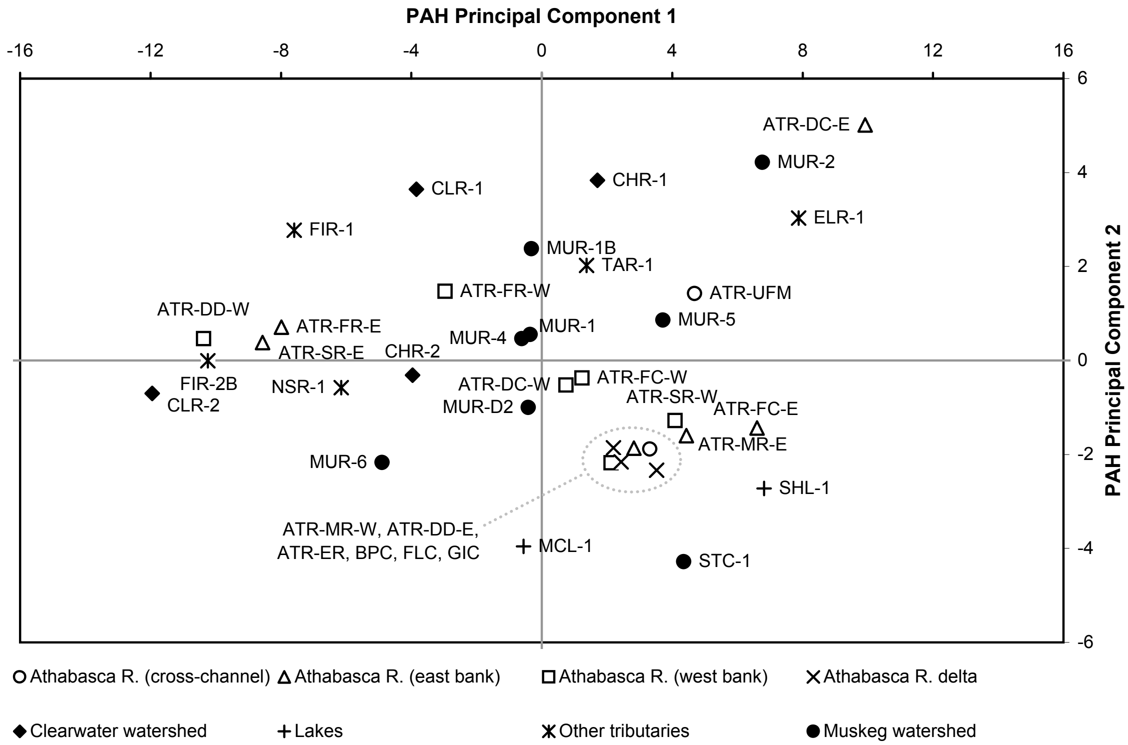
Station CLR-2 (Clearwater River upstream of Christina River) exhibited lowest PC1 scores of all stations; scores also were low at both Firebag River stations (FIR-1 and -2B), North Steepbank River (NSR-1), Athabasca River mainstem stations ATR-DD-W, ATR-SR-E and ATR-FR-E (which were 100% sand) and upper Muskeg River stations MUR-6 (upstream of Wapasu Creek). Highest scores were observed along the east bank of the Athabasca River upstream of Donald Creek (ATR-DC-E), followed by the Ells River (ELR-1) and the Muskeg River upstream of the Canterra Road crossing (MUR-2). PC1 was moderately, positively correlated with organic and inorganic carbon, silt content, TRH and TEH, as well as with Metals PC1.

Stations ATR-DC-E, ELR-1 and MUR-2 also exhibited high scores on PC2, as did stations at the mouths of the Christina and Clearwater rivers (i.e., CHR-1 and CLR-1). These stations generally exhibited low or non-detectable concentrations of low molecular weight PAHs (i.e., napthelene, biphenyl, fluorine and anthracene), and higher concentrations of high molecular weight PAHs relative to other stations. PC2 was moderately, negatively correlated with moisture, clay and silt content and Metals PC1, and also moderately, positively correlated with sand.

Generally, downstream stations within watersheds exhibited higher concentrations of PAHs (i.e., higher PC1 scores) and greater proportions of high molecular weight PAHs (i.e., higher PC2 scores) than upstream stations (Figure 4.7), particularly stations on the Firebag (i.e., FIR-2B and FIR-1) and Clearwater (CLR-2 and CLR-1) rivers. Concentrations of PAHs were similar for upstream and downstream locations in the Muskeg River watershed (i.e., MUR-6 and MUR-1). The upper Christina River (CHR-2) exhibited higher PAHs than the Christina River at its mouth (i.e., CHR-1).

PAHs are known to strongly adsorb to the organic carbon portion of sediments (CCME 1999). Therefore, PAH concentrations among stations also were compared following adjustment of values to account for varying organic carbon content at each station, with resulting concentrations expressed as µg/g organic carbon.

Figure 4.7 Results of Principal Component Analysis of polycylic aromatic hydrocarbon(PAH) data set for sediments collected by RAMP, September 2003.



Chemical and physical sediment quality variables correlated with PAH PC1 and PC2[1]

	Negative Correlations		Positive Correlations	
	Moderate (-0.5 > r_s > -0.75)	Strong (r_s < -0.75)	Moderate (0.5 < r_s < 0.75)	Strong (r_s > 0.75)
PC1	-	-	TOC, TIC, TRH, TEH, Silt, Metals PC1	-
PC2	Moisture, clay, and silt, MET PC1	-	Sand	-

[1] Variables assessed included moisture, total, inorganic, and organic carbon, recoverable and extractable hydrocarbons, clay, silt, sand, and PAH principal components.

Toxicity endpoints correlated with PAH PC1 and PC2[2]

	Negative Correlations		Positive Correlations	
	Moderate (-0.5 > r_s > -0.75)	Strong (r_s < -0.75)	Moderate (0.5 < r_s < 0.75)	Strong (r_s > 0.75)
PC1	-	-	-	-
PC2	-	-	*Chrionomus* growth	-

[2] Endpoints assessed included *Hyallela azteca, Chironomus tentans, and Lumbriculus variegatus* survival and growth.

Figure 4.8 illustrates total (summed) concentrations of PAHs and alkylated PAHs in sediments collected for RAMP in September 2003, expressed as unadjusted concentrations and concentrations normalized to μg/g organic carbon. The vast majority of PAHs observed at all stations were alkylated. Highest combined concentration of target and alkylated PAHs was observed at Stanley Creek (STC-1), followed by the east bank of the Athabasca River upstream of Donald Creek (ATR-DC-E), the Ells River (ELR-1) and the Muskeg River upstream of the Canterra Road crossing (MUR-2). Lowest unadjusted values were observed at stations CLR-2 (upper Clearwater River), west bank of the Athabasca River downstream of development (ATR-DD-W), and the upper Firebag River (FIR-2B).

Following adjustment for organic carbon concentrations, highest PAH concentrations were observed in sediments from the Ells River (ELR-1), followed by ATR-DC-E and MUR-2. Adjusted concentrations could not be calculated for several stations, given amounts of organic carbon were below the analytical detection limit (i.e., <0.1%).

Figure 4.9 illustrates the distribution of high and low molecular weight target PAHs in sediment collected from all stations in September 2003, as well as retene and total dibenzothiophenes as proportions of total PAHs observed at each station. Stations exhibiting a large proportion of LMW target and alkylated PAHs included Stanley Creek (STC-1), the upper Firebag River (FIR-2B), and McClelland lakes. Conversely, station ATR-DC-E, which exhibited high overall PAH and alkylated PAH concentrations and very high TRH relative to all other stations, exhibited no detectable concentrations of LMW target PAHs. This and other stations with low proportions of LMW to HMW PAHs – i.e., CHR-1 (Christina River mouth), MUR-2 (Muskeg River downstream of Canterra Road crossing), ELR-1 (Ells River) and CLR-1 (Clearwater River) all scored most positively on PAH PC2.

While Stanley Creek exhibited highest concentrations of alkylated PAHs of all stations, this value was comprised nearly entirely of retene. The presence of large amounts of woody and other organic debris in sediment collected from Stanley Creek, combined with very low amounts of other PAHs measured in this sample known to be associated with petroleum and coal (i.e., dibenzothiophenes) suggest PAHs in sediments at Stanley Creek may be related to natural sources other than bitumen, such as anaerobic decay of woody debris. Other stations that exhibited high retene included two other stations in the Muskeg River, MUR-6 (upstream of Wapasu Creek) and MUR-D2 (upstream of Stanley Creek), as well as the upper Christina River (CHR-2), the North Steepbank River (NSR-1) and McClelland Lake (MCL-1).

Conversely, PAH concentrations at stations ATR-DC-E, MUR-2 and ELR-1, where high total PAH concentrations were also observed, exhibited very low concentrations of retene, and high concentrations of dibenzothiophenes relative to other stations (Figure 4.9), suggesting bitumen as a primary source of PAHs at these stations. Other stations exhibiting relatively high portions of dibenzothiophenes relative to total PAHs included ATR-UFM (Athabasca River upstream of Fort McMurray), ATR-FC-E (Athabasca River upstream of Fort Creek, east bank), Ells River (ELR-1), Tar River (TAR-1), Christina River (CHR-1), Clearwater River (CLR-1), and stations in the lower Muskeg River, including MUR-5, MUR-4 and MUR-1B.

Figure 4.8 **Total PAH and alkylated PAH concentrations in sediments collected by RAMP in 2003, including concentrations adjusted for organic carbon content.**

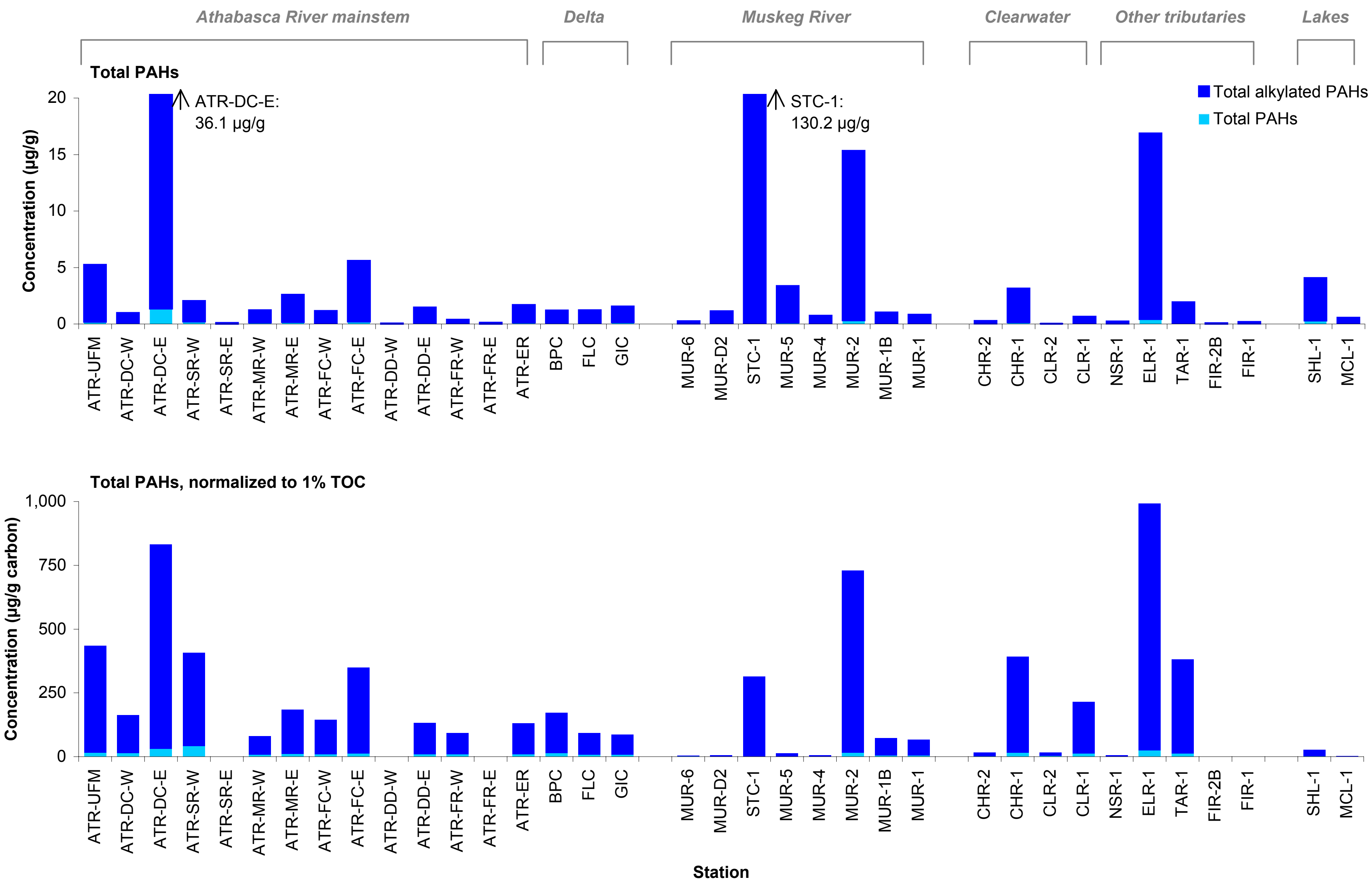
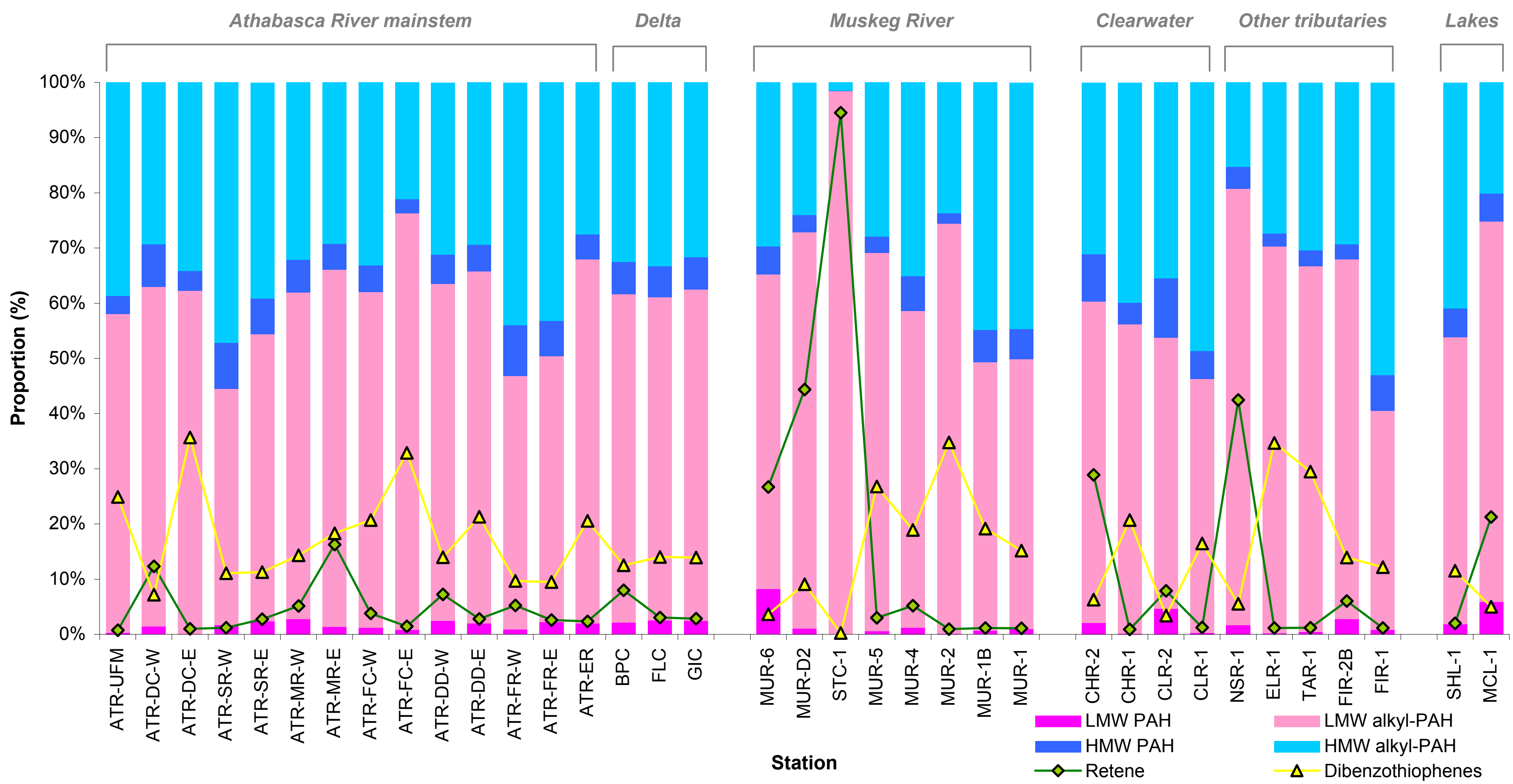


Figure 4.9 **Proportions of low and high molucular weight PAHs and alkylated PAHs, retene, and total dibenzothiophenes in sediments collected by RAMP, September 2003.**



At several of these stations, visual inspection of sediments at the time of collection indicated particles of bitumen throughout the sample, which released small slicks of hydrocarbons during homogenization of the sample (Figure 4.10). Further, some of these stations, particularly ATR-DC-E (Figure 4.11) and ATR-FC-E, were located in areas where large amounts of bitumen were visible along the river bank, suggesting an immediate, local source of PAH-containing bitumen for sediment samples collected at these stations.

Figure 4.10 Evidence of petroleum hydrocarbons in sediment at station MUR-2.

Figure 4.11 Exposed bitumen at station ATR-DC-E.

4.3.5 Correlations between Sediment Chemistry Variables

Correlations among physical and chemical characteristics of sediments collected by RAMP in September 2003 appear in Table 4.3.

Results of correlation analyses may be used to further characterize spatial differences in sediment chemistry. In Figure 4.12, Metals PC1 and PAH PC1 are plotted against each other. Stations in the upper right quadrant of the graph generally exhibited high concentrations of metals and PAHs, as well as high concentrations of carbon, moisture, and fines (i.e., silt and clay), all of which were correlated with high metals and high PAHs. These stations include Shipyard Lake (SHL-1), stations in the Athabasca delta (BPC, GIC, FLC) and Muskeg River watershed stations MUR-5 (upstream of Muskeg Creek) and Stanley Creek (STC-1). Several stations along the Athabasca River mainstem also occur in this quadrant, including upstream of the Embarras River (ATR-ER), upstream of Fort McMurray (ATR-UFM), upstream of Muskeg River (west bank) (ATR-MR-W), upstream of Steepbank River (west bank) (ATR-SR-W) and downstream of development (ATR-DD-E).

Stations in the lower left quadrant generally exhibited lowest metals and PAHs of all stations, as well as lowest carbon content and highest sand content (i.e., lowest fines). Stations placing in this quadrant include both Firebag River stations (FIR-1 and FIR-2B), both Clearwater River stations (CLR-1 and CLR-2), several Athabasca River mainstem stations which exhibited pure sand (i.e., ATR-DD-W, ATR-SR-E, ATR-FR-E), and upper Muskeg River station MUR-6. Muskeg River mouth station MUR-1 scored relatively closely with MUR-6 on metals PC1, but higher on PAH PC1.

Given the positive inter-correlation between fine sediment fractions, carbon content, metals and PAHs, the 1:1 line plotted in Figure 4.12, representing the best-fit relationship between metals and PAH concentrations, likely indicates average concentrations of metals and PAHs for given substrate types and carbon content. Stations falling near this line (e.g., SHL-1, FIR-1) exhibit concentrations of metals and PAHs that are consistent with average relationship between these variables, both of which were strongly correlated with proportion of fine sediment and carbon content. Stations falling above or below this 1:1 line (e.g., ATR-DC-E, CHR-2) exhibit higher or lower concentrations, respectively, of either metal or PAH than would be expected based on the average relationship between metals and PAHs in the data set, which may indicate unique characteristics of that station.

From this perspective, the following observations may be made:

- Stations ATR-DC-E (Athabasca River upstream of Donald Creek – east bank), MUR-2 (Muskeg River upstream of Canterra Road crossing) and

ELR-1 (Ells River) all exhibit higher PAH concentrations than would be expected given the concentration of metals at these stations; and

- Most other stations exhibit concentrations of metals and PAH that are consistent with average relationships between these two variables.

4.3.6 Sediment Toxicity

Results of sediment toxicity testing are summarized in Table 4.4. *Hyallela* survival was significantly reduced by 27% to 89%, relative to controls, following exposure to sediments from the four stations: the Firebag River mouth (FIR-1); the Tar River (TAR-1); the Athabasca River upstream of Donald Creek (east bank) (ATR-DC-E); and Athabasca River upstream of the Steepbank River (west bank) (ATR-SR-W). Most severe effects (almost 90% mortality) were observed in amphipods exposed to sediments from ATR-DC-E. Effects on *Hyallela* growth (40% reduction) were only observed for sediments from one station, ATR-DD-W, Athabasca River downstream of development (west bank).

Reduced chironomid survival was observed at six stations, including the Athabasca River downstream of development (west bank) (ATR-DD-W), upstream of the Embarras River (ATR-ER), upstream of Donald Creek (east bank) (ATR-DC-E), the Tar River (TAR-1), the Muskeg River upstream of Stanley Creek (MUR-D2), and the upper Christina River (CHR-2). Chironomid survival at these stations was reduced by 44 to 71%. Most severe effects were observed for ATR-DC-E, where 2 of 10 chrionomid larvae survived the test. Chironomid growth was reduced by 25 to 45% at three stations: the Christina River mouth (CHR-1), the Athabasca River downstream of development (west bank) (ATR-DD-W), and the Muskeg River upstream of Stanley Creek (MUR-D2), where growth was most reduced. Earthworm growth, measured as biomass, was reduced by 40% for samples from only one station, MUR-2 (Muskeg River upstream of Canterra road crossing).

Table 4.3 Spearman rank correlations (r_s) among sediment chemistry variables.

	%	Total	Total	Total				Grain Size		Metals	Metals	PAH	PAH	LMW	HMW	
	Moisture	Inorg C	Org C	Carbon	TRH	TEH	Clay	Sand	Silt	PC1	PC2	PC1	PC2	PAHs	PAHs	Retene
% Moisture	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Total Inorganic Carbon	0.32	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Total Organic Carbon	**0.86**	0.31	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Total Carbon	**0.84**	**0.44**	**0.96**	-	-	-	-	-	-	-	-	-	-	-	-	-
TRH[1]	**0.61**	**0.39**	**0.80**	**0.80**	-	-	-	-	-	-	-	-	-	-	-	-
TEH[2]	**0.67**	**0.34**	**0.74**	**0.71**	**0.73**	-	-	-	-	-	-	-	-	-	-	-
Clay	**0.74**	**0.51**	**0.59**	**0.60**	**0.42**	**0.54**	-	-	-	-	-	-	-	-	-	-
Sand	**-0.71**	**-0.49**	**-0.55**	**-0.55**	**-0.38**	**-0.47**	**-0.97**	-	-	-	-	-	-	-	-	-
Silt	**0.68**	**0.52**	**0.51**	**0.52**	**0.36**	**0.47**	**0.89**	**-0.96**	-	-	-	-	-	-	-	-
Metals PC1	**0.70**	**0.58**	**0.52**	**0.55**	**0.41**	**0.46**	**0.84**	**-0.83**	**0.84**	-	-	-	-	-	-	-
Metals PC2	**-0.48**	0.32	**-0.53**	**-0.48**	-0.25	**-0.42**	-0.03	-0.03	0.07	0.07	-	-	-	-	-	-
PAH PC1	**0.44**	**0.52**	**0.50**	**0.49**	**0.68**	**0.63**	**0.49**	**-0.49**	**0.51**	**0.64**	0.16	-	-	-	-	-
PAH PC2	**-0.60**	**-0.44**	**-0.33**	**-0.39**	-0.01	-0.25	**-0.65**	**0.63**	**-0.59**	**-0.63**	0.13	-0.09	-	-	-	-
LMW PAHs[3]	**0.68**	**0.66**	**0.56**	**0.58**	**0.49**	**0.63**	**0.79**	**-0.77**	**0.76**	**0.87**	0.05	**0.75**	**-0.63**	-	-	-
HMW PAHs[4]	**0.33**	**0.50**	**0.42**	**0.40**	**0.61**	**0.52**	**0.41**	**-0.40**	**0.42**	**0.56**	0.24	**0.96**	0.03	**0.67**	-	-
Retene	**0.73**	0.28	**0.79**	**0.71**	**0.60**	**0.69**	**0.49**	**-0.48**	**0.47**	**0.50**	-0.30	**0.63**	-0.30	**0.60**	**0.56**	-
Dibenzothiophenes	0.29	**0.37**	**0.41**	**0.39**	**0.68**	**0.55**	**0.39**	**-0.39**	**0.41**	**0.51**	0.18	**0.93**	0.17	**0.58**	**0.92**	**0.50**

Bolded values represent significant correlations (r_s > +/- 0.33 or 0.34; α=0.05).

Highlighted values represent moderate and strong correlations (I.e., r_s > 0.5)

n=35 for grain size, 36 for other variables

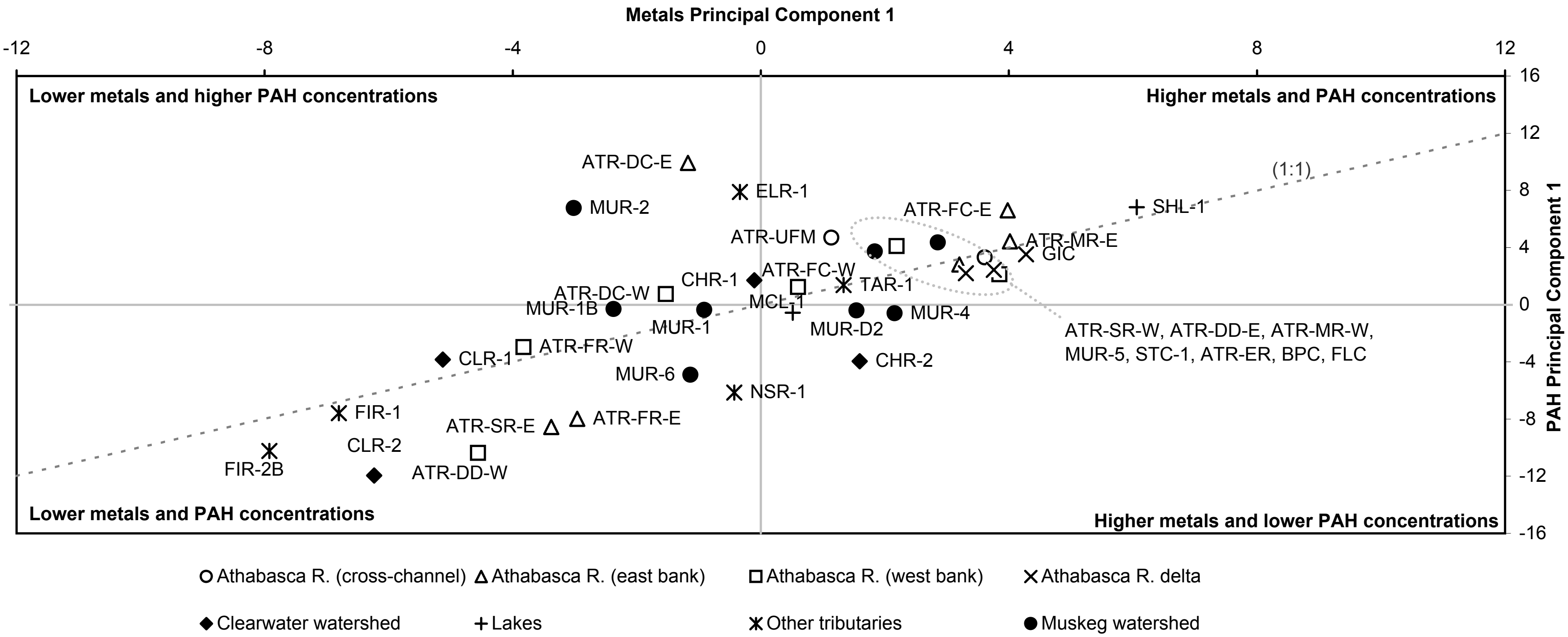
[1] Total Recoverable Hydrocarbons

[2] Total Extractable Hydrocarbons

[3] Low molecular weight target PAHs (i.e., 2 and 3-ring compounds)

[4] High molecular weight target PAHs (i.e., 4, 5 and 6-ring compounds)

Figure 4.12 Relationships of metals and PAH concentrations in sediments collected by RAMP in 2003, as represented by principal component scores.



Chemical/physical variables correlated with Metals PC1 and PAH PC1[1]

	Negative Correlations		Positive Correlations	
	Moderate	Strong	Moderate	Strong
Metals PC1	PAH PC2	Sand	Moisture, TOC, TIC, TC, PAH PC1	Clay, silt
PAH PC1	-	-	TOC, TIC, TRH, TEH, Metals PC1	-

[1] Variables assessed included moisture, total, inorganic, and organic carbon, total rec. and extractable hydrocarbons, clay, silt, sand and PAH principal components.

Toxicity endpoints correlated with Metals PC1 and PAH PC1[2]

	Negative Correlations		Positive Correlations	
	Moderate	Strong	Moderate	Strong
Metals PC1	-	-	*Chironomus* growth	-
PAH PC1	-	-	*Chironomus* growth	-

[2] Endpoints assessed included *Hyallela azteca* and *Chironomus tentans* survival & growth and *Lumbriculus variegatus* growth.

4.3.7 Relationships between Sediment Chemistry and Toxicity

Table 4.5 summarizes relationships between chemical and physical variables and toxicological endpoints. Few significant relationships were observed. *Hyallela* survival was greater in sediments with high silt content and low sand content; *Hyallela* survival and growth also were also weakly, positively correlated with TOC. Chironomid survival was not correlated with any physical or chemical variable, while chironomid growth was higher in sediments with larger fine fractions and higher metal concentrations. Chironomid growth also was weakly, positively associated with concentrations of low molecular weight PAHs, both directly and indirectly through negative association with PC2, which represented high and low molecular weight PAHs (but was itself also correlated with grain size). *Lumbriculus* growth was not strongly or moderately associated with any physical or chemical sediment variable.

Table 4.4 Results from sediment toxicity tests conducted to test effects of exposure to sediments on the survival and growth of the amphipod *Hyallela azteca*, the chironomid midge *Chironomus tentans* and the earthworm *Lumbriculus variegatus*.

		Hyallela azteca		***Chironomus tentans***		***Lumbriculus variegatus***[1]
Test Group	**Station**	Mean survival (# surviving/ replicate)	Mean growth (dry wt./ organism)	Mean survival (# surviving/ replicate)	Mean growth (dry wt./ organism)	Mean growth (dry wt./ organism)
1	Control	<u>8</u>	<u>0.05</u>	7	2.7	0.8
	CLR-2	<u>9</u>	<u>0.06</u>	7	2.9	0.8
	CHR-1	<u>8</u>	<u>0.05</u>	7	**2.0**	0.8
	CLR-1	<u>8</u>	<u>0.06</u>	8	2.2	0.8
	ATR-FC-W	<u>8</u>	<u>0.04</u>	7	2.5	0.8
2	Control	<u>8</u>	<u>0.05</u>	9	3.3	0.8
	ATR-DD-E	<u>7</u>	<u>0.04</u>	8	2.9	0.7
	ATR-DD-W	<u>4</u>	**<u>0.03</u>**	**4**	**2.2**	0.8
	ATR-FR-W	<u>8</u>	<u>0.04</u>	7	3.2	0.9
	ATR-FR-E	<u>7.8</u>	<u>0.05</u>	8	3.2	0.9
	FIR-1	**<u>5</u>**	<u>0.06</u>	8	2.6	0.9
3	Control	9	0.12	8	2.6	1.5
	MUR-2	8	0.11	6	2.5	**0.9**
	ATR-MR-E	8	0.11	6	3.3	1.3
	ATR-MR-W	9	0.15	8	3.1	1.1
4	Control	9	0.11	8	2.6	0.8
	BPC	9	0.12	7	3.6	0.8
	ATR-ER	9	0.11	**4**	4.2	0.9
	GIC	10	0.09	8	3.5	0.7
	ATR-FC-E	9.6	0.09	6	3.8	0.8
	TAR-1	**6.6**	0.10	**5**	4.0	0.9
	FLC	9.6	0.11	6	3.6	0.9

Table 4.4 (cont'd).

Test Group	Station	*Hyallela azteca*		*Chironomus tentans*		*Lumbriculus variegatus*[1]
5	Control	9	0.12	9	3.3	1.5
	NSR-1	10	0.13	7	3.1	1.1
	ELR-1	10	0.13	7	2.8	1.0
	MUR-D2	8	0.11	**3**	**1.8**	1.2
	CHR-2	10	0.11	**5**	4.3	1.2
	FIR-2B	9	0.16	6	2.7	1.2
6	Control	9	0.10	7	2.4	1.1
	ATR-UFM	9	0.10	8	2.4	0.9
	MUR-1	8	0.10	5	2.8	1.0
	ATR-DC-W	6	0.20	7	1.9	1.0
	ATR-DC-E	**1**	0.10	**2**	2.0	0.9
	ATR-SR-W	**6**	0.10	7	3.0	1.1
	ATR-SR-E	8	0.10	8	2.1	0.9

[1] Survival end-point of *L. variegatus* not included for reasons discussed in Section 4.2.5.1.

Underlined values indicate invalid test because control group did not pass minimum requirements for growth.

Bolded values indicate survival or growth differed significantly from the control group.

Table 4.5 Rank correlations (r_s) of sediment physical and chemical characteristics with sediment toxicity results, RAMP 2003.

Station	*Hyallela azteca* Mean survival	*Hyallela azteca* Mean growth	*Chironomus tentans* Mean survival	*Chironomus tentans* Mean growth	*Lumbriculus variegatus* Mean growth
Moisture	**0.47**	**0.44**	-0.28	**0.40**	-0.31
Inorganic Carbon	0.10	0.22	-0.07	0.20	**-0.42**
Organic Carbon	**0.44**	**0.41**	-0.34	0.12	-0.32
Total Carbon	**0.37**	**0.39**	-0.33	0.16	**-0.44**
TRH	0.21	0.15	-0.23	-0.08	-0.32
TEH	0.28	0.35	-0.30	0.28	-0.18
Metal PC1	**0.38**	0.23	-0.09	**0.55**	-0.26
Metal PC2	-0.12	-0.32	0.24	-0.02	0.05
PAH PC1	0.12	0.21	-0.12	0.15	-0.30
PAH PC2	**-0.40**	-0.24	-0.06	**-0.50**	0.06
LMW PAHs	0.32	0.30	-0.04	**0.46**	0.02
HMW PAHs	0.03	0.20	-0.08	0.02	-0.03
Clay (%)	**0.45**	0.18	-0.11	**0.51**	-0.08
Sand (%)	**-0.50**	-0.17	0.02	**-0.47**	0.02
Silt (%)	**0.56**	0.21	-0.00	**0.50**	-0.04

Bolded values represent significant correlations ($r_s > |0.37|$; α=0.05).

Highlighted values represent moderate and strong correlations (i.e., $r_s > |0.5|$)

n=29

Generally, physical characteristics (i.e., grain size and carbon content) were more strongly correlated with survival or growth of test organisms then chemical concentrations (i.e., metals or PAHs). Results of sediment toxicity testing are presented relative to concentrations of metals and PAHs in sediments (as represented by Metals PC1 and PAH PC1) and relative to sediment grain size and TOC, for *Hyallela*, *Chrionomus,* and *Lumbriculus* in Figure 4.13, Figure 4.14 and Figure 4.15, respectively. No relationship between metals or PAH concentrations and observed sediment toxicity were apparent for any test result.

4.3.8 Temporal Trend Analysis

Trend analysis was conducted to determine if concentrations of select analytes are increasing or decreasing over time for one station at the mouth of the Muskeg River (MUR-1). Only this station had sufficient data (i.e., 6 or more years) for these analyses. Results for beryllium, copper, molybdenum, total recoverable hydrocarbons, napthelene and pyrene are presented in Table 4.6. All variables exhibited declining trends over time, but none of these temporal trends was statistically significant.

Table 4.6 Temporal trends in beryllium, molybdenum, copper, total recoverable hydrocarbons (TRH) and pyrene in sediments from the mouth of the Muskeg River (MUR-1), September 2003.

Variable	Kendall's Tau Correlation (τ)
Beryllium	-0.745
Copper	-0.414
Molybdenum	-0.358
Total Recoverable Hydrocarbons	-0.467
Napthelene	-0.143
Pyrene	-0.143

Bolded values represent significant correlations ($\tau > |0.71|$ or $|0.87|$; $\alpha = 0.05$).
n = 6 or 7

Qualitative review and comparison of 2003 sediment quality data with data from previous years of the RAMP program indicated that most sediment quality measured at most stations in 2003 was similar to that measured in 2002 and earlier, except the following:

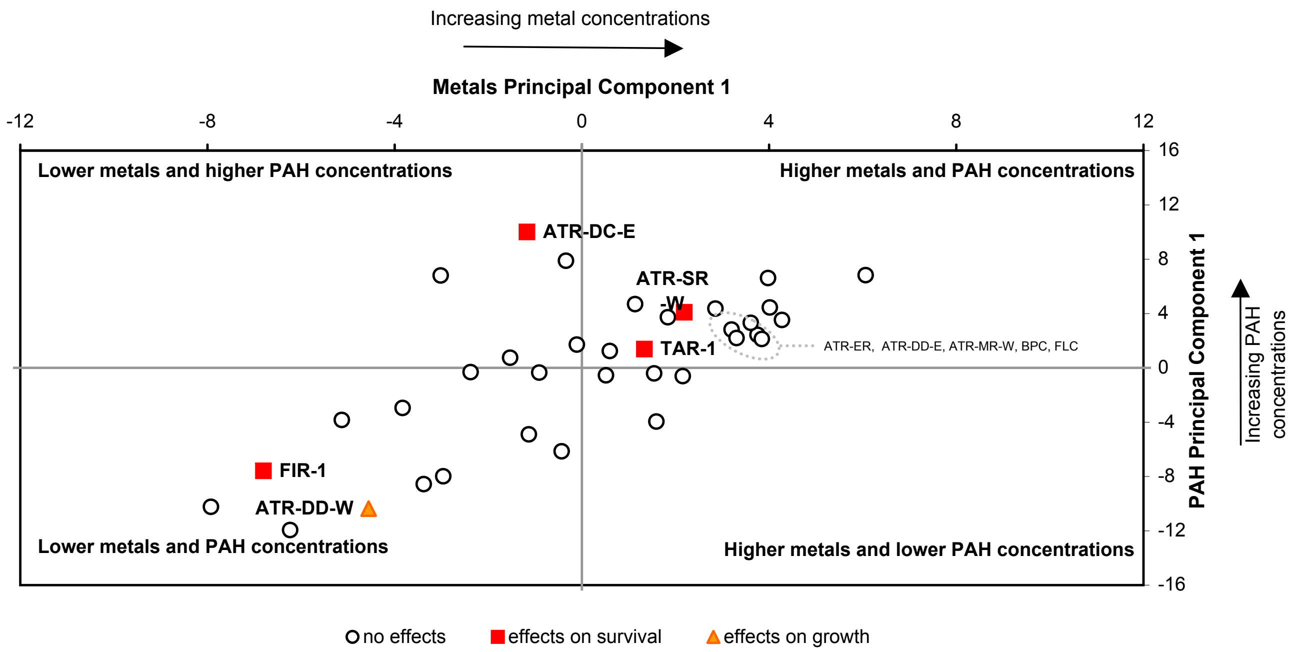
- PAHs were approximately two times higher at ATR-UFM in 2003 than in 2002, its only previous year of sampling by RAMP;
- Station ATR-DC-E (Athabasca River upstream of Donald Creek, east bank) exhibited historically high TRH and concentrations of some PAHs

relative to previous years (historical high for TRH at this station: 22,100 in 2002, relative to 39,900 in 2003);

- Shipyard Lake (SHL-1) exhibited historically high values of TRH and some PAHs;

- Ells River (ELR-1) exhibited higher THR, TEH, generally higher PAHs, and higher TOC than in 2002 and 1998, its previous years of sampling.

Figure 4.13 Relationship between physical and chemical characteristics of sediments collected by RAMP in 2003 and survival and growth of *Hyallela azteca*.



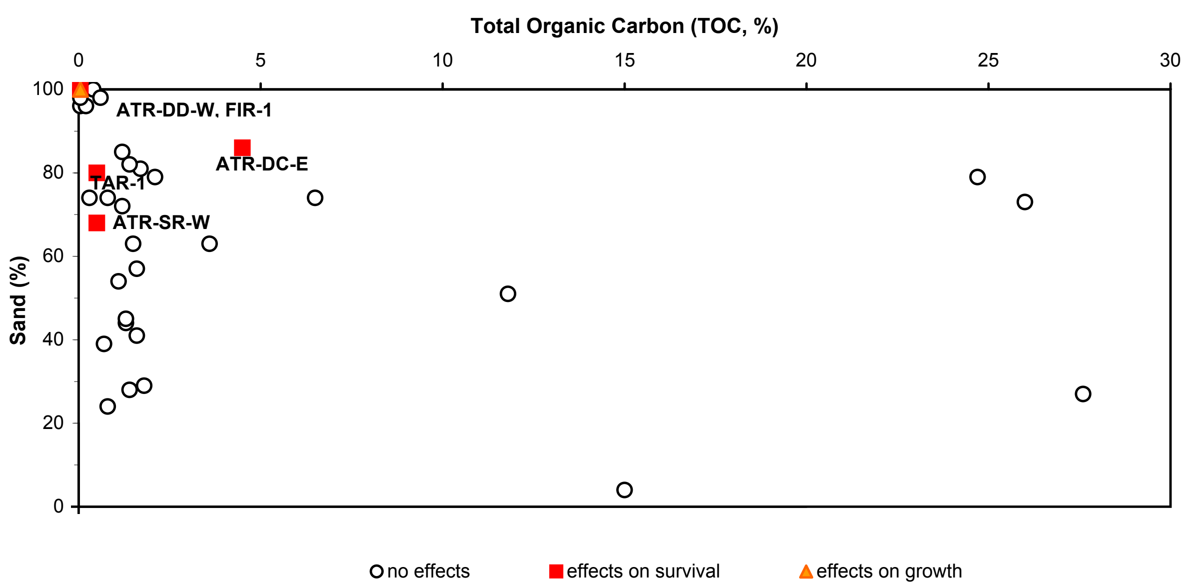
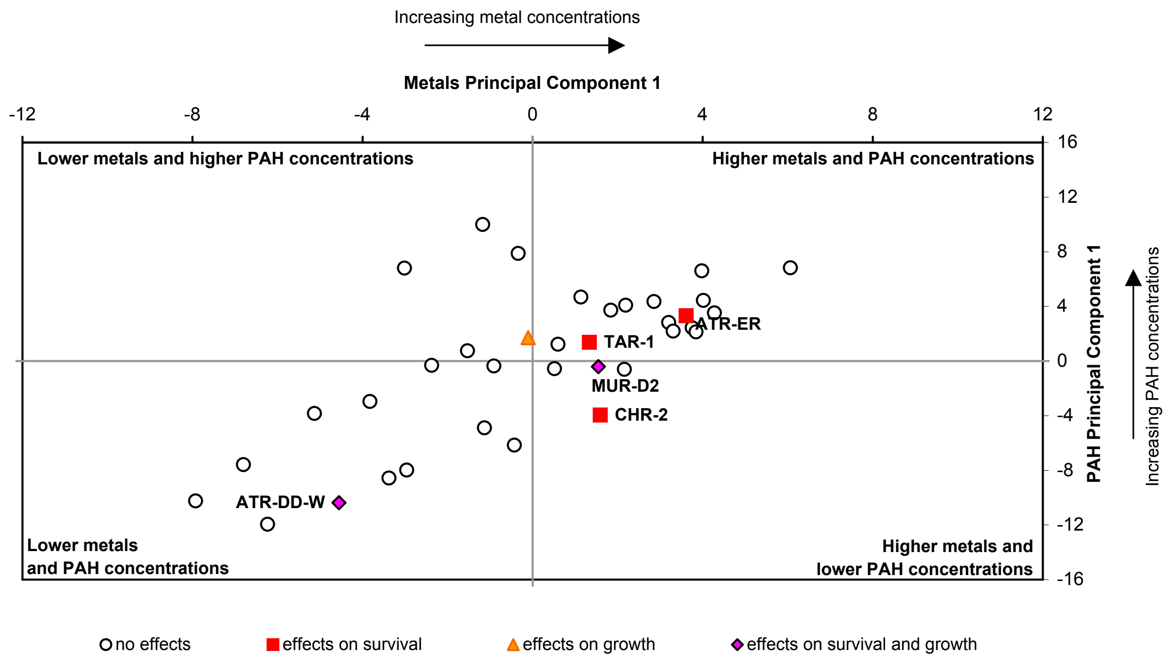


Figure 4.14 Relationship between physical and chemical characteristics of sediments collected by RAMP in 2003 and survival and growth of *Chironomus tentans*.



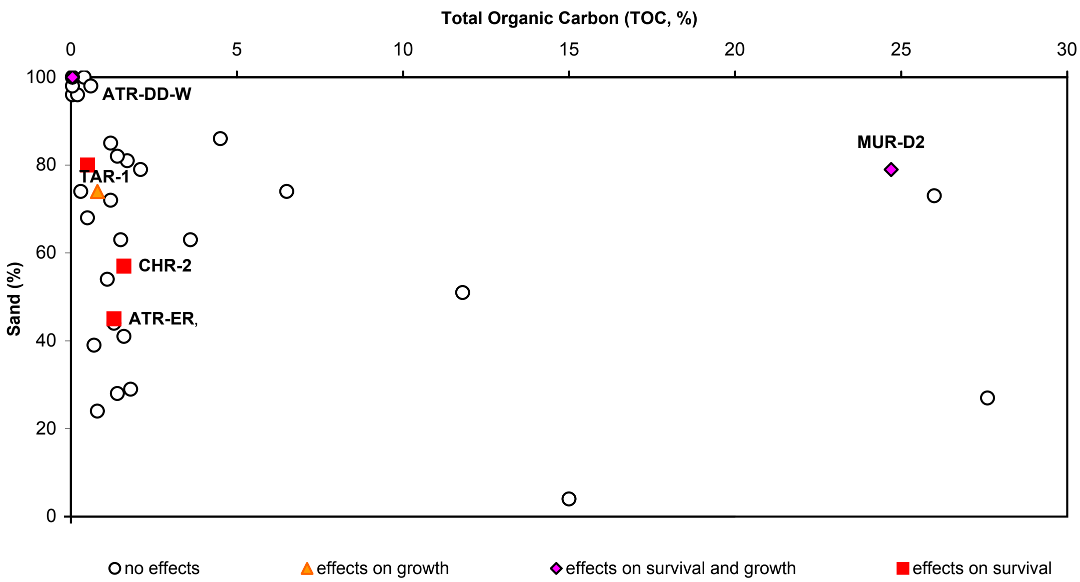
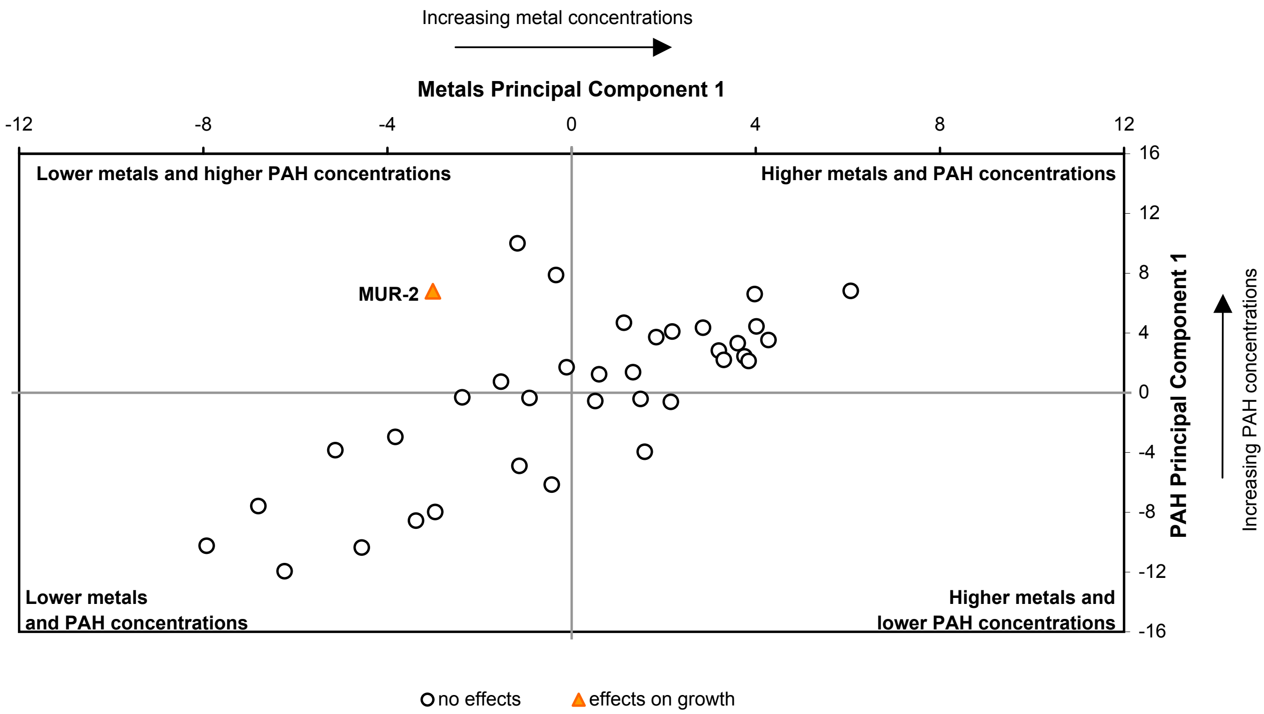
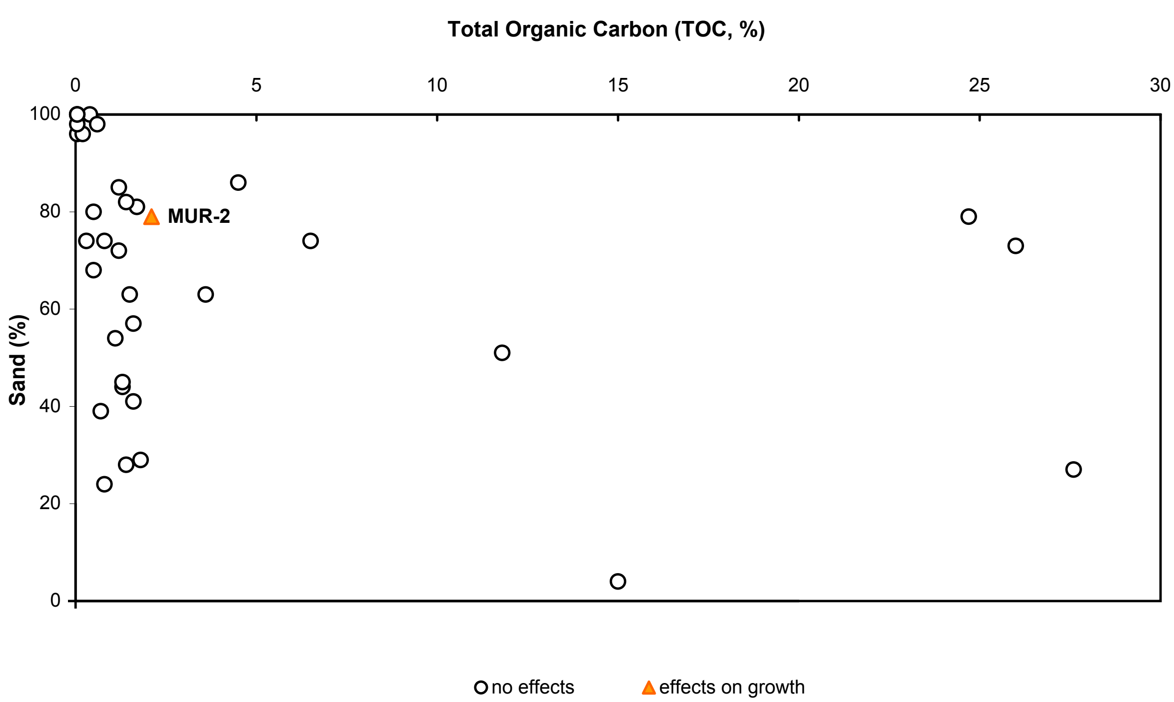


Figure 4.15 Relationship between physical and chemical characteristics of sediments collected by RAMP in 2003 and growth of *Lumbiculus variegatus*.





4.3.9 Values Exceeding Sediment Quality Guidelines

Table 4.7 lists sediment quality values that exceeded CCME interim sediment quality guidelines (ISQG) and/or Probable Effects Levels (PEL) for all stations sampled by RAMP in 2003.

Table 4.7 Sediment quality observations exceeding CCME interim sediment quality guidelines.

Variable	Station	Observed value (µg/g)	CCME Guideline ISQG	PEL
Total metals				
Arsenic (As)	STC-1	18.5	5.9	17
	TAR-1	6.1		
	SHL-1	6.2		
Copper (Cu)	SHL-1	75.4	35.7	197
PAHs				
Pyrene	ATR-DC-E	149	53	875
	ELR-1	59.8		
Chrysene	ATR-DC-E	597	57.1	862
	MUR-2	129		
	ELR-1	170		
Benzo[a]pyrene	ATR-DC-E	73.8	31.9	782
Dibenz[ah]anthracene	ATR-DC-E	38.9	6.22	135
	ATR-SR-W	8.05		
	MUR-2	6.6		
	ELR-1	8.07		
	SHL-1	10.2		

Metals concentrations generally were highest in Shipyard Lake (SHL-1), where levels of arsenic and copper exceeded CCME guidelines. Arsenic also exceeded guidelines at Stanley Creek (STC-1) and Tar River (TAR-1).

There are few established sediment quality guidelines for PAHs. However, some stations exceeded CCME interim sediment quality guidelines for high molecular weight PAHs, including pyrene, chrysene, benzo[a]pyrene, and dibenzo[a,h]anthracene. Station ATR-DC-E exceeded guideline levels for all of these variables, while Ells River (ELR-1) exceeded for all except benzo[a]pyrene. Station MUR-2 (Muskeg River upstream of the Canterra Road crossing) exceeded guidelines for chrysene and dibenzo[a,h]anthracene.

4.4 DISCUSSION

4.4.1 Sediment Quality in the RAMP Study Area

Concentrations of metals were variable among stations surveyed, with particularly high values observed at stations with a high proportion of fine sediment and high carbon content. However, following adjustment for grain size, metals concentrations were generally similar among stations.

Concentrations of PAHs are naturally high in the oil sands region, due to the presence and prevalence of exposed bitumen. Stations exhibiting highest PAHs included the Athabasca River upstream of Donald Creek (east bank) (ATR-DC-E), Stanley Creek (STC-1), Muskeg River upstream of Canterra Road crossing (MUR-2) and Ells River (ELR-1). Following adjustment for organic carbon content, concentrations were highest in the ELR-1, followed by ATR-DC-E, MUR-2, ATR-UFM (Athabasca River upstream of Fort McMurray), CHR-1 (Christina River mouth), and TAR-1.

Given PAH concentrations in Stanley Creek were comprised predominantly of retene, an anaerobic breakdown product of wood debris, the high total PAH concentration observed at this station does not suggest oil sands development as a source for PAHs at this station, unless water discharges to Stanley Creek by Syncrude Canada Ltd., described in the previous Chapter (Water Quality), contain high amounts of retene. Retene may be an effective indicator of hydrocarbons originating from decomposition of plant materials rather than bitumen.

At other stations where high PAHs in sediment were observed, particularly ATR-DC-E and ATR-FC-E, large amounts of exposed bitumen were apparent, which likely contributed to high PAH concentrations observed at these stations. Concentrations of bitumen-related PAHs, particularly dibenzothiophenes, may be good indicators of such sources of bitumen-related PAHs.

Low molecular weight PAHs were found to be strongly, positively correlated with fine sediments, and moderately, strongly correlated with TOC, while high molecular weight PAHs were only weakly correlated with grain size and TOC. HMW PAHs generally are less volatile and soluble than LMW PAHs, and therefore more resistant to weathering than low molecular weight PAHs. This is consistent with observations of PAHs in all sediment types, including those comprised entirely of sand. Sand-sized particles of bitumen were observed in sediments collected at many stations, including most stations along the Athabasca River mainstem, the Muskeg and Clearwater watersheds, and the Ells River. HMW PAHs carried with these particles likely are highly resistant to weathering; these particles likely are carried with bed (and suspended) sediments along river courses, consistent with generally higher proportions of HMW PAHs to LMW

PAHs at downstream stations relative to upstream stations in all river watersheds surveyed. Given HMW PAHs generally are more toxic to aquatic organisms than LMW PAHs, the presence of these HMW compounds in sandy sediments may have contributed to greater observed toxicity to aquatic organisms in sand-dominated samples, which also likely contained greater proportions of HMW PAHs than LMW PAHs.

Generally, sediment quality was highly variable among stations surveyed, with any effects of oil sands development or operations suggested. In the Muskeg River, whose watershed has seen the most oil sands-related development, sediment quality was similar upstream of development (i.e., MUR-6) and at the river's mouth (i.e., MUR-1), and consistent with historical observations. No significant temporal trends were observed in sediments collected from the mouth of the Muskeg River; weak, decreasing trends were observed for all metals and PAHs examined.

4.4.2 RAMP Sediment Quality Component

4.4.2.1 Station Locations

Effective monitoring of sediment quality in the mainstem of the Athabasca River is problematic, given sediments in the river mainstem are predominantly transitional between erosional and depositional (i.e., sand), and are constantly being moved, deposited and remobilized by the river flow. Most stations sampled for sediments in the Athabasca River mainstem by RAMP in 2003 and previous years have been predominantly sand, covered in fall by a thin veneer of finer sediments likely deposited following reduction in river flow after spring freshet. The bulk of this fine fraction likely is remobilized and carried downstream the next year, along with much of the underlying sand. With the exception of a few locations where the presence of larger amounts of fine sediments suggested a continuously depositional environment, it is unlikely that sediments sampled one year are sampled again the next year.

Therefore, the sediment sampling program in the Athabasca River mainstem is not monitoring changes in (i.e., potential accumulation of) sediment-borne chemicals at each station from year to year, but rather monitoring the chemistry of newly-deposited sediments at each station. Given such deposition is governed by dynamics of flow along in the river and along its banks, which are highly variable spatially and temporally, movement and deposition of sediment, particularly fine fractions, may vary significantly even from one bank to another at a given station. This in turn may yield very different sediment quality data for east and west banks of the river at a given location, which has been observed at nearly every sediment sampling station on the Athabasca River mainstem in 2003 and earlier. Such variable results at given locations along the river confound analysis and assessment of potential changes in sediment quality from upstream to downstream locations.

Sampling sediments in areas where deposition and accumulation do not occur does not effectively address the general premise for sampling sediments, namely that specific chemicals of interest (i.e., metals and PAHs) may accumulate in sediments (naturally or due to human activities) to levels that may cause environmental harm. To make the sediment quality monitoring program more effective, the following modifications could be considered:

- Focus sediment quality studies on tributaries to the Athabasca River only, given potential compounds of concern from developments (e.g., sediment-borne metals and PAHs) are likely to be observed first in tributary watersheds experiencing development;

- Focus sediment quality studies on the Athabasca River delta, a truly depositional environment where most sediments carried by the Athabasca River accumulate, using trends in sediment quality in the delta as an indicator of quality of sediments being carried from the Athabasca River upstream; and/or

- Relocate sediment collection stations on the Athabasca River mainstem to known areas of sediment deposition, with subsequent sampling stations located *downstream* of tributaries expected to experience development, rather than upstream as currently exists, so that potential effects of tributary inputs on Athabasca River sediment quality may be more effectively monitored.

A modified RAMP sediment quality program could adopt one or all of these strategies to make sediment monitoring more effective and meaningful. A program that focused more directly on the Athabasca River delta would also benefit from a single year of more intensive sampling at each station, with sufficient replication to quantify local spatial variability and provide a context for evaluation of future data. Sediment cores also could be collected from delta stations to examine changes in sediment deposition rates and chemistry over the past several decades. Relocation of stations in the Athabasca River mainstem to depositional areas would first require a comprehensive survey to identify and map such depositional areas in the mainstem.

4.4.2.2 Sediment Quality Variables

The RAMP 5-year review suggested monitoring of PAHs could possibly be eliminated, given most PAHs were positively correlated with TRH. However, a more detailed assessment of the presence and distribution of individual PAHs in sediments among stations in 2003 suggests that the distribution of individual PAHs varies among stations in important ways, particularly with respect to the behaviour of low and high molecular weight PAHs, and that the concentrations of many PAHs do not correlated strongly or directly with TRH or TEH. Further, specific PAHs such as retene and dibenzothiophene may be good indicators of specific sources of petroleum hydrocarbons measured at given stations. Therefore, continued measurement of individual PAHs and alkylated PAHs is warranted, although perhaps not on an annual basis.

TRH and TEH were general indicators of the presence of petroleum hydrocarbons. However, these variables were too coarse to discriminate the nature of petroleum hydrocarbons at different stations. These measures are no longer widely used for measuring environmental concentrations of hydrocarbons in soil or sediment, partly for this reason (R. Zolkewski, ETL, *pers. comm.*). To generate more meaningful results and collect data that are consistent and comparable with other studies of hydrocarbons in soil and sediment, RAMP should consider replacement of TRH, TEH and TVH variables with the CCME four-fraction hydrocarbon scan (CCME 2001a), a recently adopted standard test that measures hydrocarbons in four fractions: C6 to C10 (F1), C10 to C16 (F2), C16-C34 (F3) and >C34 (F4). In addition to providing more detailed, standardized information, it is possible that four-fraction data could provide sufficient detail and correlation with PAH fractions (particularly LMW and HMW PAHs) that the four-fraction test could supplant detailed PAH scans in future RAMP programs. The four-fraction end-points have the added advantage of having associated CCME soil/sediment quality guidelines, which TRH, TEH and TVH do not.

4.4.2.3 Sediment Toxicity Tests

Where sediment toxicity tests indicated reduced survival or growth of test organisms, such results were correlated more clearly with physical characteristics of sediment than metals or PAH concentrations in sediments. Survival of the amphipod *Hyallela azteca* was more clearly related to fine sediment grain sizes and organic carbon content than metals or PAH concentrations. Similarly, growth of *Chironomus* was also clearly associated with grain size, with survival being lowest in sand substrates. Although *Chrionomus* growth also was positively associated with metals concentrations (i.e., metals PC1), this likely is an artifact of inter-correlation, given metals concentrations were higher in fine sediments than in sand.

The 10-day *Lumbriculus variegatus* survival and growth test is inappropriate for the RAMP program, given: (a) survival results are not useable due to persistent problems with organism breakage in sandy sediments; (b) there is no formally accepted method for this test (i.e., it follows a 28-day ASTM method that is truncated to 10 days to agree with exposure periods of other tests); (c) *Lumbiculus* is a terrestrial organism; and (d) observed effects of exposure to RAMP sediments on *Lumbriculus* growth could not be related to any physical or chemical characteristics of sediment. Given two other measures of sediment toxicity (i.e., *Hyallela* and *Chrinonomus*) exist in the program for which results are more clearly indicative of sediment quality, elimination of the *Lumbriculus* test from the RAMP testing protocol would not reduce useful data available to the program, and would a generate substantial savings (i.e., of $800/test) to the program.

5.0 BENTHIC INVERTEBRATE COMMUNITY

5.1 OVERVIEW OF 2003 PROGRAM

A total of 26 locations were sampled in 2003 for the benthic invertebrate sampling program, including 22 river reaches, three stations in the Peace-Athabasca Delta and three lakes (Table 5.1, Figure 5.1). Of the 20 river reaches sampled, six were newly established in 2003. These new reaches were added in key tributaries to characterize benthic communities in upstream control areas. Two additional river reaches, both on the Steepbank River, could not be sampled in 2003 due to unusually high river flows that made sampling unsafe.

Table 5.1 Summary of the Fall 2003 Benthic Invertebrate Sampling Program.

Waterbody	Location Sampled	Sample Code	Habitat	Sample Date
Athabasca Delta	Big Point Channel	BPC-1 to BPC-10	Depositional	Sept 11
	Fletcher Channel	FLC-1 to FLC-10	Depositional	Sept 10
	Goose Island Channel	GIC-1 to GIC-10	Depositional	Sept 11
Calumet River	lower reach	CAL-D-1 to CAL-D-15	Depositional	Sept 14 & 16
	upper reach[1]	CAL-D-16 to CAL-D-20	Depositional	Sept 20
Christina River	lower reach	CHR-D-1 to CHR-D-15	Depositional	Sept 19
	upstream of Janvier	CHR-D-16 to CHR-D-30	Depositional	Sept 6
Clearwater River	downstream of Christina River	CLR-D-1 to CLR-D-15	Depositional	Sept 7
	upstream of Christina River	CLR-D-16 to CLR-D-30	Depositional	Sept 18
Ells River	lower reach	ELR-D-1 to ELR-D-15	Depositional	Sept 15 & 20
	upper reach[1]	ELR-E-1 to ELR-E-15	Erosional	Sept 22
Firebag River	lower reach[1]	FIR-D-1 to FIR-D-15	Depositional	Sept 13
	upper reach[1]	FIR-E-1 to FIR-E-15	Erosional	Sept 14
Fort Creek	lower reach	FOC-D-1 to FOC-D-5	Depositional	Sept 13
Jackpine Creek	lower reach	JAC-D-1 to JAC-D-15	Depositional	Sept 21
	upper reach[1]	JAC-D-16 to JAC-D-30	Depositional	Sept 19
MacKay River	lower reach	MAC-E-1 to MAC-E-15	Erosional	Sept 12 & 13
	upper reach	MAC-E-16 to MAC-E-30	Erosional	Sept 17
Muskeg River	lower reach	MUR-E-1 to MUR-E-15	Erosional	Sept 8,15,16, 20
	low to mid-reach	MUR-D-1 to MUR-D-15	Depositional	Sept 11
	upper reach	MUR-D-16 to MUR-D-30	Depositional	Sept 21
Steepbank River	lower reach	STR-E-1 to STR-E-15	Erosional	Not sampled*
	upper reach[1]	-	-	Not sampled*
Tar River	lower reach	TAR-D-1 to TAR-D-15	Depositional	Sept 16 & 17
	upper reach[1]	TAR-E-1 to TAR-E-15	Erosional	Sept 16
Kearl Lake	10 samples throughout lake	KEL-1 to KEL-10	Depositional	Sept 10
McClelland Lake	10 samples throughout lake	MCL-1 to MCL-10	Depositional	Sept 14
Shipyard Lake	10 samples throughout lake	SHL-1 to SHL-10	Depositional	Sept 9

* not sampled in 2003 due to unsafe flow conditions.

[1] new station in 2003

5.2 METHODS

5.2.1 Station Locations

As in previous years, samples were collected in the dominant habitat type found in each reach (Table 5.1). This method was followed for new sampling reaches in 2003. Habitats were defined as being either depositional (i.e., dominated by fine sediment deposits and with low to no current) or erosional (i.e., dominated by rocky substrates and with frequent riffle areas). Most tributaries in the study area are predominately depositional, with some variation within watercourses. Erosional reaches were sampled in the lower Muskeg River, lower and upper MacKay River, the upper Tar River, the upper Ells River, and the upper Firebag River. Several reaches exhibited predominantly sandy substrates, which are generally transitional between erosional and depositional habitats; for purposes of this study, predominantly sandy habitats were classified as depositional.

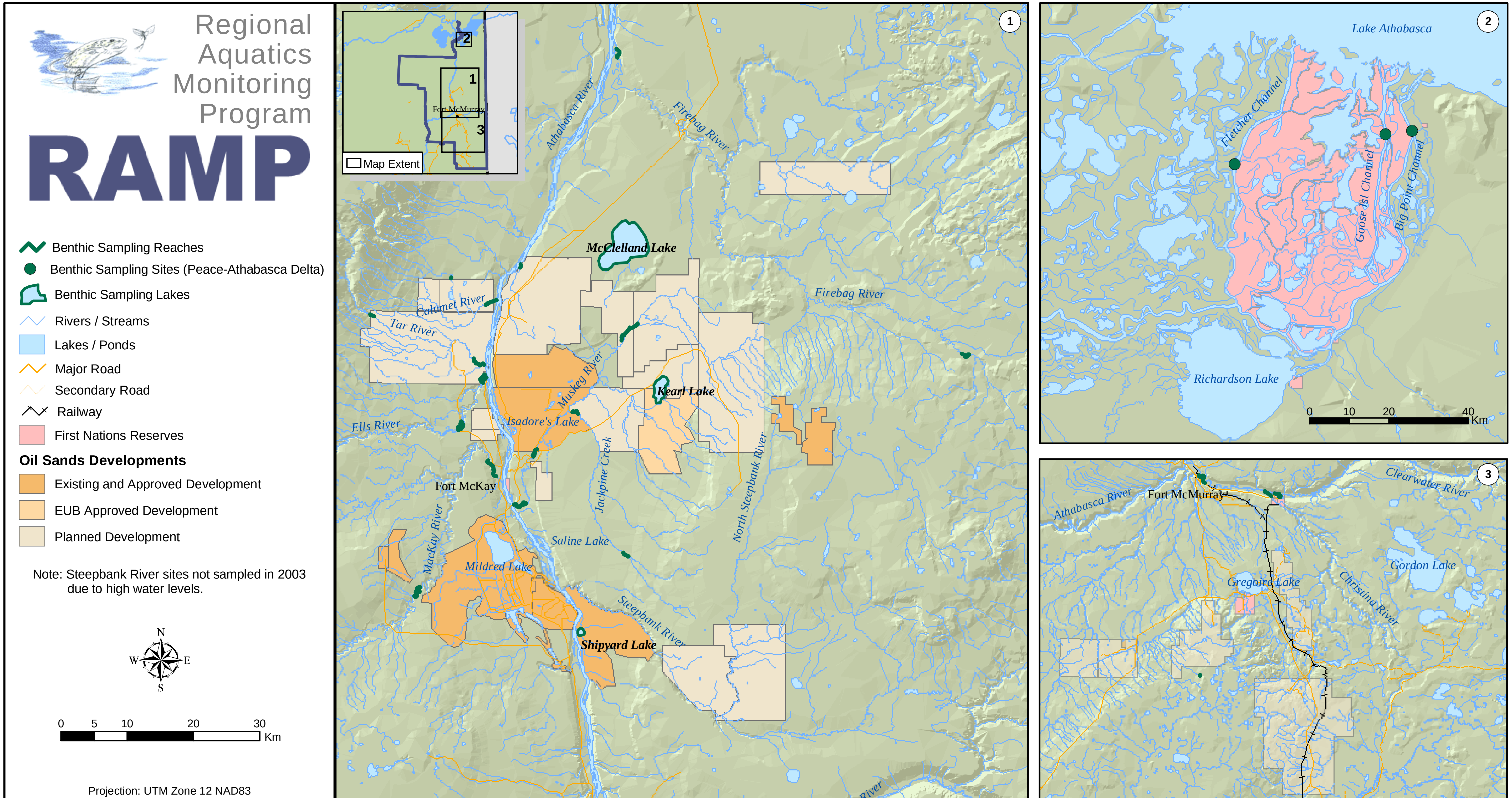
Habitats reaches were selected that were representative of the dominant habitat in given sections of river. The rationale for this approach is that by collecting replicate samples throughout a predetermined river reach, the range of benthic invertebrate communities present may be established. Selection of individual replicate samples was based on habitat suitability/availability and access (e.g., helicopter landing sites). In smaller reaches, a minimum of 50 m separated replicate samples.

Two reaches on the Steepbank River were not sampled in 2003 due to unseasonably high flow conditions, which prevented field crews from safely entering the water. The reach at the Steepbank River mouth had been sampled in previous years and was scheduled to be re-sampled. The upstream reach in the Steepbank River was to be established and sampled for the first time in 2003. Flow conditions were monitored through the remainder of the fall season with the hope of completing the sampling; however, high water levels persisted and sampling was not possible. These stations will be sampled in 2004 as planned.

5.2.2 Field Methods

The benthic field program was conducted from September 4 to 22, 2003. Benthic invertebrates were collected according to standard methods used in previous years (Golder 2003b). A Neill-Hess cylinder (0.093 m^2 opening and 210 μm mesh) was used to sample invertebrates in erosional areas. In depositional habitats, a pole-mounted Ekman grab (0.023 m^2, 6″ x 6″) was used. In lakes greater than 1 m deep, the 6″ x 6″ Ekman grab was deployed using a rope and messenger from the surface.

Figure 5.1 Location of 2003 Benthic Invertebrate Sampling Reaches, Stations and Lakes.



Data Sources:
National Topographic Data Base (NTDB) obtained from the Centre for Topographic Information - Sherbrooke, used under license. Oil Sands Development Areas derived from CEMA Development Scenario GIS Mapping Database and Oil Sands Lease Boundaries from Alberta Government.

Mxd: G:\DATA\PROJECTS\RAMP1069\GIS\Fig5-1_Benthic2003.mxd
Last Modified: 2/18/2004 12:07:36 PM

In rivers, a total of 15 replicate samples were collected from within each established reach. Reaches were typically 2 to 4 km of river distance in length. Samples were selected randomly from within the reach, based on habitat availability. In lakes and wetlands (i.e., Shipyard Lake, Kearl Lake and McClelland Lake), a total of 10 replicate samples were randomly selected within each lake at depths between 1.5 m to 3 m. Five replicate samples were collected at each of the three stations in the Peace-Athabasca Delta. Depositional samples were sieved in the field using a 250 μm screen, preserved in 10% buffered formalin and bottled for transport. As in previous years, Dr. Jack Zloty (Calgary, AB) performed sorting and taxonomic identification of all benthos samples.

A series of physical measurements were recorded as supporting information from each replicate station. These measurements are identical to those recorded in previous RAMP sampling years, including:

- Wetted and bankfull channel widths: visual estimate (for rivers/streams only);
- Field water quality measurements: dissolved oxygen (±0.1 mg/L), conductivity (±1 μS/cm) and temperature (±0.1 ˚C) measured using a YSI85 multi-meter. pH (±0.1 units) was measured using a WTW Set 2 pH meter. All instruments were calibrated daily;
- Current velocity (±0.1 m/s): measured using a Marsh-McBirney current velocity meter or a Swoffer Model 2100 current velocity meter;
- Water depth (±0.01 m): measured from the graduated wading rod associated with each current velocity meter;
- Amount of benthic algae at erosional stations (for chlorophyll *a* measurement): obtained by scraping a 2 cm x 2 cm square from three randomly selected rocks and combined into one composite sample per station;
- Substrate particle size distribution (erosional stations only): visual estimates of areal coverage by particles in standard size categories using the modified Wentworth classification system (Cummins 1962), and expressed as percentages;
- Geographical position: using a hand-held Magellan Global Positioning System (GPS) unit; and
- General station appearance (bank stability, presence of macrophytes, qualitative assessment of periphyton level, level of substrate embeddedness.

All laboratory analyses were conducted by Enviro-Test Laboratories Ltd. (ETL) in Edmonton, AB.

5.2.3 Laboratory Methods

Benthic samples were sieved in the laboratory using a 250 µm mesh sieve to remove preservative and any remaining fine sediments. Material retained by the sieve was elutriated using a flotation technique to separate organic material from sand and gravel, and invertebrates from organic material. Samples containing bitumen were treated with paint thinner to remove hydrocarbons prior to sorting. Inorganic material was scanned under a magnifying lens and any remaining invertebrates were removed before discarding. The remaining organic material was separated into coarse and fine size fractions using a 1 mm sieve. The fine size fraction of large samples was subsampled using a method based on that described by Wrona *et al.* (1982). Invertebrates were removed from the detritus under a dissecting microscope. All sorted material was preserved for random checks of removal efficiency. A detailed description of the methods used by Dr. Jack Zloty for invertebrate sorting and identification is presented in Appendix A5.1.

Invertebrates were identified using recognized taxonomic keys (Brooks and Kelton 1967, Teskey 1969, Edmunds *et al.* 1976, Oliver and Roussel 1983, Currie 1986, Wiederholm 1986, McCafferty and Randolph 1988, Stewart and Stark 1988, Brinkhurst 1989, Pennak 1989, Clifford 1991, Merritt and Cummins 1996, Westfall and May 1996, Wiggins 1996, Zloty and Pritchard 1997, Epler 2001). Organisms were identified to the lowest practical level, typically genus, with the exception of oligochaete worms which were identified to family. Small, early-instar or damaged specimens were identified to the lowest level possible, generally family.

5.2.4 Data Analyses

Taxonomic and water/sediment quality summaries were generated for all river and lake samples collected in 2003, averaged across sample locations for each reach/lake. The distribution of abundance across taxa was also averaged for each sample reach or lake. Percent of the total samples represented by the EPT taxa (Ephemeroptera – mayflies, Plecoptera – stoneflies, and Trichoptera – caddisflies) was also determined for each sampling location. Aquatic larvae or nymphs of these insect families are generally considered to be sensitive to pollution (e.g., Gaufin 1973, Bode *et al.* 1996); other taxa, such as tubificid worms, are generally considered to be pollution-tolerant. Taxa present at each station or reach studied in 2003 by RAMP were classified where possible with regard to their perceived sensitivity to pollution, from sensitive to tolerant, following classifications outlined by Bode *et al.* (1996), which allowed further characterization of habitat quality in reaches or stations surveyed.

Although such classifications provide insight into habitat quality at given locations, it is important to note that the presence or abundance of sensitive or tolerant species is also determined largely by availability of appropriate habitats. Many pollution-sensitive species, such as EPT, generally thrive only in erosional habitats that exhibit sufficient flow, large enough substrate to provide interstitial spaces or clinging habitats, low temperature, high dissolved oxygen, etc. (Merritt and Cummins 1984). Similarly, several pollution-tolerant taxa, particularly tubificid worms, thrive naturally in depositional areas with fine sediments (Terrell and Bergersen 2003), and are more tolerant of high organic matter and lower dissolved oxygen (Thorp and Covich 1991), and other sediment and water quality characteristics that often are associated with polluted stream environments. Such conditions often occur naturally in slow-flowing, impounded, or lentic aquatic habitats, including several stations surveyed by RAMP in 2003 located in undeveloped watersheds.

For each sample, the following general descriptors of community composition were calculated:

- Abundance (total number of individuals/m^2);
- Taxon richness (number of distinct taxa);
- Simpson's Diversity Index (D), where,

$$D = 1 - \sum (p_i)^2 \qquad [1]$$

and, p_i is the proportion that taxon i contributes to the total number of invertebrates in a sample.

- Evenness, where,

$$\text{Evenness} = \frac{D}{D_{max}} \qquad [2]$$

$$D_{max} = 1 - \left(\frac{1}{S}\right) \qquad [3]$$

and, S is the total number of taxa in the sample. In situations where S = 1 (i.e., only one taxon was identified in a sample), evenness was set to 1.

Abundance, richness, diversity and evenness were determined for each sample location and then averaged to reach or lake level. The indices were computed for all RAMP data dating from 1998 onward to evaluate trends in these measures over time. Indices were plotted graphically by reach. All data were reported as means ±1 standard deviation (SD), representing the range about the mean over which ~68% of observations can be expected to lie.

Differences in benthic community indices (abundance, richness, diversity, evenness) between reaches in 2003 were evaluated with *t*-tests in systems where only two reaches were sampled (Calumet, Christina, Clearwater, Ells, Firebag, Jackpine, MacKay and Tar Rivers). Analysis of variance and planned comparisons (Hoke *et al.* 1990) were used to test for differences between reference and impact reaches in systems where three reaches were sampled (Muskeg River) and for the lakes. These analyses focused only on systems where there is current or planned development within the drainage basin that may impact the benthic community.

Correspondence Analysis (CA) was used to summarize variations in community composition among stations and years for the lake and river systems where there is current potential for impact from oil sands development. As such, CAs were conducted separately for the three river systems, the Muskeg River, the MacKay River, the Christina River and the Clearwater River. Correspondence analysis is more useful than some ordination methods because it automatically ordinates both the samples and the taxa. The CA ordination procedure is designed to calculate a set of theoretical (synthetic) variables (axes) that best explain the variations in abundances of taxa across samples. Calculation of sample and taxa scores on the first ordination axis is done by iteratively estimating the weighted average sample scores and the weighted average taxa scores. For the first iteration, axis scores are arbitrarily assigned to each taxon. For each sample, the procedure determines the weighted average axis score, which is the average of the taxa scores weighted by the abundances of each taxon. The next iteration produces new weighted average axis scores for the taxa, calculated from the sample scores. The iterative procedure continues until there is little change in the sample and taxa scores. Estimation of the second and third ordination axes follows a similar routine, except that the sample scores of additional axes area made orthogonal (uncorrelated) with the first and other axes. Sample scores in the CA are usually scaled to have a mean of zero and standard deviation of 1 (ter Braak 1992).

The distribution of samples in a CA diagram indicates the relative similarities and differences in composition based on taxa abundances. Samples with similar scores will have taxa in similar proportions, while samples with different scores will have taxa in different proportions. The scatter diagram for taxa portrays the dispersion of taxa along the theoretical variables (axes). Thus, a sample with an axis-1 score of 2 would be dominated by those taxa that also had axis-1 scores close to 2.

With CA, the configuration of ordination diagrams tends to be sensitive to rare taxa (Gauch 1982). Therefore, only those taxa found in at least 10% of samples from a system were retained for the analysis. Taxa abundances were log-transformed prior to analysis. The CA was conducted using an Excel add-in (Biplot 1.1 2002). We did not include data collected from systems in 1998 because of poor station correspondence and different sampling strategies in that year.

5.2.5 Changes from the 2002 Study

Six reaches on five rivers were added to the 2003 study. These included the upper reaches of the Tar, Ells, Calumet, Jackpine and Firebag rivers, and the lower reach of the Firebag River. An additional station in the Steepbank River (upper reach) was planned for 2003, however, unseasonably high discharges made it impossible to sample both the new upper reach and the previously sampled lower reach.

5.3 RESULTS

Results of the benthic invertebrate monitoring survey are discussed here according to waterbody and river reach. Particular attention is paid to habitat characteristics and benthic community measures for data collected in 2003, but trends in abundance, richness, diversity and evenness since 1998 are also plotted where available. RAMP data from 1997 were not included in these analyses given all stations sampled in 1997 were located along the mainstem Athabasca River and did not correspond to current study stations. Raw benthic invertebrate data for 2003 are presented in Appendix A5.2. Supporting information from each location (i.e., habitat measurements, field water quality results) is presented in Appendix A5.3.

5.3.1 Kearl, McClelland and Shipyard Lakes

Lakes sampled as part of the RAMP monitoring program were similar in terms of habitat characteristics (Table 5.2). Sampling sites were selected at consistent depths (mean depth range from 1.7 to 2.0 m). Water temperature and pH were generally uniform across the lakes. Conductivity was highest in Shipyard Lake and lowest in Kearl Lake. Dissolved oxygen was low in Shipyard Lake, and below the Canadian Environmental Quality Guideline range for the preservation of aquatic life of 5.5 to 9.0 mg/L (CCME 2002); whereas dissolved oxygen was higher and above the recommended guidelines in Kearl and McClelland Lakes. Sediments of Shipyard Lake consisted primarily of silt and clay, with low sand content (8%) and low total organic carbon (9%) compared with other lakes surveyed. By comparison, the sediments of Kearl Lake had higher sand content (14%) and total organic carbon (36%), but were still dominated by silt and clay. The sediments of McClelland Lake were more evenly distributed across the three fractions of sand, silt and clay, and total organic carbon in the sediments was high (39%).

Shipyard Lake has been monitored within the RAMP framework since 2000 and, as such, provides the longest historical record among the lakes monitored. With the exception of 2002, mean abundance in Shipyard Lake was consistently below ~10,000 individuals/m² (Figure 5.2). Abundances were similarly low in Kearl and McClelland lakes for years in which these lakes were sampled. Mean taxonomic richness in the three lakes varied between 4 and 14 taxa, and richness was most variable among years in Shipyard Lake. Diversity and evenness were quite similar among lakes and years, with the exception of Shipyard Lake in 2001 that had low diversity and evenness. Excluding the 2001 Shipyard Lake sample, diversity varied between ~ 0.6 and 0.8, and evenness varied between ~ 0.75 and 0.9 among the lakes and years. Richness in 2003 was significantly lower in Shipyard Lake than in Kearl and McClelland Lakes ($p = 0.009$, Table 5.3). There were no significant differences in abundance, diversity, or evenness among Shipyard (exposed) and Kearl and McClelland (reference) lakes in 2003.

Table 5.2 Habitat characteristics of Kearl, McClelland, and Shipyard Lakes, 2003.

Variable	Units	Kearl Lake	McClelland Lake	Shipyard Lake
Sample date	-	Sept. 10, 2003	Sept. 14, 2003	Sept. 9, 2003
Habitat	-	Depositional	Depositional	Depositional
Water depth	m	1.7 (1.3 – 2.1)	2.0 (1.6 – 2.7)	2.0 (2.0 – 2.2)
Macrophyte cover	%	-	-	-
Field Water Quality[1]				
Dissolved oxygen	mg/L	6.2 (5.5 – 6.9)	9.0 (8.4 – 9.4)	3.6 (3.2 – 4.0)
Conductivity	µS/cm	174 (170 – 178)	254 (252 – 256)	424 (418 – 426)
pH		7.2 (7.1 – 7.3)	n/a	7.3 (7.3 – 7.4)
Water temperature	EC	16.0 (15.9 – 16.0)	14.2 (13.9 – 14.6)	16.7 (16.3 – 17.2)
Sediment Composition				
Sand	%	14.2	39.4	8.2
Silt	%	34.8	28.8	39.7
Clay	%	51.4	39.8	52.0
Total Organic Carbon	%	36.4	38.9	8.8

[1] Mean value (minimum – maximum)

Table 5.3 Analysis of variance of benthic community indices (abundance, richness, diversity, evenness) among lakes in the oil sands region in 2003.

	SS	df	F	p
Abundance				
Among lakes	8.62×10^7	2	1.666	0.208
Exposed vs Reference	8.47×10^7	1	3.276	0.081
Error	6.98×10^8	27		
Richness				
Among lakes	223	2	4.558	0.020
Exposed vs Reference	194	1	7.939	0.009
Error	661	27		
Diversity				
Among lakes	0.059	2	1.014	0.376
Exposed vs Reference	0.026	1	0.911	0.348
Error	0.784	27		
Evenness				
Among lakes	0.009	2	0.164	0.849
Exposed vs Reference	0.006	1	0.210	0.650
Error	0.747	27		

Note: df = degrees of freedom, SS = sum of squares, F = F ratio, p = probability of no significant effect.

The benthic community of each lake was generally comprised of chironomids, amphipods, bivalves, ostracods and worms (Table 5.4). The CA of the lake benthos demonstrated apparent separation of lakes based on dominant taxa (Figure 5.3). Shipyard Lake in 2001 and 2003 had high CA Axis 1 scores, reflecting higher relative abundances of *Chaoborus*, *Chironomus* and *Valvata* sp. Shipyard Lake in 2000 and 2002 had similar CA Axis 1 scores relative to Kearl and McClelland lakes, but high CA Axis 2 scores, reflecting higher relative abundances of *Psectrocladius*, *Caenis*, *Armiger crista*, *Paratanytarsus*, *Dicrotendipes*, and Naididae. By comparison, Kearl and McClelland Lakes in all sampling years tended to have low CA Axis 1 scores and low to intermediate CA Axis 2 scores, reflecting higher relative abundances of *Microtendipes*, *Einfeldia*, *Cryptochironomus*, *Pseudochironomus*, *Stylaria*, *Procladius*, the amphipod *Hyalella azteca*, and the bivalves *Pisidium/Sphaerium*. Kearl Lake was unique in having Trichoptera (*Mystacides* and *Polycentropus*). Chironomids in Kearl Lake were also dominated by the relatively tolerant forms *Glyptotendipes* and *Microtendipes*. McClelland Lake was unique in having high numbers of the relatively tolerant ephemeropteran mayfly *Caenis*. Dominant chironomids in McClelland Lake included *Polypedilum*, *Procladius* and *Ablabesmyia*, all of which are relatively tolerant to disturbance. Shipyard Lake did not exhibit any EPT taxa, but did contain phantom midges (Chaoboridae). Chironomids in Shipyard Lake were represented by only *Chironomus* and *Procladius*.

In general, the benthic community of Shipyard Lake was less diverse than either Kearl or McClelland Lakes. The composition of the benthic community in Shipyard Lake demonstrated substantial year-to-year variability relative to the other lakes (Figure 5.3). Some (e.g., Underwood 1994) consider an increase in temporal variation in indices of composition to be a significant indicator of stress.

Table 5.4 Mean, standard deviation (SD), percent abundance and summary statistics for major taxa in Kearl, McClelland and Shipyard lakes, 2003.

Taxon	Kearl Lake			McClelland Lake			Shipyard Lake		
	Abundance no./m^2	SD	% Abundance	Abundance no./m^2	SD	% Abundance	Abundance no./m^2	SD	% Abundance
Hydra	0	0	0	9	0	<1	0	0	0
Nematoda	0	0	0	52	0	1	43	0	3
Glossiphoniidae	4	0	<1	0	0	0	4	0	<1
Erpobdellidae	0	0	0	4	0	<1	0	0	0
Enchytraeidae	65	152	1	0	0	0	0	0	0
Naididae	250	554	5	810	1,009	17	0	0	0
Tubificidae	0	0	0	47	274	1	43	0	3
Lumbriculidae	0	0	0	9	0	<1	0	0	0
Hydracarina	4	0	<1	4	0	<1	0	0	0
Ostracoda	103	448	2	177	178	4	112	100	7
Copepoda	0	0	0	0	0	0	172	0	11
Chydoridae	9	0	<1	0	0	0	0	0	0
Daphniidae	4	0	<1	0	0	0	0	0	0
Amphipoda	1,586	1,523	30	405	343	8	69	324	5
Bivalvia	336	421	6	478	678	10	52	224	3
Gastropoda	0	0	0	4	0	<1	108	424	7
Ephemeroptera	0	0	0	151	417	3	0	0	0
Trichoptera	56	74	1	0	0	0	0	0	0
Zygoptera	0	0	0	9	0	<1	0	0	0
Chaoboridae	0	0	0	0	0	0	444	339	29
Ceratopogonidae	4	0	<1	0	0	0	13	0	1
Chironomidae	2,944	2,180	55	2,664	904	55	470	293	31
EPT	56	74	1	151	417	3	0	0	0
Total Abundance	5,366	7,496	100	4,823	4,558	100	1,530	782	100
Richness	8.3	5.9		10.7	6.1		4.1	1.5	
Simpson's Diversity	0.63	0.12		0.71	0.18		0.61	0.20	
Evenness	0.79	0.12		0.81	0.16		0.83	0.21	

Note: EPT: sum of Ephemeroptera, Plecoptera and Trichoptera taxa

Figure 5.2 Benthic community measures (means ± SD) of abundance, richness, diversity and evenness in Kearl, McClelland and Shipyard lakes from 2001 – 2003.

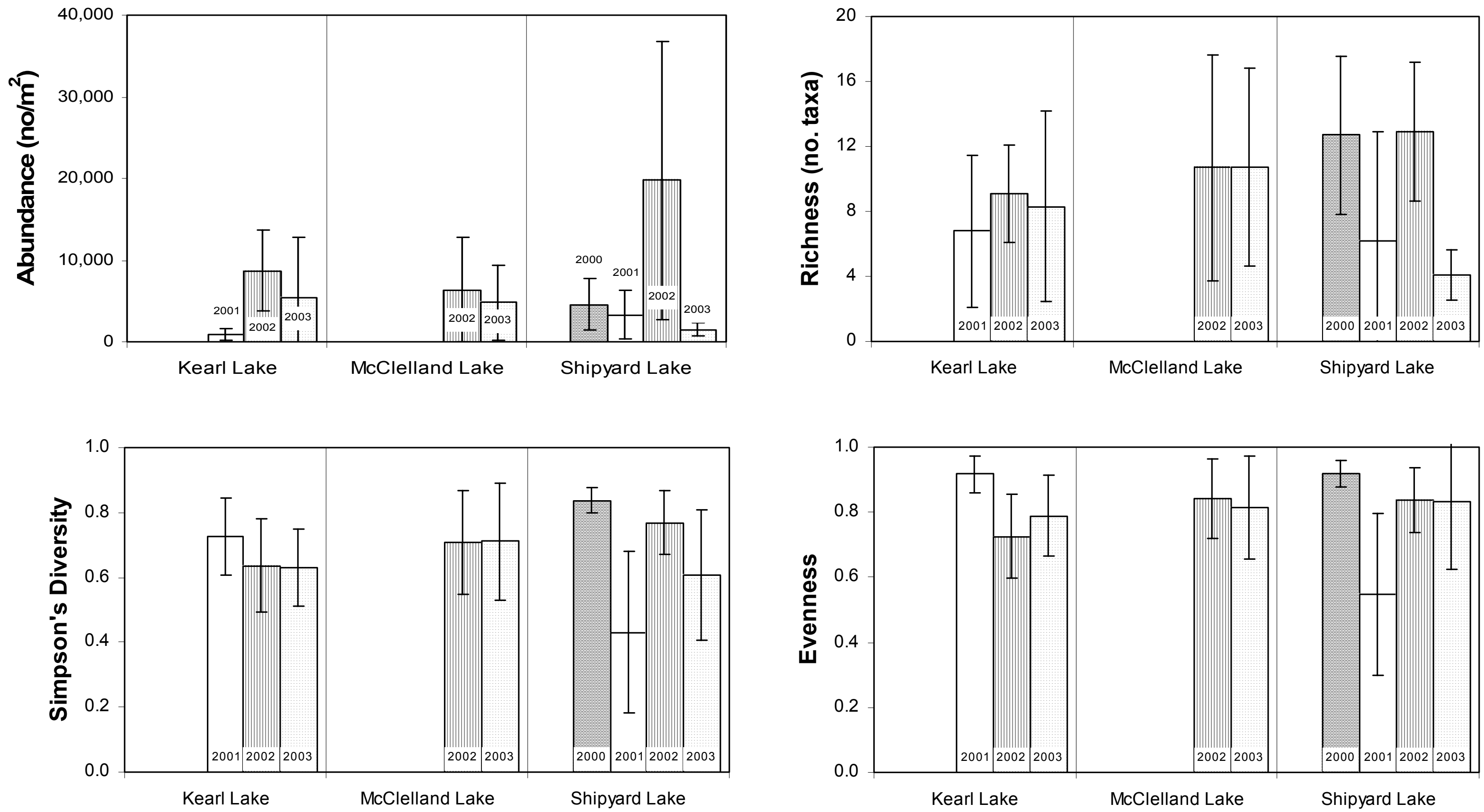
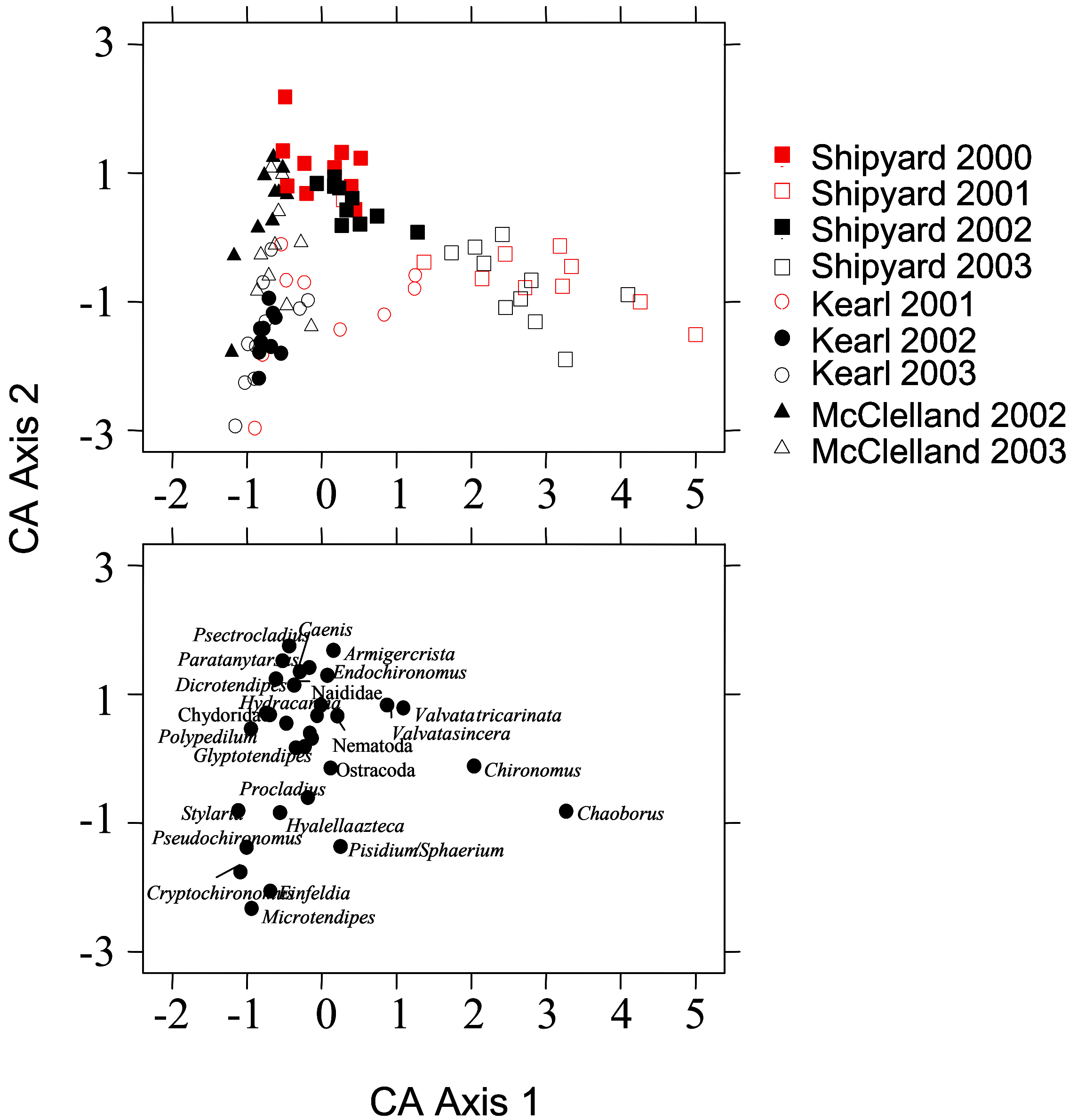


Figure 5.3 Ordination diagrams for Shipyard, Kearl and McClelland lakes from 2000 to 2003.



Note: The distribution of lakes in ordination space is plotted in the upper panel and taxa in the lower panel.

5.3.2 Peace-Athabasca River Delta

The three channels of the Peace-Athabasca Delta (PAD) selected for analysis of benthic invertebrate samples in 2003 were similar in terms of habitat characteristics (Table 5.5). All three stations were in depositional habitats with depths of 0.3 to 1.5 m and sediments consisting predominantly of sand and silt. Current velocity was low; field water quality measures (i.e., dissolved oxygen, conductivity, pH, and temperature) were similar among stations.

Benthic communities from the three PAD stations were similar and reflected the slow current velocities and fine substrates present. Invertebrate abundance in the PAD sampling stations was uniformly low in 2003, averaging approximately 10,000 individuals/m^2 (Table 5.6). The biggest difference in abundance between 2002 and 2003 was in Goose Island Channel, where abundance declined by >30,000 individuals/m^2. Taxonomic richness was also lower in 2003 than 2002 in Goose Island Channel, but was approximately equal across the three channels sampled in 2003. In contrast, Simpson's diversity and evenness increased in 2003 relative to 2002 in both Goose Island and Fletcher Channels. Diversity and evenness were lower in Big Point Channel than in Goose Island and Fletcher Channels in 2003 (Figure 5.4).

Invertebrate samples in Big Point Channel in 2003 were dominated by the Tubificidae (75%), Bivalvia (10%) and Chironomidae (6%), whereas the dominant taxa in Fletcher Channel were the Tubificidae (26%), Naididae (15%), and Gastropoda (14%) (Table 5.6). Bivalvia and Chironomidae were also quite abundant (13% each) in Fletcher Channel. In Goose Island Channel, the dominant taxa were Chironomidae (28%), Tubificidae (27%), and Ceratopogonidae (18%). The most abundant chironomids, gastropods, and bivalves at the three reaches were *Procladius*, *Probythinella* and the *Pisidium/Sphaerium* group, respectively. Percent EPT at the three reaches was uniformly low (0-1%) (Table 5.6).

Table 5.5 Habitat characteristics of depositional stations in the Peace-Athabasca Delta, 2003.

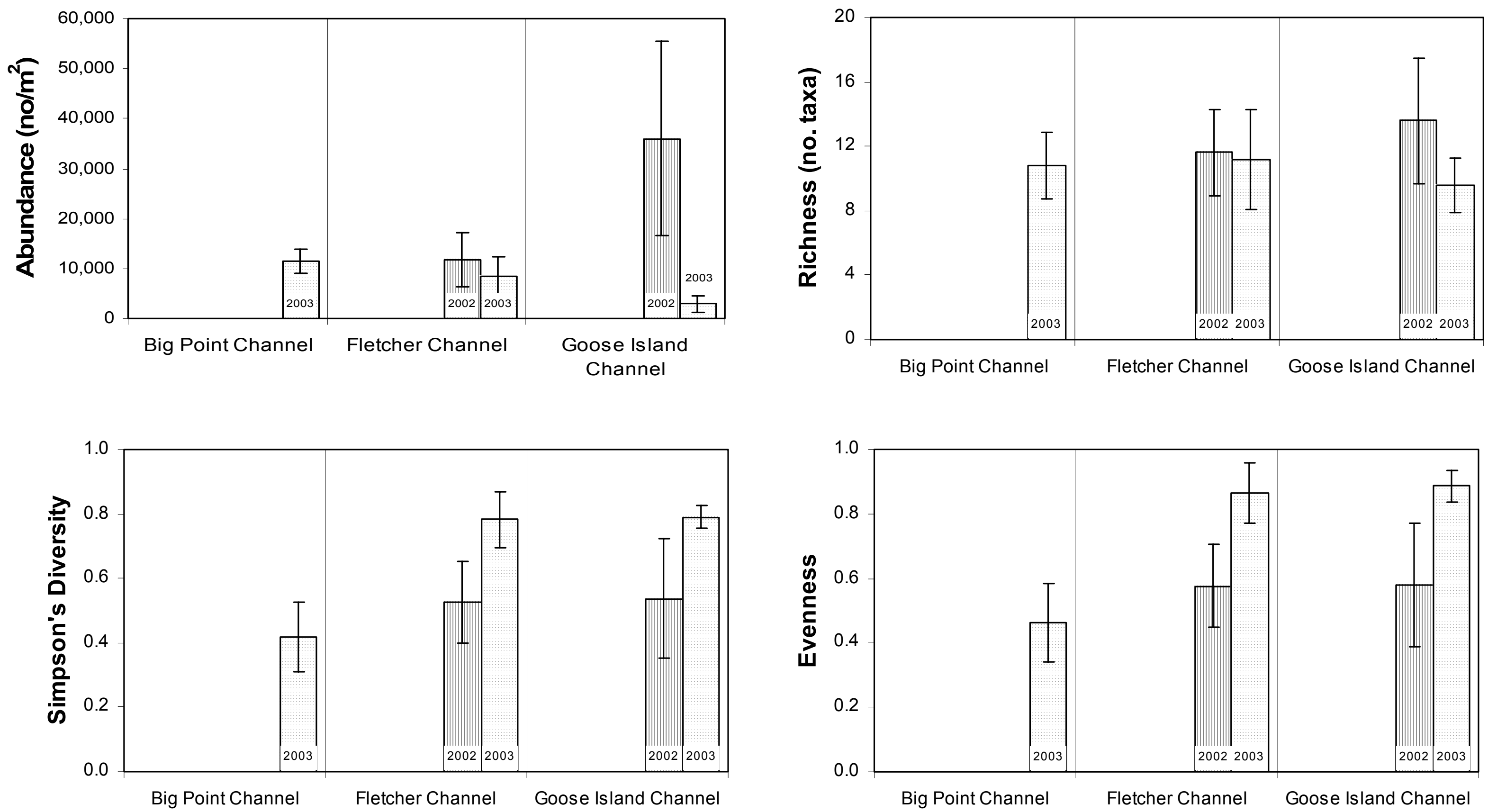
Variable	Units	Big Point Channel	Fletcher Channel	Goose Island Channel
Sample date	-	Sept. 11, 2003	Sept. 10, 2003	Sept. 11, 2003
Habitat	-	Depositional	Depositional	Depositional
Water depth	m	0.3	1.5	1.5
Current velocity	m/s	0	0.1	0.1
Field Water Quality				
Dissolved oxygen	mg/L	8.6	9.4	8.6
Conductivity	μS/cm	280	300	300
pH	-	7.6	7.6	7.6
Water temperature	EC	16.6	16.0	16.6
Sediment Composition				
Sand	%	39	44	29
Silt	%	45	38	51
Clay	%	16	18	20
Total Organic Carbon	%	0.7	1.3	1.8

Table 5.6 Mean, standard deviation (SD), percent abundance and summary statistics for major taxa in the Peace-Athabasca Delta, 2003.

Taxon	Big Point Channel			Fletcher Channel			Goose Island Channel		
	Abundance no./m^2	SD	% Abundance	Abundance no./m^2	SD	% Abundance	Abundance no./m^2	SD	% Abundance
Nematoda	17	0	<1	448	850	5	0	0	0
Naididae	112	138	1	1,233	2,850	15	0	0	0
Tubificidae	8,698	2,460	75	2,181	963	26	776	649	27
Lumbriculidae	0	0	0	0	0	0	9	0	<1
Hydracarina	17	0	<1	0	0	0	9	0	<1
Ostracoda	17	0	<1	155	149	2	276	498	9
Macrothricidae	0	0	0	0	0	0	69	0	2
Bivalvia	1,207	625	10	1,121	757	13	121	127	4
Gastropoda	414	231	4	1,155	437	14	310	350	11
Ephemeroptera	43	91	<1	60	100	1	0	0	0
Trichoptera	95	274	1	34	25	<1	0	0	0
Anisoptera	17	0	<1	26	0	<1	9	0	<1
Heteroptera	9	0	<1	9	0	<1	9	0	<1
Tipulidae	9	0	<1	0	0	0	0	0	0
Tabanidae	0	0	0	26	30	<1	0	0	0
Ceratopogonidae	155	86	<1	819	514	10	509	480	17
Chironomidae	741	191	6	1,060	328	13	819	231	28
EPT	138	183	1	95	69	1	0	0	0
Total Abundance	11,552	2,463	100	8,328	3,889	100	2,914	1,675	100
Richness	11	2		11	3		10	2	
Simpson's Diversity	0.42	0.11		0.78	0.09		0.79	0.04	
Evenness	0.50	0.10		0.90	0.10		0.90	0.00	

Note: EPT: sum of Ephemeroptera, Plecoptera and Trichoptera taxa

Figure 5.4 Benthic community measures (means ±SD) of abundance, richness, diversity and evenness in the Peace-Athabasca Delta, 2002 – 2003.



5.3.3 Tributaries East of the Athabasca River

5.3.3.1 Clearwater River Watershed

Clearwater River

The Clearwater River reaches were generally similar in terms of habitat type (depositional), water depth (0.3 m at both reaches), current velocity (0.1 – 0.2 m), and all field water quality measures except water temperature, which was much higher at the downstream station (i.e., 16.8°C vs. 9.1°C). Macrophyte cover was relatively high at the upstream reach (29%) relative to the downstream reach (2%). Sediment composition at both reaches was similar, with low total organic carbon (<1%) and high sand content (>75%, Table 5.7).

Communities varied in composition from upstream to downstream in the Clearwater River. Abundance of benthic invertebrates in the Clearwater River ranged from less than 10,000 individuals/m^2 to ~35,000 individuals/m^2 at both upstream and downstream stations from 2001 to 2003 (Figure 5.5). Abundance was highest in 2001 at the downstream station and highest in 2002 at the upstream station, but all abundances fell within the ranges of the standard deviations. Richness was slightly higher at the upstream station than the downstream station in all three sampling years, and richness was lower in 2003 than in the other two years at both stations. The same trend was apparent for diversity. Evenness was approximately the same among years at the upstream station and slightly more variable at the downstream station. Richness, diversity, and evenness were significantly lower at the downstream station than the upstream station of the Clearwater River in 2003 ($p=0.034$, Table 5.8). Abundance was also lower at the downstream station in 2003, but the difference was not significant ($p=0.06$).

Correspondence analysis of invertebrate abundance data in the lower and upper reaches of the Clearwater River from 2001 to 2003 revealed little separation among reaches and years (Figure 5.6). Lower reaches in 2003 tended to have lower Axis 2 scores than upper reaches reflecting higher relative abundances of chironomids like *Paracladopelma* and *Stempellinella*, and lower relative abundances of the snail *Valvata triculata* and *Stagnicola*, or the chironomid *Tribelos*. The downstream community was dominated by Chironomidae (80%) including *Polypedilum*, *Robackia* and *Rheosmittia* (Table 5.9). Tubificidae were also dominant with other worms (naidids, lumbriculids), nematodes, and bivalves less abundant. Mayflies were rare but included *Ametropus neavei* and *Caenis*. The upstream community was dominated by bivalves (*Pisidium/Sphaerium*), chironomids (principally *Polypedilum,* but including several others such as *Tribelos*, *Micropsectra/Tanytarsus*, etc.), worms (tubificids and naidids) and ostracods. Eight EPT taxa were found in the upstream reach including the mayflies *Caenis*, *Leptophlebia* and *Siphlopecton*, the stoneflies *Isoperla* and *Pteronarcys*, and the caddisfly *Ceraclea*.

The composition of the benthic community in the lower reach of the Clearwater River was different than the community in the upstream reach in 2003. The observed differences, more chironomids, lower diversity and richness, imply a potential decline in the quality of the aquatic environment, or may be reflective of differences in habitat, such as lower water temperatures and higher macrophyte cover in the upstream reach.

Table 5.7 Habitat characteristics of depositional reaches in the Clearwater River, 2003.

Variable	Units	Clearwater River downstream of Christina River	Clearwater River upstream of Christina River
Sample date	-	Sept 7, 2003	Sept 18, 2003
Habitat	-	Depositional	Depositional
Water depth	m	0.3	0.3
Current velocity	m/s	0.2	0.1
Macrophyte cover	%	2.3	29
Field Water Quality			
Dissolved oxygen	mg/L	8.1	9.7
Conductivity	µS/cm	301	200
pH	-	7.6	7.3
Water temperature	EC	16.8	9.1
Sediment Composition			
Sand	%	76.4	83.5
Silt	%	15.6	12.0
Clay	%	8.1	5.3
Total Organic Carbon	%	0.7	0.9

Table 5.8 Results of *t*-tests of benthic community indices (abundance, richness, diversity and evenness) between upper and lower reaches of the Clearwater River in 2003.

	t	n	p
Abundance	-2.023	30	0.060
Richness	-2.927	30	0.009
Diversity	-2.929	30	0.007
Evenness	-2.282	30	0.034

Note: A negative *t* implies that the upper reach was greater than the lower reach, and vice versa.

Table 5.9 Mean, standard deviation (SD), percent abundance and summary statistics for major taxa in the Clearwater River, 2003.

Taxon	Clearwater River downstream of Christina River			Clearwater River upstream of Christina River		
	Abundance no./m^2	SD	% Abundance	Abundance no./m^2	SD	% Abundance
Hydra	0	0	0	6	0	0
Nematoda	14	30	<1	92	390	1
Glossiphoniidae	0	0	0	11	0	<1
Erpobdellidae	0	0	0	6	0	<1
Enchytraeidae	0	0	0	103	456	1
Naididae	86	228	2	1,371	2,641	10
Tubificidae	721	1,739	14	1,083	3,028	8
Lumbriculidae	3	0	<1	20	0	<1
Hydracarina	0	0	0	29	0	<1
Ostracoda	0	0	0	1,675	4,377	12
Chydoridae	0	0	0	14	0	<1
Daphniidae	0	0	0	29	0	<1
Macrothricidae	0	0	0	29	0	<1
Amphipoda	0	0	0	17	122	<1
Bivalvia	69	270	1	4753	9683	33
Gastropoda	0	0	0	32	42	<1
Ephemeroptera	14	50	<1	52	114	<1
Plecoptera	0	0	0	26	213	<1
Trichoptera	0	0	0	3	0	<1
Anisoptera	6	0	<1	14	91	<1
Coleoptera	0	0	0	3	<1	<1
Heteroptera	0	0	0	3	0	<1
Tipulidae	0	0	0	26	86	<1
Dolichopodidae	0	0	0	6	0	<1
Ephydridae	0	0	0	172	0	1
Ceratopogonidae	17	43	<1	583	1,803	4
Chironomidae	4,092	3,350	80	3,874	2,091	27
Psychodidae	0	0	0	279	1,943	2
Simuliidae	103	0	2	0	0	0
EPT	14	50	<1	80	125	1
Total Abundance	5,126	4,927	100	14,310	16,874	100
Richness	4.5	2.6		10.1	6.9	
Simpson's Diversity	0.4	0.3		0.6	0.2	
Evenness	0.6	0.3		0.8	0.1	

Note: EPT: sum of Ephemeroptera, Plecoptera and Trichoptera taxa

Figure 5.5 **Benthic community measures (means ± SD) of abundance, richness, diversity and evenness in the Clearwater River from 2001 – 2003.**

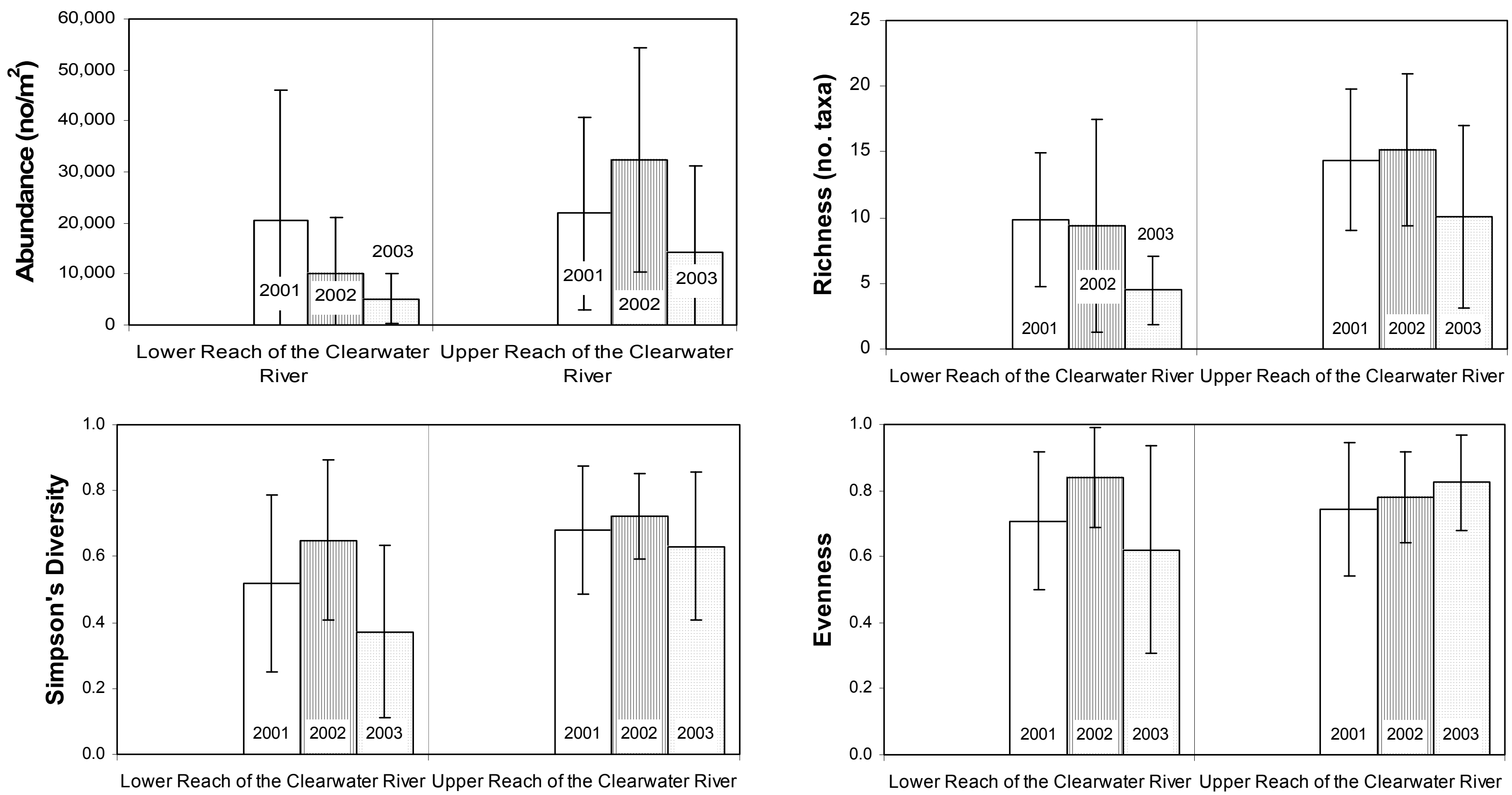
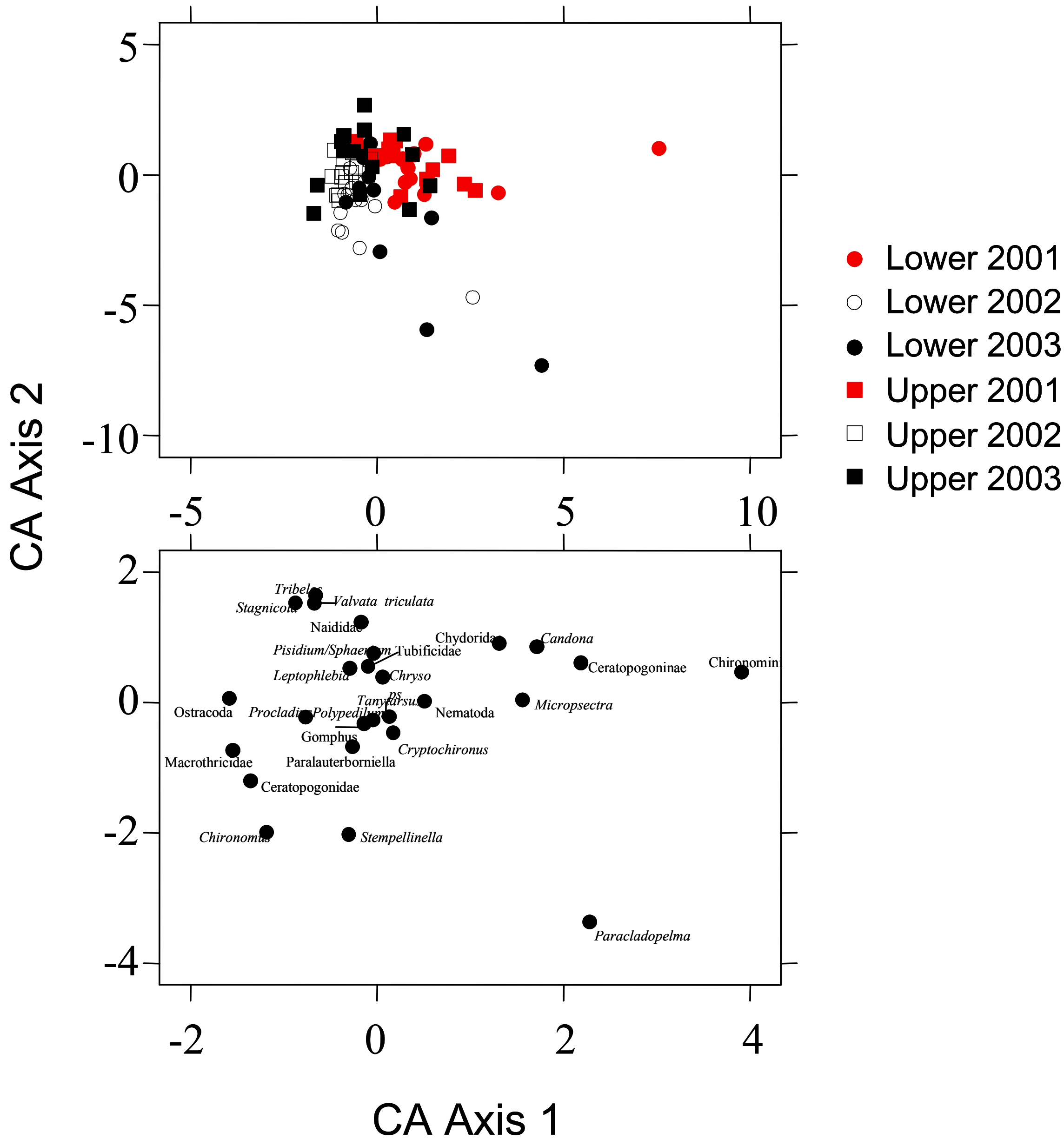


Figure 5.6 Ordination diagrams for the upper and lower reaches of the Clearwater River from 2001 to 2003.



Note: The distribution of reaches in ordination space is plotted in the upper panel and taxa in the lower panel.

Christina River

The upper and lower reaches of the Christina River were depositional in habitat (Table 5.10). Both were relatively shallow (0.2 – 0.3 m), but the upper reach had higher current velocity (0.4 m/s) compared to the lower reach (0.1 m/s). There was no macrophyte cover at the upper reach, and 12 % cover at the lower reach. Dissolved oxygen was similarly high at both reaches (>9 mg/L); conductivity (270 - 319 μS/cm) and pH (7.7 - 7.8) also were similar. Water temperature was cooler at the lower reach relative to the upper reach (i.e., 9°C vs. 16°C), perhaps due to sampling of the lower reach nearly two weeks later in the fall than the upper reach. Upper reach sediments consisted nearly entirely of sand (97.5%) while upper reach sediments exhibited significant silt (19 %) and some clay (10 %) components. Sediments at both reaches were low in total organic carbon (<1%).

The year 2003 was only the second time the Christina River reaches had been sampled as part of the RAMP study. Abundances were lower in 2003 than in 2002, as were richness, diversity and evenness, although the differences in diversity and evenness were comparatively small (Figure 5.7). Richness was significantly higher at the lower reach than the upper reach of the Christina River in 2003 (p=0.02), whereas there were no detectable differences in abundance, diversity and evenness among reaches in the same year (p=0.14, Table 5.11).

Upstream and downstream communities were similar in being dominated by organisms that require depositional habitats (Table 5.12), although naidid and tubificid worms, which may thrive in fine sediments, were nearly absent from the sandy substrates of the upper reach. In 2002, the communities were very similar in composition (Figure 5.8), but there were significant changes in 2003. The downstream community in 2003 had higher relative abundances of several groups, including tolerant forms (i.e., tubificids, 66%), than upstream, which was dominated by chironomids (99%). These differences are reflected in the separation in the CA diagram (Figure 5.8). Sixteen chironomid taxa were collected in the upstream reach, being dominated by *Rheosmittia*, *Polypedilum*, and *Robackia.* There were 18 chironomid taxa in the lower reach, also dominated by *Polypedilum* and *Cryptochironomus*. Ceratopogonidae and Naididae were important in the downstream reach (Figure 5.8). EPT taxa were detected in both reaches and were more abundant in absolute terms in the downstream reach. However, their abundances made up no more than 1% of total abundance at either reach (Table 5.12). Eleven EPT taxa were identified downstream including the mayflies *Ametropis neavei*, *Hexagenia limbata*, *Heptagenia, Tricorythodes* and *Leptophlebia*, stoneflies *Isoperla*, *Taeniopteryx* and *Pteronarcys*, and caddisflies *Brachycentrus, Hydroptilidae* and *Hydropsyche*.

The higher relative abundances of worms in the lower reach in 2003, relative to upstream, may suggest downstream declines in habitat quality between upstream and downstream reaches, or may be reflective of habitat differences, particularly the significant fine sediment fraction in the downstream reach that was not present in the upstream reach. Taxa richness downstream was high, and all the sensitive groups of invertebrates (i.e., EPT) were present.

Table 5.10 Habitat characteristics of depositional reaches in the Christina River, 2003.

Variable	Units	Lower Reach of the Christina River	Upper Reach of the Christina River
Sample date	-	Sept 19, 2003	Sept 6, 2003
Habitat	-	Depositional	Depositional
Water depth	m	0.2	0.3
Current velocity	m/s	0.1	0.4
Macrophyte cover	%	12	0
Field Water Quality			
Dissolved oxygen	mg/L	10.4	9.3
Conductivity	µS/cm	319	270
pH	-	7.7	7.8
Water temperature	EC	9.4	16.1
Sediment Composition			
Sand	%	70.9	97.5
Silt	%	19.5	0.8
Clay	%	9.8	1.9
Total Organic Carbon	%	0.9	0.1

Table 5.11 Results of *t*-tests of benthic community indices (abundance, richness, diversity and evenness) between upper and lower reaches of the Christina River in 2003.

	t	n	p
Abundance	-0.499	30	0.623
Richness	2.506	30	0.021
Diversity	1.527	30	0.138
Evenness	1.162	30	0.255

Note: A negative *t* implies that the upper reach was greater than the lower reach, and vice versa.

Table 5.12 Mean, standard deviation (SD), percent abundance and summary statistics for major taxa in the Christina River, 2003.

Taxon	Lower Reach of the Christina River			Upper Reach of the Christina River		
	Abundance no./m^2	SD	% Abundance	Abundance no./m^2	SD	% Abundance
Nematoda	121	430	1	17	75	<1
Erpobdellidae	3	0	<1	0	0	0
Naididae	494	1,203	5	6	0	<1
Tubificidae	6,701	7,816	66	6	0	<1
Lumbriculidae	3	0	<1	0	0	0
Hydracarina	0	0	0	3	0	<1
Ostracoda	11	0	<1	11	25	<1
Copepoda	6	0	<1	0	0	0
Bivalvia	129	319	1	11	61	<1
Gastropoda	29	183	<1	0	0	0
Ephemeroptera	115	186	1	3	0	<1
Plecoptera	26	36	<1	0	0	0
Trichoptera	9	0	<1	23	61	<1
Anisoptera	32	30	<1	3	0	<1
Heteroptera	3	0	<1	0	0	0
Tabanidae	11	25	<1	0	0	0
Empididae	23	0	<1	0	0	0
Ceratopogonidae	86	86	1	0	0	0
Chironomidae	2,376	1,847	23	12,879	11,120	99
EPT	149	154	1	26	56	<1
Total Abundance	10,178	10,664	100	12,963	18,804	100
Richness	7.9	4.8		4.5	2.1	
Simpson's Diversity	0.51	0.26		0.37	0.24	
Evenness	0.62	0.32		0.49	0.29	

Note: EPT: sum of Ephemeroptera, Plecoptera and Trichoptera taxa

Figure 5.7 Benthic community measures (means ± SD) of abundance, richness, diversity and evenness in the Christina River from 2002 – 2003.

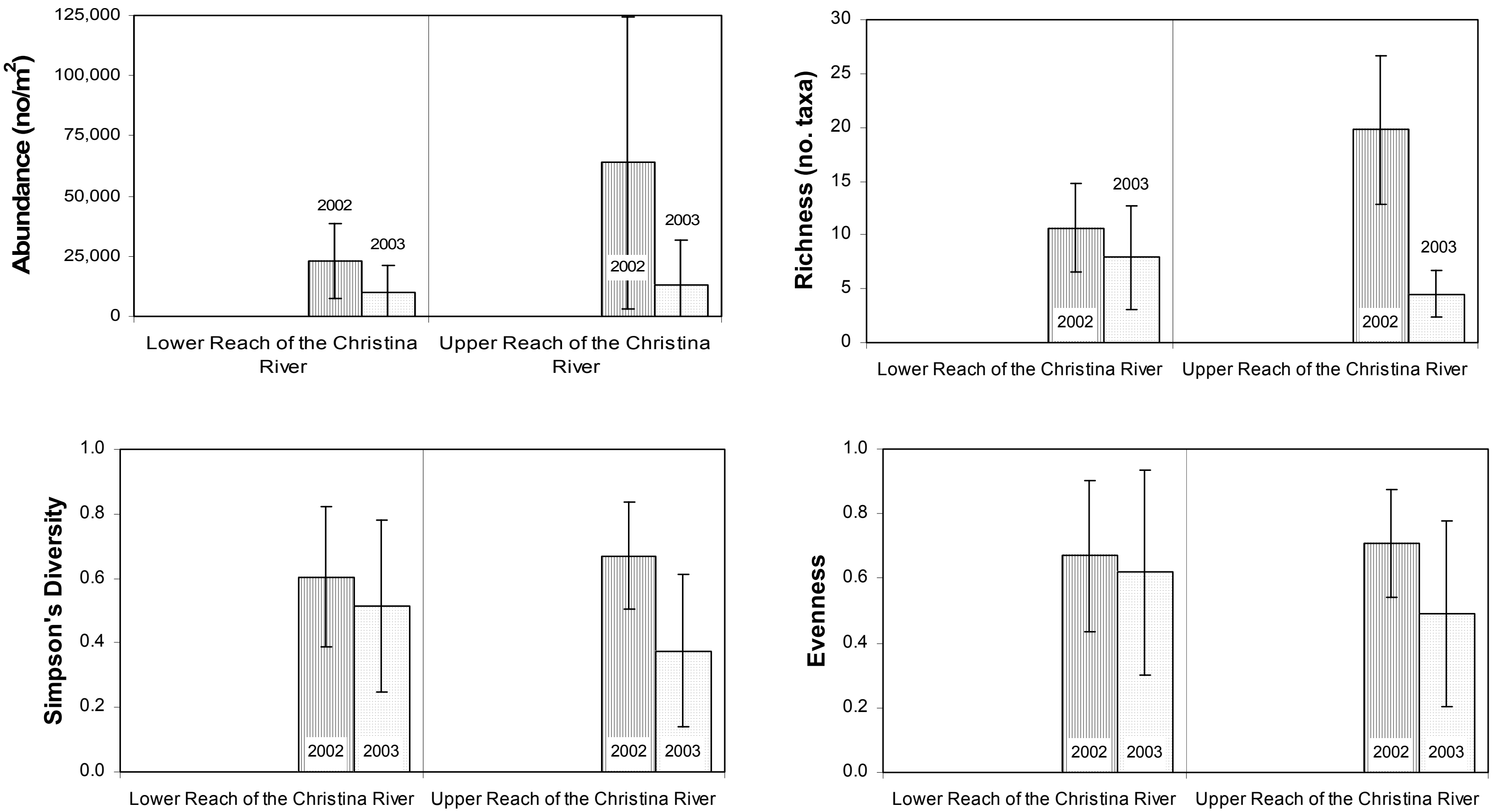
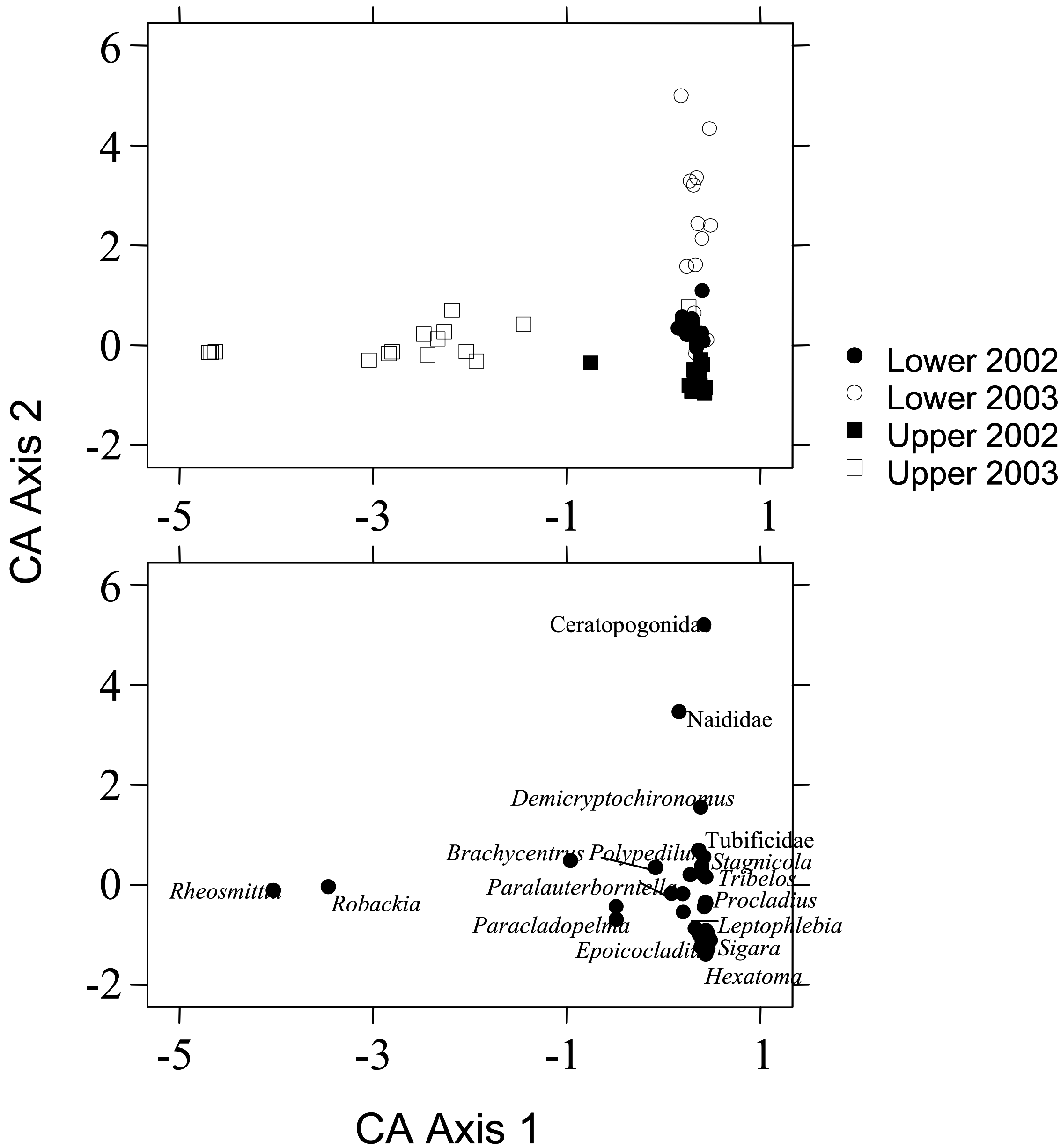


Figure 5.8 Ordination diagrams for the upper and lower reaches of the Christina River from 2001 to 2003.



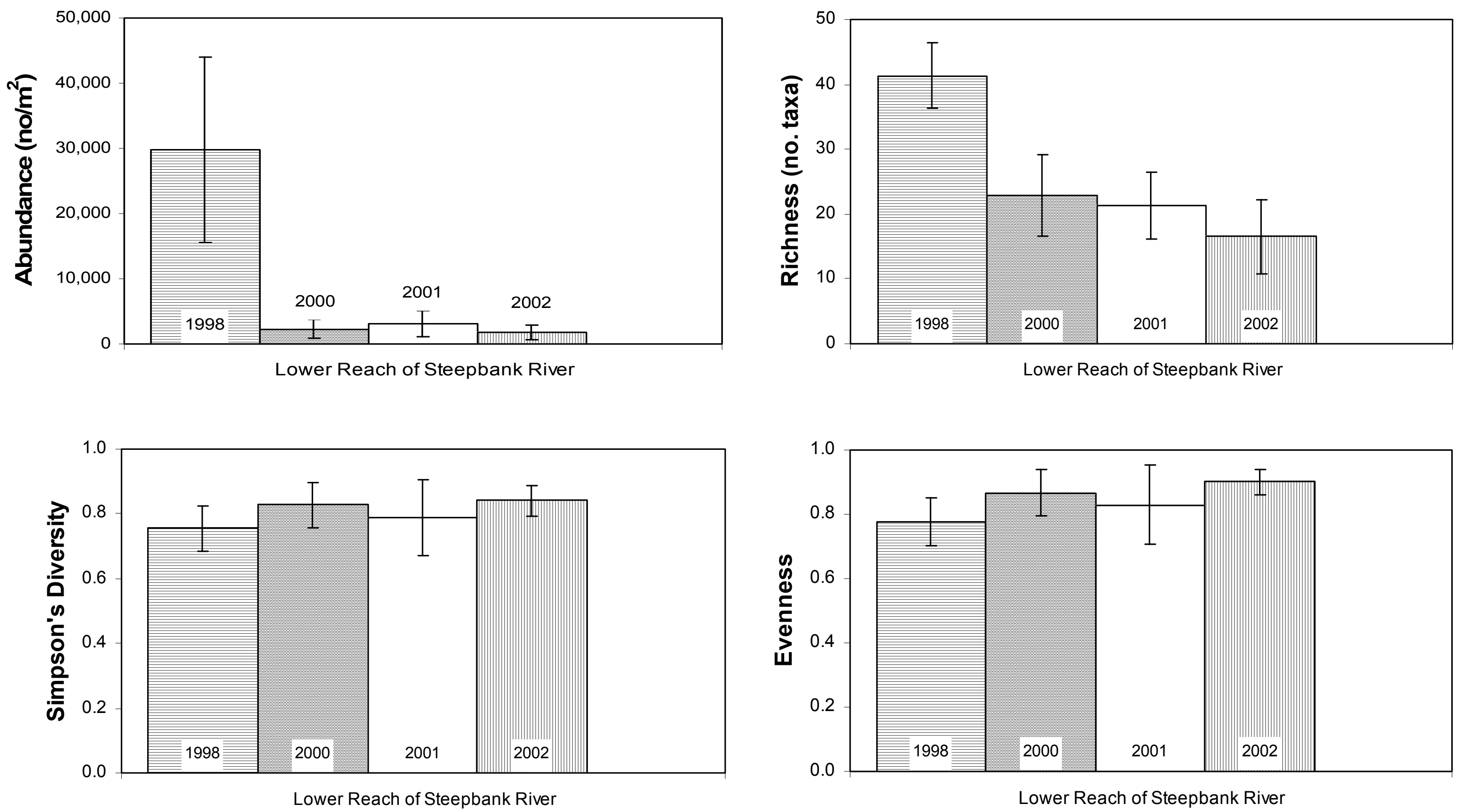
Note: The distribution of reaches in ordination space is plotted in the upper panel and taxa in the lower panel.

5.3.3.2 Steepbank River

It was not possible to evaluate habitat quality or benthic invertebrate abundance, richness, diversity or evenness in the Steepbank River in 2003 due to unsafe sampling conditions. However, temporal trends in invertebrate data (1998 to 2002) were examined.

Abundance and richness were considerably higher and diversity and evenness were slightly lower in 1998 than from 2000 to 2002, possibly because of a different sampling protocol (Figure 5.9). Invertebrate samples in 1998 were taken at three locations within the reach, and five samples were collected and enumerated for each location. Thus, there were only three locations that were intensively sampled in 1998 compared to 15 locations extensively sampled in the other years, which could lead to differences in invertebrate community measures. Looking only at the years 2000-2002, abundance was stable and very low (< 5,000 individuals/m^2) in the Steepbank River, richness ranged from 15 to 22 taxa, and diversity and evenness were consistently high (>0.8) among years.

Figure 5.9 Benthic community measures (means ±SD) of abundance, richness, diversity and evenness in the Steepbank River (lower reach) from 1998 – 2002.



5.3.3.3 Muskeg River Watershed

Muskeg River

The lower reach of the Muskeg River was erosional in nature, shallow (0.2 m), exhibited high current velocity (0.6 m/s) and low macrophyte cover. Benthic algae was low (1.3 mg/m^2) at this station and dissolved oxygen was high (Table 5.13). By comparison the lower to mid reach and the upper reach of the Muskeg River were depositional in nature, had deeper water with slower current velocities, and detectable macrophyte cover. Dissolved oxygen at the upper reach of the Muskeg River was low (3.9 mg/L), below the recommended Canadian water quality guideline for the protection of warm water aquatic life (CCME 2002). Conductivity, pH and water temperature were similar at the three reaches. Substrate in the lower erosional reach consisted mostly of large gravel, and small and large cobble, whereas sediments in the lower to mid reach of the Muskeg River were dominated by sand with low total organic carbon content (<1%). Sediments of the upper reach of the Muskeg were composed of sand (50%), followed by clay (32%) and silt (18%). Total organic carbon was high (24%) in the upper reach compared to the lower to mid reach of the Muskeg River. Habitat differences between different reaches of the Muskeg River likely confound comparisons of benthic communities found in these reaches.

The lower reach of the Muskeg River has been sampled regularly since 1998. With the exception of 1998, abundance has generally been low in the reach (Figure 5.10). Abundance in the lower-to-mid reach has been more variable over time, while abundance in the upper reach in 2002 and 2003 was similar to that of the lower reach. Richness tended to be highest in the lower reach, and gradually declined with distance upstream such that the lower to mid-reach had intermediate richness and the upper reach had lower relative richness. Richness in the lower reach in 1998 was high, likely reflecting different sampling protocols in that year. Diversity and evenness were relatively stable over time and appear to be similar among reaches.

There were no differences in abundance or evenness among reaches of the Muskeg River in 2003. In contrast, richness and diversity were significantly higher in 2003 at the lower reach when compared to the upper reach ($p=0.029$, Table 5.14). No differences in any of the community indices (abundance, richness, diversity and evenness) were detected in 2003 between the lower to mid-reach and the upper reach of the Muskeg River (Table 5.14).

Invertebrate community composition differed among reaches (Figure 5.11) and reflected the physical features of the three reaches. Though all reaches were dominated by chironomids, various differences in community composition among reaches were apparent (Table 5.15). The lower erosional reach of the

Muskeg River was dominated by the chironomids *Micropsectra/Tanytarsus*, *Polypedilum*, *Rheotanytarsus*, and *Saetheria*. The lower reach also separated from the lower-mid and upper reaches because of higher relative abundances of taxa like the Ephemerellidae, Heptageniidae, and genera such as *Isogenoides*, *Brachycentrus*, *Acentrella*, *Pteronarcys*, *Isoperla*, and *Lopescladius*. *Hydracarina* were abundant in the lower reach of the Muskeg River, as were the EPT taxa, consisting primarily of *Baetis* (Ephemeroptera), the Chloroperlidae (Plecoptera), and *Brachycentrus* (Trichoptera).

The lower to mid-reach was similar to the lower reach except that *Parakiefferiella* was abundant and *Rheotanytarsus* was not. The lower to mid and upper depositional reaches of the Muskeg River tended to have higher relative abundances of *Helobdella stagnalis*, *Heterotrissocladius*, *Procladius*, *Caenis*, the Lumbriculidae, Macrothricidae and Planorbidae (Figure 5.11) reflecting slower flow velocities and more depositional habitats. The upper reach was dominated by *Micropsectra/Tanytarsus*, *Procladius* and the Tanypodinae. The clams *Pisidium/Sphaerium* were abundant in the upper reach, as was the mayfly *Letophlebia* (Ephemeropta).

All of the reaches exhibited significant temporal variation, including the upper reach (Figure 5.11). In each reach, the direction of change (i.e., nature of change) was the same (negative along CA axis 2) implying systematic changes in the tributary between 2000 and 2003.

Differences in habitat type among the reaches make it difficult to make specific meaningful spatial comparisons in the tributary. However, as data are collected over time, differences in time trends among reaches may develop, which could be used to assess development-related effects.

Table 5.13 Habitat characteristics of sampling reaches in the Muskeg River, 2003.

Variable	Units	Lower Reach of the Muskeg River	Lower to Mid Reach of the Muskeg River	Upper Reach of the Muskeg River
Sample date	-	Sept 8 – 20, 2003	Sept 11, 2003	Sept 21, 2003
Habitat	-	Erosional	Depositional	Depositional
Water depth	m	0.2	0.5	0.9
Current velocity	m/s	0.6	0.1	0
Macrophyte cover	%	0.3	13.3	14.6
Benthic algae	mg/m^2	1.3	n/a	n/a
Field Water Quality				
Dissolved oxygen	mg/L	9.8	7.6	3.9
Conductivity	µS/cm	314	380	398
pH	-	7.3	7.6	7.3
Water temperature	EC	10.8	13.4	7.5
Sediment Composition				
Sand	%	n/a	92.1	51
Silt	%	n/a	5.1	18
Clay	%	n/a	2.7	32
Total Organic Carbon	%	n/a	0.8	24
Small gravel	%	12.7	n/a	n/a
Large gravel	%	41.0	n/a	n/a
Small cobble	%	37.7	n/a	n/a
Large cobble	%	18.6	n/a	n/a
Boulder	%	5	n/a	n/a
Bedrock	%	0	n/a	n/a

Table 5.14 Analysis of variance of benthic community indices (abundance, richness, diversity, evenness) among reaches of the Muskeg River in 2003.

	SS	df	F	p
Abundance				
Among reaches	3.740×10^7	2	0.231	0.795
Lower vs upper	3.708×10^7	1	0.457	0.503
Low-mid vs upper	6.501×10^6	1	0.080	0.778
Error	3.404×10^9	42		
Richness				
Among reaches	2711	2	23.48	<0.001
Lower vs upper	1718	1	29.75	<0.001
Low-mid vs upper	43.2	1	0.75	0.392
Error	2425	42		
Diversity				
Among reaches	0.265	2	7.78	0.001
Lower vs upper	0.087	1	5.11	0.029
Low-mid vs upper	0.047	1	2.78	0.103
Error	0.716	42		
Evenness				
Among reaches	0.165	2	5.29	0.009
Lower vs upper	0.036	1	2.31	0.135
Low-mid vs upper	0.047	1	2.99	0.091
Error	0.656	42		

Note: df = degrees of freedom, SS = sum of squares, F = F ratio, p = probability of no significant effect.

Table 5.15 Mean, standard deviation (SD), percent abundance and summary statistics for major taxa in the Muskeg River, 2003.

Taxon	Lower Reach of the Muskeg River			Lower to Mid Reach of the Muskeg River			Upper Reach of the Muskeg River		
	Abundance no./m^2	SD	% Abundance	Abundance no./m^2	SD	% Abundance	Abundance no./m^2	SD	% Abundance
Nematoda	388	302	3	420	582	3	276	529	2
Glossiphoniidae	0	0	0	17	25	<1	121	318	1
Erpobdellidae	0	0	0	9	0	<1	3	0	<1
Enchytraeidae	50	73	<1	299	435	2	29	0	<1
Naididae	349	412	3	193	267	2	175	453	1
Tubificidae	124	366	1	302	762	2	247	295	2
Lumbriculidae	22	76	<1	75	0	1	49	224	<1
Hydracarina	1,477	1,283	13	184	274	1	129	371	1
Ostracoda	22	0	<1	0	0	0	158	551	1
Copepoda	22	27	<1	52	240	<1	92	390	1
Chydoridae	0	0	0	6	0	<1	3	0	<1
Daphniidae	0	0	0	11	0	<1	0	0	0
Macrothricidae	0	0	0	0	0	0	29	0	<1
Amphipoda	1	0	<1	72	511	1	135	124	1
Bivalvia	167	155	1	121	197	1	2261	3308	17
Gastropoda	1	0	<1	6	0	<1	75	331	1
Ephemeroptera	592	194	5	158	242	1	644	702	5
Plecoptera	364	154	3	3	0	<1	0	0	0
Trichoptera	431	142	4	14	25	<1	20	0	<1
Anisoptera	151	139	1	6	0	<1	11	0	<1
Coleoptera	285	186	3	0	0	0	2,302	3,399	17
Heteroptera	0	0	0	0	0	0	26	36	<1
Tipulidae	7	0	<1	0	0	0	0	0	0
Tabanidae	0	0	0	29	22	<1	3	0	<1
Empididae	315	366	3	9	30	<1	0	0	0

Table 5.15 (cont'd).

Taxon	Lower Reach of the Muskeg River			Lower to Mid Reach of the Muskeg River			Upper Reach of the Muskeg River		
	Abundance no./m^2	SD	% Abundance	Abundance no./m^2	SD	% Abundance	Abundance no./m^2	SD	% Abundance
Ceratopogonidae	0	0	0	365	611	3	287	747	2
Chironomidae	6,576	1,067	58	10,287	2,789	81	8,753	1,758	65
EPT	1,387	169	12	175	216	1	664	682	5
Total Abundance	11,343	7,022	100	12,635	9,495	100	13,566	10,183	100
Richness	31.8	8.3		14.3	6.8		16.7	7.7	
Simpson's Diversity	0.89	0.07		0.70	0.18		0.78	0.11	
Evenness	0.92	0.07		0.77	0.18		0.85	0.10	

Note: EPT: sum of Ephemeroptera, Plecoptera and Trichoptera taxa

Figure 5.10 Benthic community measures (means ± SD) of abundance, richness, diversity and evenness in the Muskeg River from 1998 – 2003.

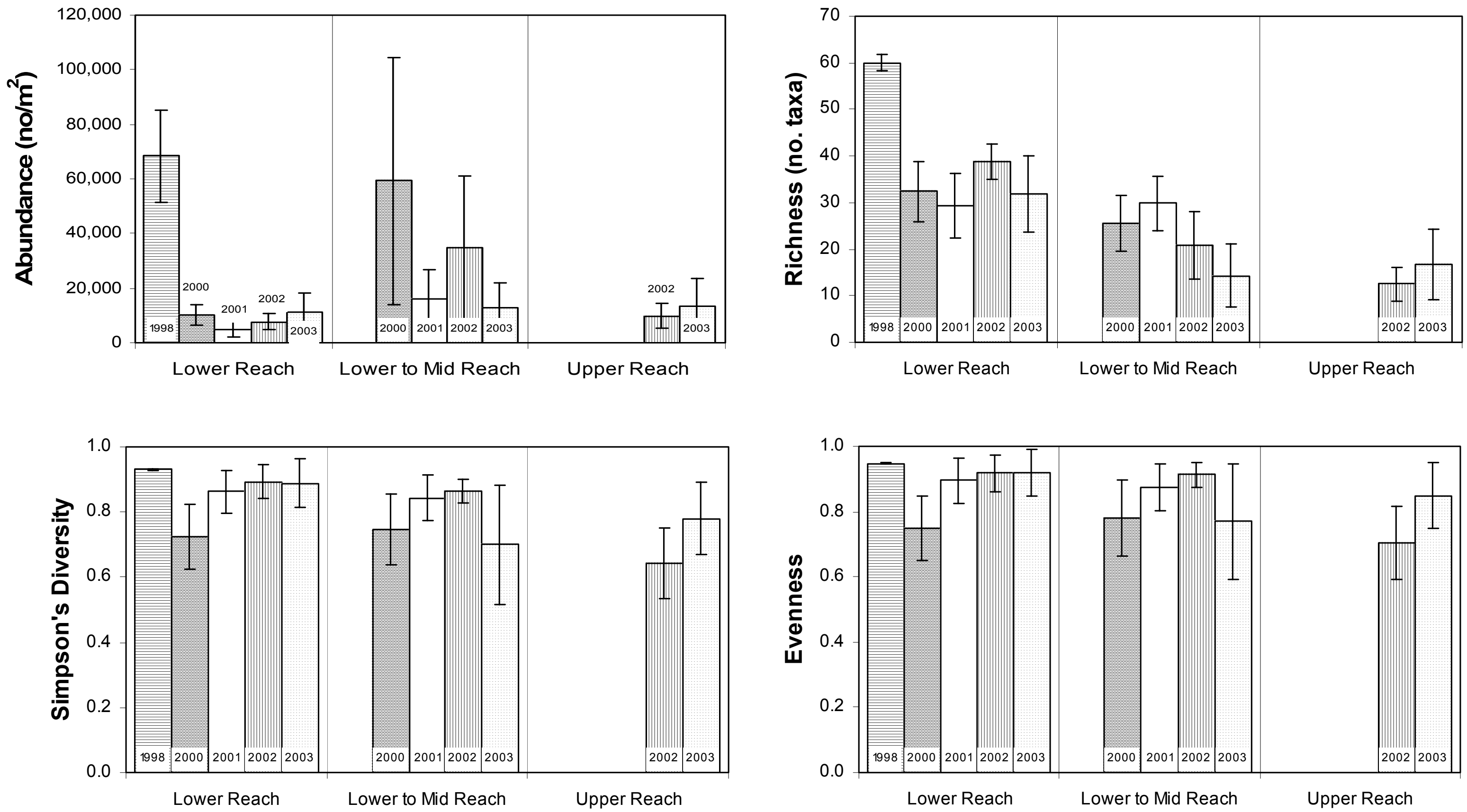
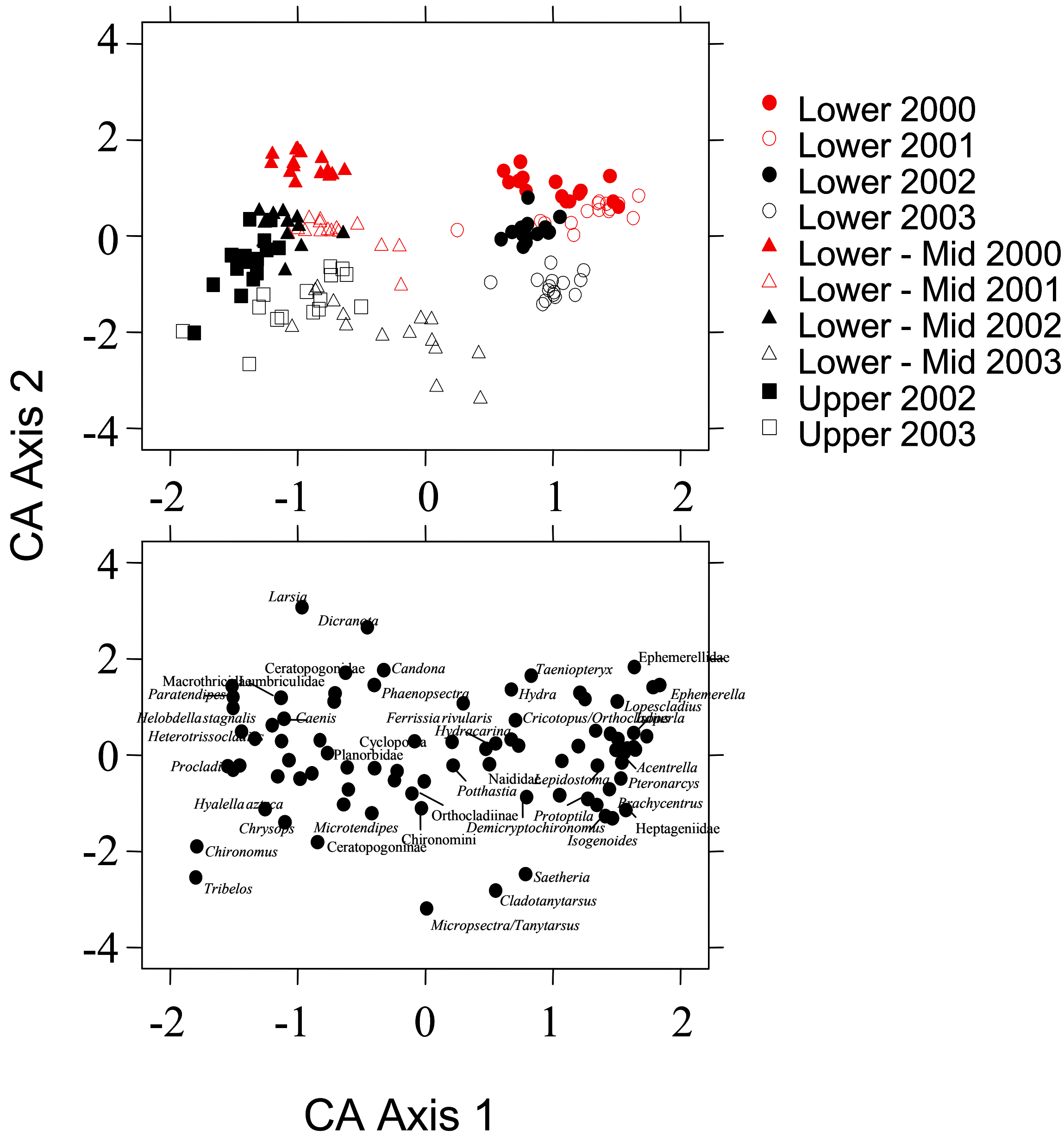


Figure 5.11 Ordination diagrams for the lower, lower to mid, and upper reaches of the Muskeg River from 2000 to 2003.



Note: The distribution of reaches in ordination space is plotted in the upper panel and taxa in the lower panel.

Jackpine Creek

The two reaches sampled in Jackpine Creek were representative of depositional habitats, with intermediate water depths (0.4 - 0.5 m), low current velocities (0.1 - 0.2 m/s), and low to intermediate macrophyte cover (0.7 – 8.3 %) (Table 5.16). Dissolved oxygen in the upper reach was low (5 mg/L) compared to the lower reach (11 mg/L) and below recommended concentrations for the preservation of aquatic life (CCME 2002). Conductivity in Jackpine Creek was low (~180 μS/cm) compared to other stations sampled in the RAMP program, but was similar in the two reaches of Jackpine Creek. The substrate in both reaches was sand (>74%) with relatively low TOC (≤2%).

Mean abundance in the lower reach of Jackpine Creek in 2003 was less than in 2002, but abundance at the upper reach was similar to the lower reach in 2003 (Figure 5.12). The same was true of richness, although the difference between number of taxa detected in 2002 and 2003 in the lower reach was negligible, given the high variability. Diversity and evenness were stable between 2002 and 2003 and similar between the lower and upper reaches of Jackpine Creek in 2003. There were no detectable differences in abundance, richness, diversity, or evenness between reaches on Jackpine Creek in 2003 (p=0.47, Table 5.17).

The invertebrate communities in both the upper and lower reaches of Jackpine Creek were generally similar in terms of composition (Figure 5.13, Table 5.18). They were diverse, and had taxa typically associated with sand substrates (Table 5.18). Chironomids dominated both reaches with *Polypedilum* and *Paralauterborniella* common genera. *Pseudosmittia* was also abundant in the lower reach and *Micropsectra / Tanytarsus* and *Saetheria* were abundant in the upper reach. Cyclopoid copepods, nematodes, and the clams *Pisidium/Sphaerium* were also abundant in the lower reach, whereas the Enchytraeidae, nematodes, and the coleopteran *Dubiraphia* were abundant in the upper reach. EPT taxa were not abundant in Jackpine Creek, making up no more than 1% of the total abundance in either reach. The only EPT taxon downstream was the caddisfly *Lepidostoma*, which tends to be associated with fine substrates (Bode *et al.* 1996). The upstream reach supported the mayfly *Leptophlebia*, the stonefly *Isoperla* and the caddisfly *Brachycentrus*.

Table 5.16 Habitat characteristics of the depositional reaches in Jackpine Creek, 2003.

Variable	Units	Lower Reach of Jackpine Creek	Upper Reach of Jackpine Creek
Sample date	-	Sept 21, 2003	Sept 19, 2003
Habitat	-	Depositional	Depositional
Water depth	m	0.4	0.5
Current velocity	m/s	0.1	0.2
Macrophyte cover	%	0.7	8.3
Field Water Quality			
Dissolved oxygen	mg/L	10.6	5.3
Conductivity	µS/cm	188	174
pH	-	7.3	7.3
Water temperature	EC	7.9	7.6
Sediment Composition			
Sand	%	85.1	74.1
Silt	%	12.5	13.9
Clay	%	3.8	12.3
Total Organic Carbon	%	2.0	1.2

Table 5.17 Results of *t*-tests of benthic community indices (abundance, richness, diversity and evenness) between upper and lower reaches of Jackpine Creek in 2003.

	t	n	p
Abundance	-0.440	30	0.663
Richness	-0.424	30	0.675
Diversity	-0.731	30	0.472
Evenness	-0.116	30	0.909

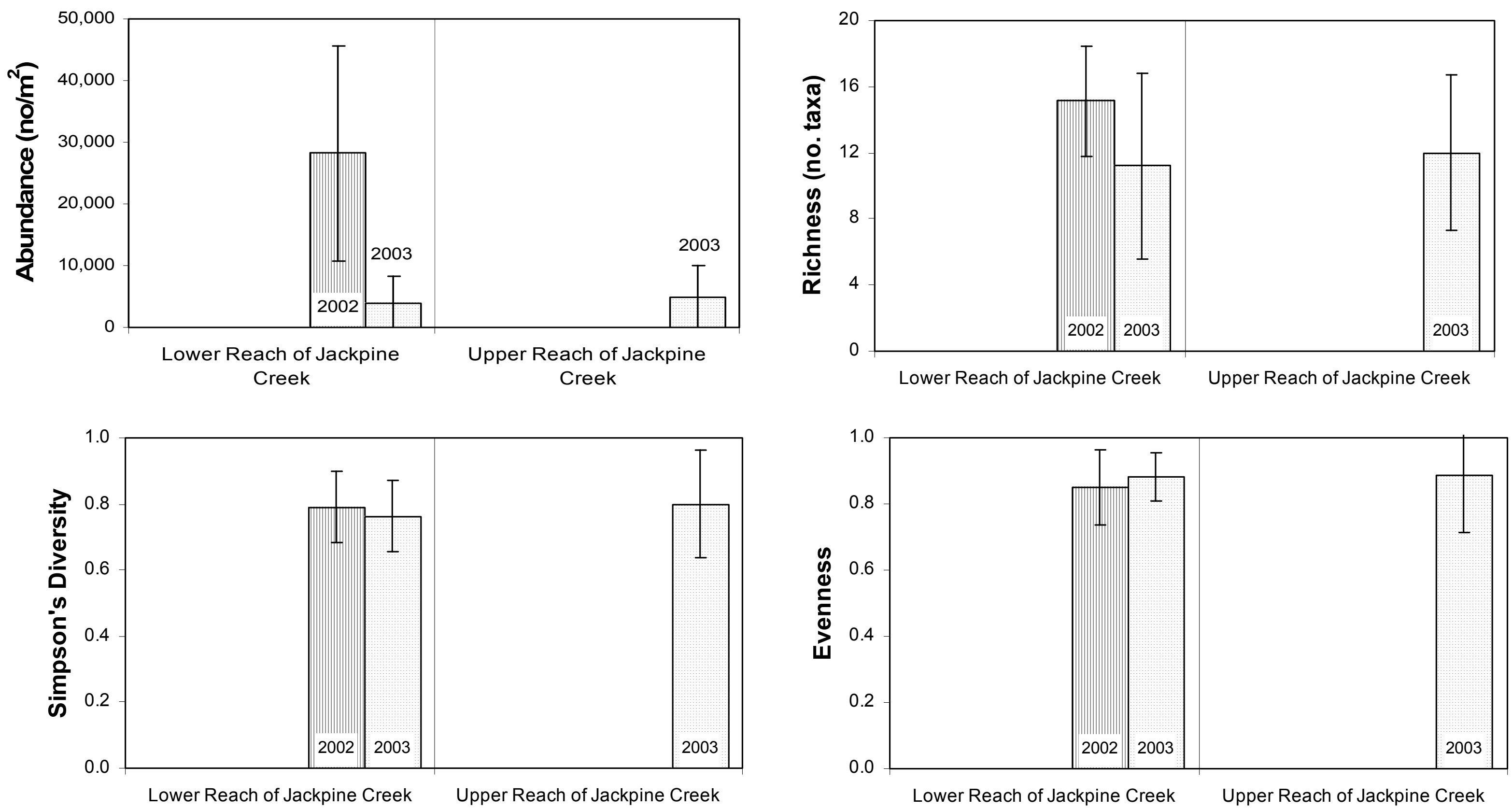
Note: A negative *t* implies that the upper reach was greater than the lower reach, and vice versa.

Table 5.18 Mean, standard deviation (SD), percent abundance and summary statistics for major taxa in Jackpine Creek, 2003.

Taxon	Lower Reach of Jackpine Creek			Upper Reach of Jackpine Creek		
	Abundance no./m^2	SD	% Abundance	Abundance no./m^2	SD	% Abundance
Nematoda	233	1,001	6	264	443	6
Glossiphoniidae	6	0	<1	0	0	0
Enchytraeidae	161	258	4	486	1,357	10
Naididae	66	140	2	164	308	3
Tubificidae	11	0	<1	83	177	2
Hydracarina	34	122	1	6	0	<1
Ostracoda	0	0	0	3	0	<1
Copepoda	385	3,718	10	0	0	0
Macrothricidae	3	0	<1	0	0	0
Amphipoda	3	0	<1	0	0	0
Collembola	0	0	0	11	0	<1
Bivalvia	135	243	3	23	61	<1
Ephemeroptera	0	0	0	20	30	<1
Plecoptera	0	0	0	3	0	<1
Trichoptera	17	0	<1	11	0	<1
Anisoptera	3	0	<1	0	0	0
Zygoptera	3	0	<1	0	0	0
Coleoptera	17	45	1	310	597	6
Heteroptera	11	0	<1	3	0	<1
Tipulidae	80	90	2	52	53	1
Dolichopodidae	40	83	1	17	61	<1
Tabanidae	6	0	<1	26	108	1
Empididae	60	252	2	29	56	1
Ephydridae	6	0	<1	11	0	<1
Ceratopogonidae	80	115	2	66	140	1
Chironomidae	2,655	664	66	3,198	735	67
EPT	17	0	<1	34	61	1
Total Abundance	4,017	4,394	100	4,787	5,159	100
Richness	11.2	5.6		12.0	4.7	
Simpson's Diversity	0.76	0.11		0.80	0.16	
Evenness	0.88	0.07		0.89	0.18	

Note: EPT: sum of Ephemeroptera, Plecoptera and Trichoptera taxa

Figure 5.12 Benthic community measures (means ± SD) of abundance, richness, diversity and evenness in Jackpine Creek from 2002 – 2003.



5.3.3.4 Firebag River and Fort Creek

The lower reach of the Firebag River is dominantly depositional (i.e., sand substrate), whereas the upper reach is dominantly erosional (i.e., gravel cobble substrate). Given the need to identify relatively homogeneous reaches (i.e., 3-5 km in length), it was not possible to establish upper and lower reaches with similar habitat conditions, despite every effort to do so. Despite the confounding issue of habitat type, these reaches could be monitored over time to evaluate potential impacts related to development.

Water depth and current velocity were similar at both locations, but macrophyte cover was higher at the upper reach (22%) compared to the lower reach (3%) (Table 5.19). Dissolved oxygen was high in both reaches (≥ 7.9 mg/L), while conductivity increased from upstream (154 μS/cm) to downstream (239 μS/cm). Water temperatures (~12°C) and pH (~7) were similar at both reaches. Sediments at the lower reach were dominated by sand (83%), with low total organic carbon content (0.8%), whereas the sediments at the upper reach consisted mostly of small cobble (41%) but also exhibited significant fractions of sand, silt and clay, small and large gravel, large cobbles and boulders.

Water was shallow (0.1 m) and current velocity was low (0.1 m/s) in the depositional reach of Fort Creek (Table 5.19). Dissolved oxygen (10 mg/L), conductivity (560 μS/cm) and pH (7.8) were high relative to field water quality measurements in the Firebag River (the closest tributary sampled). Sediments in Fort Creek were similar to those in the lower reach of the Firebag River: high in sand content and low in total organic carbon.

Chironomids were the dominant taxa in both reaches of the Firebag River (Table 5.20). *Micropsectra/Tanytarsus* were the most abundant chironomids in lower reach, whereas *Rheosmittia* were the most abundant chironomids in the upper reach. The EPT taxa were the second most dominant group in the lower reach of the Firebag River (16%), consisting mainly of the mayfly *Baetis*, the stonefly *Taeniopteryx* and the caddisfly *Lepidostoma*. EPT taxa in the upper reach of the Firebag River were low (<1%). The lower reach of the Firebag River had a variety of additional taxa including mites (*Hydracarina*), beetles (Coleoptera), nematodes, and worms that were subdominant. Other taxa present in low abundances in the upper reach of the Firebag River included the worms (Tubificidae), Naididae, and water boatmen (Hemiptera).

Chirononomidae were also the most abundant taxa in Fort Creek, and *Micropsectra/Tanytarsus* were most abundant among the chironomids (Table 5.20). EPT taxa in Fort Creek were nearly absent (<1%). Other taxa present in low abundances in Fort Creek included the Ceratopogonidae, copepods (Copepoda), and Enchytraeidae.

Given the Firebag River was sampled for benthos for the first time in 2003, no temporal data set yet exists for this river. At Fort Creek, which has been sampled since 2001, abundance appears to exhibit a steady increase over time (Figure 5.13). Richness, diversity, and evenness have decreased over the same period, although decreases in richness are very small.

Table 5.19 Habitat characteristics of sampling reaches in the Firebag River and Fort Creek, 2003.

Variable	Units	Lower Reach of the Firebag River	Upper Reach of the Firebag River	Fort Creek
Sample date	-	Sept 13, 2003	Sept 14, 2003	Sept 13, 2003
Habitat	-	Depositional	Erosional	Depositional
Water depth	m	0.3	0.3	0.1
Current velocity	m/s	0.3	0.3	0.1
Macrophyte cover	%	3.3	22	0
Benthic algae	mg/m^2	n/a	1.1	n/a
Field Water Quality				
Dissolved oxygen	mg/L	9.5	7.9	10.0
Conductivity	µS/cm	239	154	560
pH	-	7.0	7.2	7.8
Water temperature	EC	12.3	11.9	10.3
Sediment Composition				
Sand	%	83.2	n/a	75.6
Silt	%	13.3	n/a	15.2
Clay	%	3.5	n/a	9.4
Total Organic Carbon	%	0.8	n/a	2.7
Sand/Silt/Clay	%	n/a	10.7	n/a
Small gravel	%	n/a	14.5	n/a
Large gravel	%	n/a	23.7	n/a
Small cobble	%	n/a	40.7	n/a
Large cobble	%	n/a	17.3	n/a
Boulder	%	n/a	13.3	n/a
Bedrock	%	n/a	0	n/a

Table 5.20 Mean, standard deviation (SD), percent abundance and summary statistics for major taxa in the Firebag River and Fort Creek, 2003.

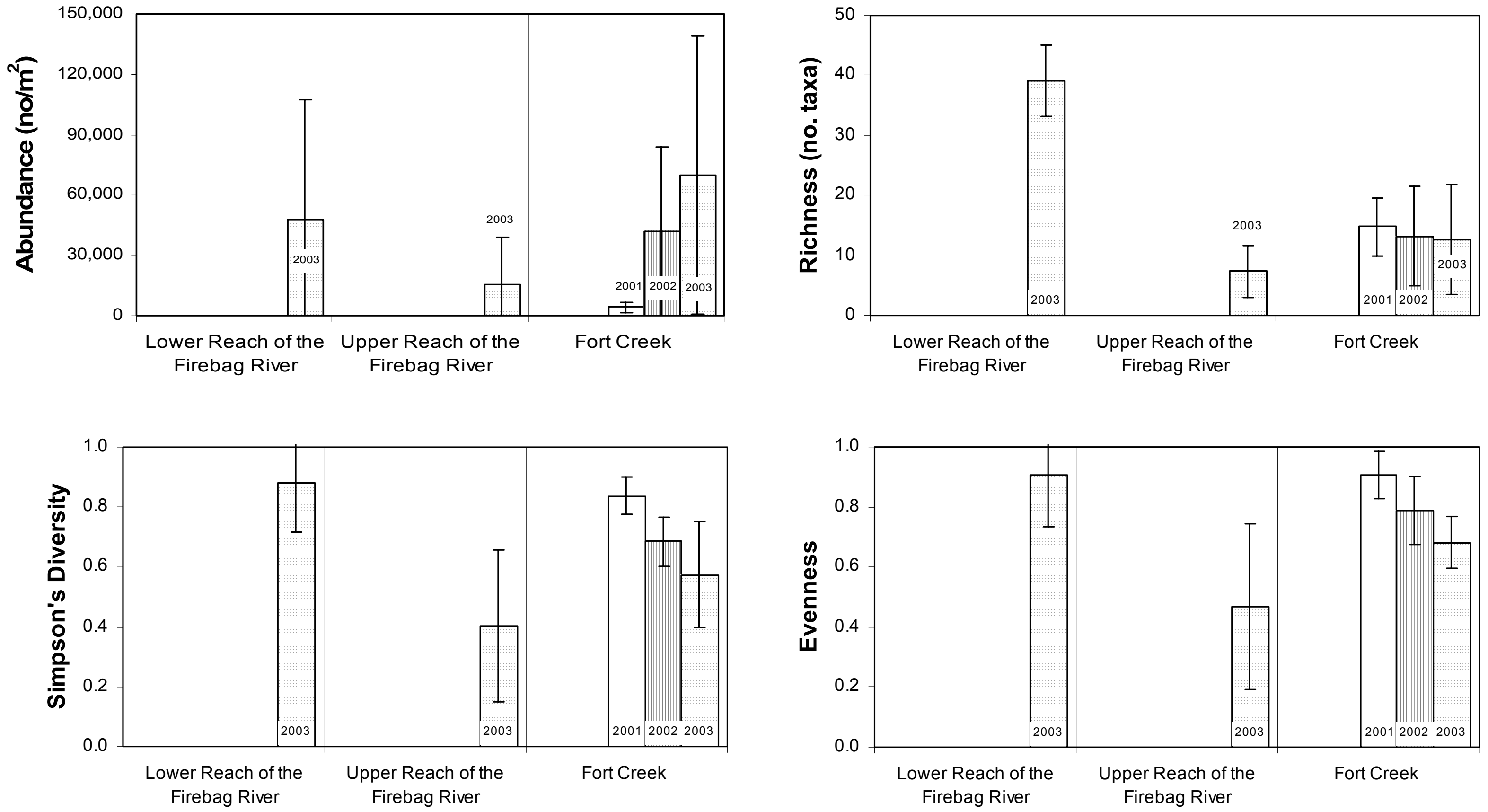
Taxon	Lower Reach of the Firebag River			Upper Reach of the Firebag River			Fort Creek		
	Abundance no./m2	SD	% Abundance	Abundance no./m2	SD	% Abundance	Abundance no./m2	SD	% Abundance
Hydra	6	0	<1	0	0	0	0	0	0
Nematoda	1,011	769	2	7	0	<1	353	0	1
Glossiphoniidae	43	147	<1	0	0	0	0	0	0
Piscicolidae	3	0	<1	0	0	0	0	0	0
Enchytraeidae	693	722	1	0	0	0	431	0	1
Naididae	871	519	2	173	710	1	345	0	<1
Tubificidae	305	470	1	221	580	1	233	416	<1
Lumbriculidae	37	151	<1	0	0	0	0	0	0
Hydracarina	2,256	2,176	5	0	0	0	86	0	<1
Ostracoda	181	320	<1	0	0	0	86	0	<1
Copepoda	313	689	1	0	0	0	603	658	1
Macrothricidae	0	0	0	0	0	0	345	0	<1
Amphipoda	14	0	<1	0	0	0	0	0	0
Bivalvia	1,029	951	2	0	0	0	95	274	<1
Gastropoda	267	211	1	0	0	0	17	0	<1
Ephemeroptera	4,247	1,412	9	4	30	<1	0	0	0
Plecoptera	1,014	372	2	1	0	<1	0	0	0
Trichoptera	2,609	741	5	0	0	0	9	0	<1
Anisoptera	158	122	<1	9	56	<1	0	0	0
Coleoptera	1310	1,192	3	0	0	0	0	0	0
Heteroptera	52	138	<1	118	386	1	9	0	<1
Tipulidae	319	254	1	0	0	0	9	0	<1
Tabanidae	26	82	<1	1	0	<1	0	0	0
Empididae	989	949	2	11	0	<1	86	0	<1
Ceratopogonidae	0	0	0	13	15	<1	862	498	1

Table 5.20 (cont'd).

Taxon	Lower Reach of the Firebag River			Upper Reach of the Firebag River			Fort Creek		
	Abundance no./m2	SD	% Abundance	Abundance no./m2	SD	% Abundance	Abundance no./m2	SD	% Abundance
Chironomidae	30,043	15,308	63	15,039	10,901	96	66,224	16,680	95
Simuliidae	26	213	<1	0	0	0	9	0	<1
EPT	7,871	1,009	16	5	25	<1	9	0	<1
Total Abundance	47,822	59,368	100	15,596	23,554	100	69,802	69,014	100
Richness	39.1	6.0		7.3	4.3		12.6	9.2	
Simpson's Diversity	0.88	0.16		0.40	0.25		0.57	0.18	
Evenness	0.90	0.17		0.47	0.28		0.68	0.09	

Note: EPT: sum of Ephemeroptera, Plecoptera and Trichoptera taxa

Figure 5.13 Benthic community measures (means ± SD) of abundance, richness, diversity and evenness in the Firebag River (2003) and Fort Creek (2001 – 2003).



5.3.4 Tributaries West of the Athabasca River

5.3.4.1 Calumet River

The lower reach of the Calumet River was shallow (0.2 m) and slow moving (≤0.1 m/s) (Table 5.21). The new upstream reach was established in a beaver impoundment due to the lack of flowing-water habitat (i.e., extensive marshy areas with no defined channel). This site was also sampled during the CNRL Horizon Project environmental baseline program (CNRL 2002). Macrophytes were absent from the lower reach but were abundant in the impounded upper sampling reach. Dissolved oxygen at the upper reach was low (3.4 mg/L) and below recommended water quality guidelines for the protection of aquatic life (CCME 2002). Conductivity in the Calumet River was high (>550 μS/cm) compared to other RAMP monitoring locations, and was similar at both reaches. Water temperature and pH also were similar at both reaches. Sediments in the lower reach were dominated by sand, whereas clay was the dominant component of the sediments at the upper reach. Total organic carbon (TOC) in the sediments at both reaches was relatively high (>3%), perhaps consistent with the depositional nature of these reaches. Ontario Ministry of Environment sediment quality guidelines (Persaud *et al.* 1993) suggest that TOC levels in excess of 1% may pose a potential risk to benthic animals, except where natural, background concentrations already exceed this guideline, in which case background levels should be used as a baseline to assess impact or change. This is the case in both reaches of the Calumet River, which have yet to experience any extensive development.

Chironomids dominant both reaches of the Calumet River (Table 5.22). *Micropsectra / Tanytarsus* were the most abundant chironomids in the lower reach, while *Parachironomus* was the most abundant chironomid in the upper reach. Naididae also were abundant at both stations, as were the Planorbidae at the upper reach of the Calumet River. Few EPT were collected from the Calumet River. The mayflies *Callibaetis*, and caddisflies *Nemotaulius* were found in both the upper and lower Reaches.

Only the lower reach of the Calumet River was sampled prior to 2003, and abundance and richness were lower in 2003 than in 2002, whereas diversity and evenness were similar among years (Figure 5.14). Abundance, richness, diversity and evenness were all similar among the lower and upper reaches and no significant differences were detected in the benthic community indices among the reaches ($p=0.25$, Table 5.23).

Table 5.21 Habitat characteristics of depositional reaches in the Calumet River, 2003.

Variable	Units	Lower Reach of the Calumet River	Upper Reach of the Calumet River
Sample date	-	Sept 14 & 16, 2003	Sept 20, 2003
Habitat	-	Depositional	Depositional
Water depth	m	0.2	0.8
Current velocity	m/s	0.1	0
Macrophyte cover	%	0	n/a
Field Water Quality			
Dissolved oxygen	mg/L	9.7	3.4
Conductivity	µS/cm	689	558
pH	-	7.5	7.3
Water temperature	EC	8.7	7.9
Sediment Composition			
Sand	%	72.1	20.0
Silt	%	18.2	33.4
Clay	%	9.7	46.0
Total Organic Carbon	%	3.2	6.7

Table 5.22 Mean, standard deviation (SD), percent abundance and summary statistics for major taxa in the Calumet River, 2003.

Taxon	Lower Reach of the Calumet River			Upper Reach of the Calumet River		
	Abundance no./m^2	SD	% Abundance	Abundance no./m^2	SD	% Abundance
Nematoda	35	122	<1	414	524	4
Erpobdellidae	3	0	<1	0	0	0
Enchytraeidae	23	0	<1	0	0	0
Naididae	859	1,285	4	948	2,743	9
Tubificidae	261	573	1	0	0	0
Hydracarina	29	0	<1	345	0	3
Ostracoda	445	1,498	2	0	0	0
Copepoda	339	1,857	2	431	0	4
Daphniidae	3	0	<1	259	0	3
Macrothricidae	14	0	<1	0	0	0
Amphipoda	0	0	-	336	896	3
Bivalvia	319	437	2	86	0	1
Gastropoda	43	68	<1	1,310	2,577	13

Table 5.22 (cont'd).

Taxon	Lower Reach of the Calumet River			Upper Reach of the Calumet River		
	Abundance no./m^2	SD	% Abundance	Abundance no./m^2	SD	% Abundance
Ephemeroptera	3	0	<1	17	0	<1
Trichoptera	6	0	<1	34	61	<1
Anisoptera	6	0	<1	9	0	<1
Coleoptera	6	0	<1	0	0	0
Heteroptera	20	22	<1	0	0	0
Dolichopodidae	14	0	<1	0	0	0
Tabanidae	152	225	1	0	0	0
Chaoboridae	0	0	-	284	240	3
Ceratopogonidae	376	1,117	2	259	86	3
Chironomidae	16,707	4,549	85	5,569	850	54
EPT	9	0	<1	52	43	1
Total Abundance	19,664	19,544	100	10,302	12,849	100
Richness	13.6	4.1		11.6	8.4	
Simpson's Diversity	0.75	0.11		0.76	0.17	
Evenness	0.82	0.11		0.87	0.10	

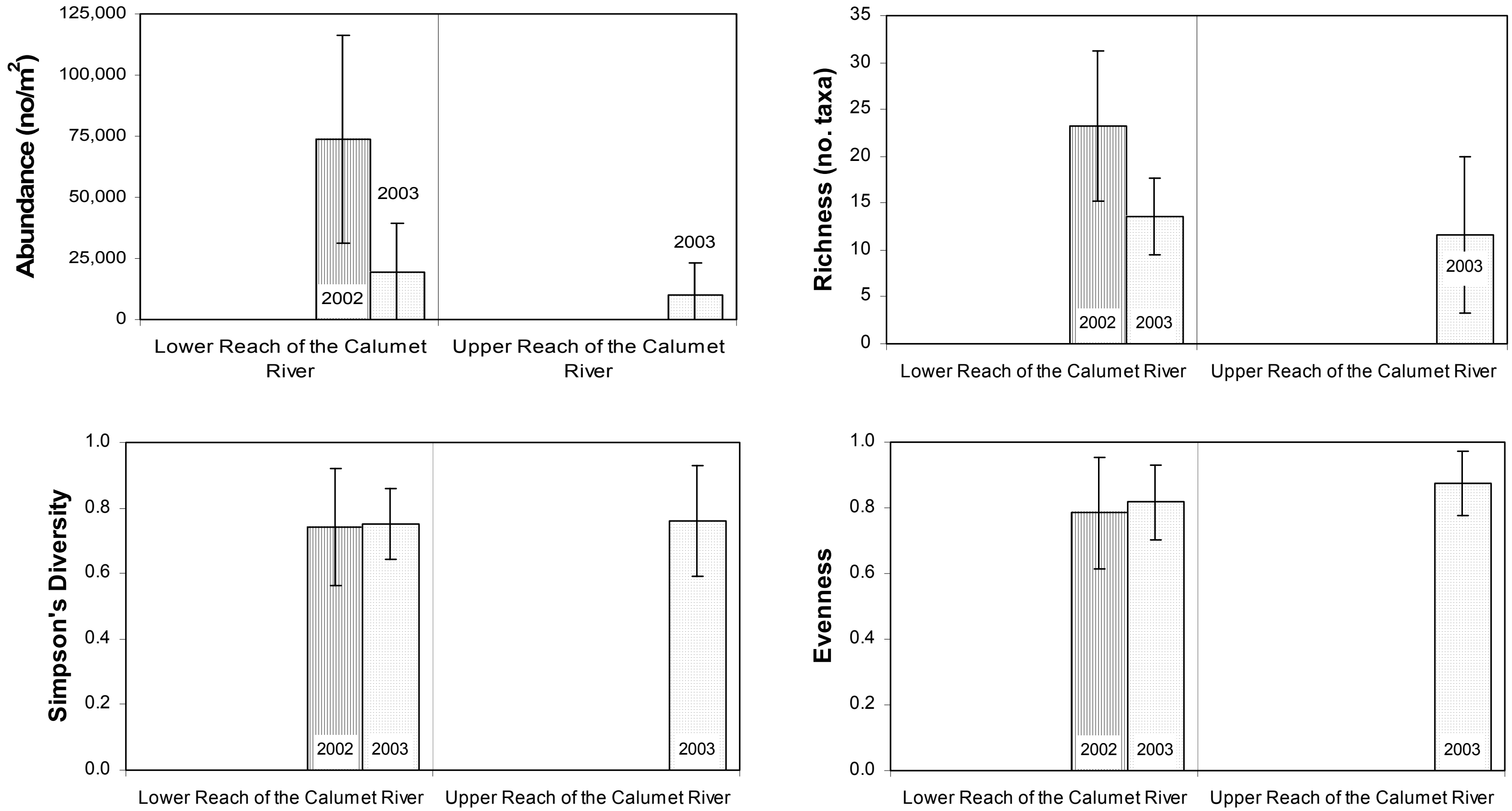
Note: EPT: sum of Ephemeroptera, Plecoptera and Trichoptera taxa

Table 5.23 Results of *t*-tests of benthic community indices (abundance, richness, diversity and evenness) between upper and lower reaches of the Calumet River in 2003.

	t	n	p
Abundance	1.224	20	0.247
Richness	0.496	20	0.643
Diversity	-0.094	20	0.929
Evenness	-1.098	20	0.304

Note: A negative *t* implies that the upper reach was greater than the lower reach, and vice versa.

Figure 5.14 Benthic community measures (means ± SD) of abundance, richness, diversity and evenness in the Calumet River from 2002 – 2003.



5.3.4.2 Tar River

The upper and lower reaches of the Tar River had similar depths, current velocities, and macrophyte cover, but the habitat was depositional at the lower reach and erosional at the upper reach (Table 5.24). Despite the confounding issue of habitat type, ongoing sampling at these reaches could be monitored over time to evaluate potential impacts related to development. Benthic algal concentration at the upper reach was low (3.7 mg/m^2). Dissolved oxygen (8.1 mg/L), conductivity (328-380 µS/cm), pH and water temperature were similar at both reaches, although the upper reach was two degrees cooler than the lower reach, even though they were sampled at the same time. Sediments in the lower reach were dominated by sand with low total organic carbon (0.4%), whereas sediments at the upper reach included a wide variety of sediment fractions from sand/silt/clay to boulders and bedrock.

Composition of the benthic communities reflected differences associated with erosional and depositional habitat types. Both upper and lower reaches were dominated by the Chironomidae, with *Polypedilum* dominant in the deposition lower reach, and *Rheotanytarsus* dominant in the upper erosional reach (Table 5.25). Naidid oligochaetes were present in both reaches, while mayflies (e.g., *Heptagenia*), caddisflies (e.g., *Glossosoma*, *Brachycentrus*) and stoneflies (e.g., *Nemoura*, Capniidae, Chloroperlidae) were only abundant in the upper reach (15%). There were almost no EPT taxa present in the lower reach.

Only the lower reach of the Tar River was sampled prior to 2003. Abundance and richness declined in 2003 compared to 2002 at this location (Figure 5.15). Diversity and evenness were similar among years at the lower reach. Richness was significantly lower at the lower reach of the Tar River, compared to the upper reach, in 2003 ($p<0.001$). Abundance, diversity and evenness did not differ among reaches in 2003 ($p=0.076$, Table 5.26).

Table 5.24 Habitat characteristics of sampling reaches in the Tar River, 2003.

Variable	Units	Lower Reach of the Tar River	Upper Reach of the Tar River
Sample date	-	Sept 16-17, 2003	Sept 16, 2003
Habitat	-	Depositional	Erosional
Water depth	m	0.2	0.2
Current velocity	m/s	0.1	0.3
Macrophyte cover	%	2.5	0.3
Benthic algae	mg/m^2	n/a	3.7
Field Water Quality			
Dissolved oxygen	mg/L	8.1	8.1
Conductivity	µS/cm	380	328
pH	-	7.3	7.2
Water temperature	EC	7.4	5.5
Sediment Composition			
Sand	%	81.5	n/a
Silt	%	10.3	n/a
Clay	%	8.2	n/a
Total Organic Carbon	%	0.4	n/a
Sand/Silt/Clay	%	n/a	12.0
Small gravel	%	n/a	13.1
Large gravel	%	n/a	20.7
Small cobble	%	n/a	30.4
Large cobble	%	n/a	28.7
Boulder	%	n/a	12.5
Bedrock	%	n/a	25.0

Table 5.25 Mean, standard deviation (SD), percent abundance and summary statistics for major taxa in the Tar River, 2003.

Taxon	Lower Reach of the Tar River			Upper Reach of the Tar River		
	Abundance no./m^2	SD	% Abundance	Abundance no./m^2	SD	% Abundance
Nematoda	92	112	<1	119	94	2
Erpobdellidae	3	0	<1	0	0	0
Enchytraeidae	0	0	0	158	170	2
Naididae	819	1,161	4	447	577	6
Tubificidae	193	535	1	72	146	1

Table 5.25 (cont'd).

Taxon	Lower Reach of the Tar River			Upper Reach of the Tar River		
	Abundance no./m^2	SD	% Abundance	Abundance no./m^2	SD	% Abundance
Lumbriculidae	0	0	0	65	167	1
Hydracarina	210	246	1	95	125	1
Ostracoda	75	95	<1	0	0	0
Copepoda	83	248	<1	73	187	1
Chydoridae	3	0	<1	0	0	0
Collembola	11	0	<1	0	0	0
Bivalvia	43	116	<1	0	0	0
Ephemeroptera	26	213	<1	365	167	5
Plecoptera	11	0	<1	547	211	8
Trichoptera	11	0	<1	151	127	2
Heteroptera	0	0	0	1	0	<1
Tipulidae	37	151	<1	40	26	1
Tabanidae	37	63	<1	0	0	0
Empididae	184	168	1	173	92	2
Ephydridae	0	0	0	4	15	<1
Ceratopogonidae	293	595	1	18	114	<1
Chironomidae	18,672	6,675	90	4,834	1,086	67
Psychodidae	0	0	0	1	0	0
EPT	49	124	<1	1,063	185	15
Total Abundance	20,805	27,094	100	7,166	5,792	100
Richness	16	7		25	3	
Simpson's Diversity	0.74	0.24		0.85	0.06	
Evenness	0.90	0.10		0.90	0.10	

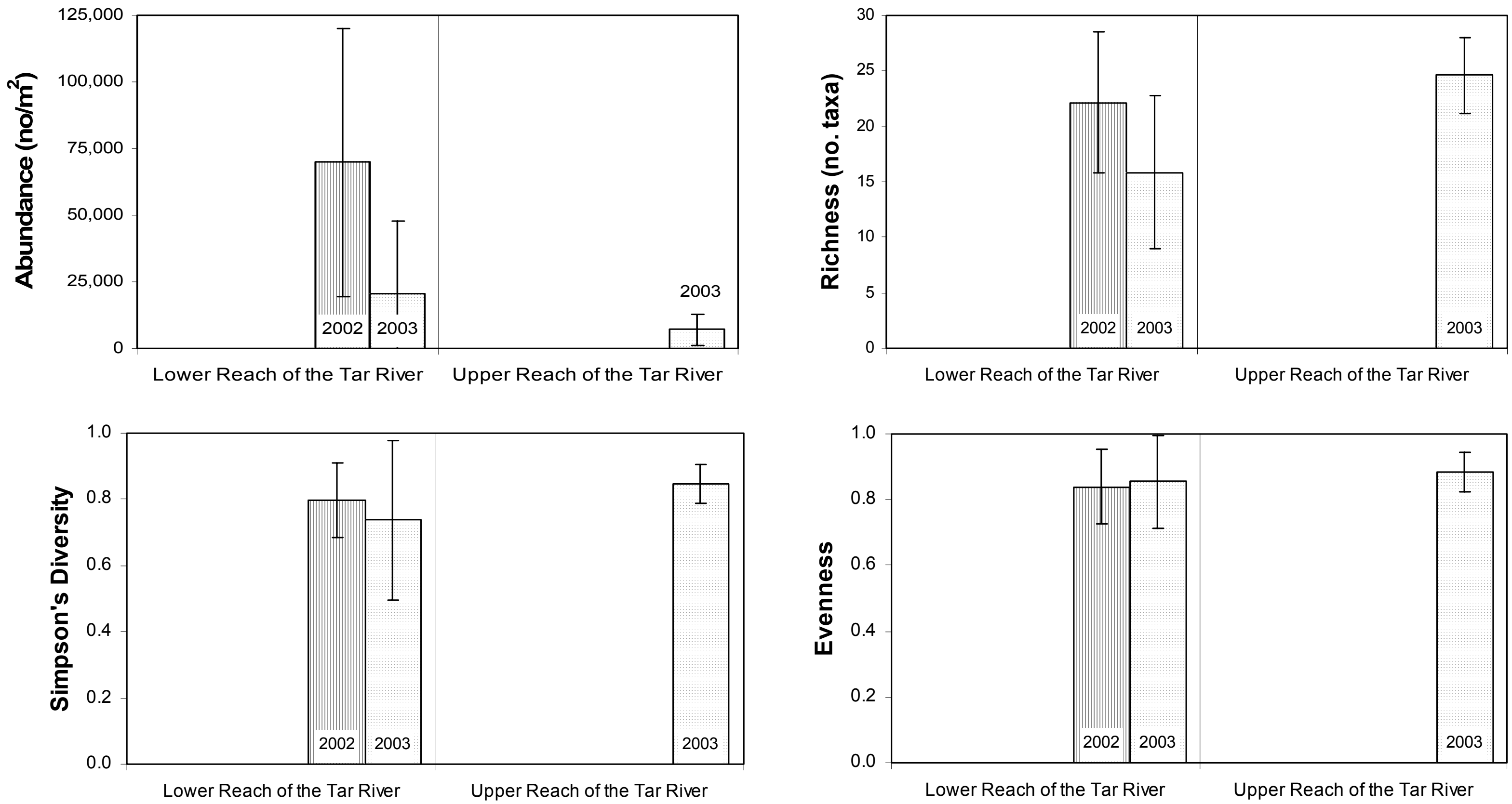
Note: EPT: sum of Ephemeroptera, Plecoptera and Trichoptera taxa

Table 5.26 Results of *t*-tests of benthic community indices (abundance, richness, diversity and evenness) between upper and lower reaches of the Tar River in 2003.

	t	n	p
Abundance	1.906	30	0.076
Richness	-4.374	30	<0.001
Diversity	-1.717	30	0.106
Evenness	-0.729	30	0.475

Note: A negative *t* implies that the upper reach was greater than the lower reach, and vice versa.

Figure 5.15 Benthic community measures (means ± SD) of abundance, richness, diversity and evenness in the Tar River from 2002 – 2003.



5.3.4.3 Ells River

Although the majority of habitat in the Ells River is erosional in nature, within 10 km of the river mouth, habitats are strongly depositional. Despite the confounding issue of habitat type, ongoing monitoring of these reaches over time could allow evaluation of any potential impacts related to development. Depths (0.2 to 0.3 m) were similar at both reaches but current velocity was higher at the erosional station (Table 5.27). Macrophyte cover (approximately 15%) and field water quality parameters were also similar at both reaches. Sediments at the lower reach were dominated by sand with some silt and clay but very low total organic carbon, whereas sediments at the upper reach were fairly evenly spread across the sand/silt/clay and different classes of gravels, cobbles, and boulders.

The lower reach of the Ells River was dominated by tubificid (52%) and naidid (24%) oligochaete worms and chironomids (19%) (Table 5.28). Dominant chironomid taxa at the lower reach were *Polypedilum*, *Paralauterborniella*, and *Procladius*. The upper reach of the Ells River was dominated by chironomids (60%), particularly *Rheotanytarsus*, *Polypedilum*, *Tvetenia*, and *Micropsectra/Tanytarsus*. Naididae and *Hydracarina* were also abundant at the upper reach of the Ells River. EPT taxa comprised 10% of the total abundance in the upper reach, compared to only 1% in the lower reach. The upper reach EPT taxa consisted primarily of the mayfly *Baetis*, the stonefly *Isoperla*, and the caddisfly *Hydropsyche*. EPT taxa in the lower reach consisted primarily of *Baetis*.

No data were available to assess trends over time in Ells River benthic communities (samples were collected at the lower reach in 2002 but lost in shipping and could not be analyzed). Data from 2003 are presented graphically in Figure 5.16. Mean abundance was similar between reaches in 2003, whereas richness, diversity and evenness were all slightly higher at the upper reach of the Ells River in 2003. Richness, diversity and evenness were significantly lower in the lower reach than in the upper reach ($p=0.029$), although abundance was not significantly different ($p=0.25$, Table 5.29).

Table 5.27 Habitat characteristics of sampling reaches in the Ells River, 2003.

Variable	Units	Lower Reach of the Ells River	Upper Reach of the Ells River
Sample date	-	Sept 15 & 20, 2003	Sept 22, 2003
Habitat	-	Depositional	Erosional
Water depth	m	0.3	0.2
Current velocity	m/s	0.1	0.4
Macrophyte cover	%	16.7	13.0
Benthic algae	mg/m^2	n/a	41
Field Water Quality			
Dissolved oxygen	mg/L	8.9	9.6
Conductivity	µS/cm	198	236
pH	-	7.3	7.7
Water temperature	EC	9.6	8.4
Sediment Composition			
Sand	%	67.3	n/a
Silt	%	19.9	n/a
Clay	%	13.0	n/a
Total Organic Carbon	%	2.2	n/a
Sand/Silt/Clay	%	n/a	0
Small gravel	%	n/a	10.0
Large gravel	%	n/a	17.9
Small cobble	%	n/a	31.4
Large cobble	%	n/a	35.0
Boulder	%	n/a	16.5
Bedrock	%	n/a	0

Table 5.28 Mean, standard deviation (SD), percent abundance and summary statistics for major taxa in the Ells River, 2003.

Taxon	Lower Reach of the Ells River			Upper Reach of the Ells River		
	Abundance $no./m^2$	SD	% Abundance	Abundance $no./m^2$	SD	% Abundance
Nematoda	69	169	<1	126	156	1
Enchytraeidae	0	0	0	232	216	1
Naididae	7,319	10,839	24	2,277	1,297	13
Tubificidae	16,144	44,095	52	62	223	<1

Table 5.28 (cont'd).

Taxon	Lower Reach of the Ells River			Upper Reach of the Ells River		
	Abundance no./m^2	SD	% Abundance	Abundance no./m^2	SD	% Abundance
Hydracarina	89	376	<1	1,853	832	11
Ostracoda	0	0	0	14	0	<1
Copepoda	14	0	<1	0	0	0
Macrothricidae	3	0	<1	0	0	0
Bivalvia	118	219	<1	44	81	<1
Gastropoda	106	112	<1	87	136	1
Ephemeroptera	149	363	<1	1,190	380	7
Plecoptera	0	0	0	161	124	1
Trichoptera	23	0	<1	308	235	2
Anisoptera	6	0	<1	77	47	<1
Heteroptera	3	0	<1	0	0	0
Tipulidae	0	0	0	9	62	<1
Athericidae	0	0	0	5	4	<1
Tabanidae	83	112	<1	1	0	<1
Empididae	40	132	<1	283	298	2
Ceratopogonidae	986	1,664	3	207	259	1
Chironomidae	5,764	1,745	19	10,242	1,460	60
Simuliidae	0	0	0	29	68	<1
EPT	172	321	1	1,659	313	10
Total Abundance	30,917	44,015	100	17,207	7,870	100
Richness	11.6	4.3		27.9	4.6	
Simpson's Diversity	0.69	0.21		0.87	0.05	
Evenness	0.76	0.23		0.91	0.05	

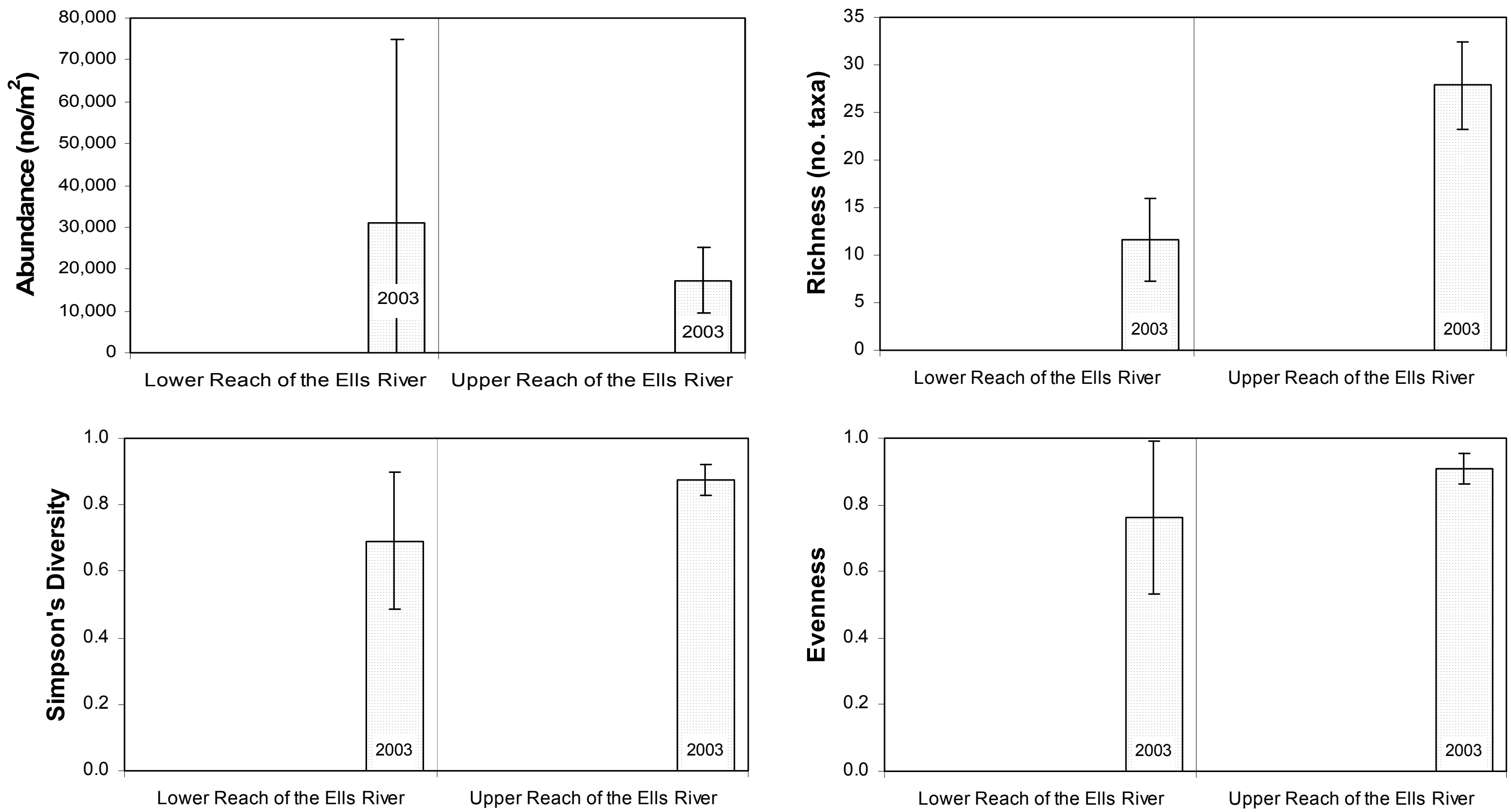
Note: EPT: sum of Ephemeroptera, Plecoptera and Trichoptera taxa

Table 5.29 Results of *t*-tests of benthic community indices (abundance, richness, diversity and evenness) between upper and lower reaches of the Ells River in 2003.

	t	n	p
Abundance	1.188	30	0.254
Richness	-10.06	30	<0.001
Diversity	-3.353	30	0.004
Evenness	-2.419	30	0.029

Note: A negative *t* implies that the upper reach was greater than the lower reach, and vice versa.

Figure 5.16 Benthic community measures (means ± SD) of abundance, richness, diversity and evenness in the Ells River, 2003.



5.3.4.4 MacKay River

Both reaches of the MacKay River were erosional, with fairly high current velocities (0.5 m/s), shallow depths (0.2 m), low macrophyte cover (<6%) and low to intermediate benthic algal biomass (5 to 14 mg/m^2) (Table 5.30). Dissolved oxygen at both reaches was high, and conductivity and pH were similar at both locations. Water temperature was about 8 °C cooler at the upper reach. Substrate at the lower reach was dominated by large gravel, whereas small cobble was dominant at the upper reach. Percentages of each substrate type were approximately evenly divided among the remaining classes.

The lower reach of the MacKay River has been sampled regularly since 1998. For the same reasons discussed for the Steepbank River (i.e., narrower geographic range of sampling reach with more intensive local sampling), abundance and richness were higher and diversity and evenness were similar in 1998 compared to subsequent years (Figure 5.17). Data collected after 1998 indicate abundance, diversity and evenness were low and stable from 2000 to 2003. Richness in 2002 was high relative to the other years, but this was consistent among lower and upper river sampling reaches, and corresponded to high abundance in both reaches that year. Abundance, richness, diversity and evenness were similar in 2002 and 2003 for the lower and upper reaches of the MacKay River. There were no significant differences among reaches in 2003 ($p=0.14$, Table 5.31).

Benthic communities of the upper and lower reaches were similar, and were dominated by chironomids, mayflies, mites and worms (Table 5.32). Despite the general similarities, differences in genera separated the benthos of the three reaches (Figure 5.18). The lower reach of the MacKay River was dominated by chironomids (particularly *Polypedilum*), followed by Ephemeroptera (*Heptagenia*) and Hydracarina. Chironomids (*Thienemannimyia*) were also the most abundant group in the upper reach of the MacKay River, followed by Hydracarina and Naididae. EPT taxa comprised 21-22% of the total abundance in both reaches. Temporal patterns in composition were similar for the upper and lower reaches (Figure 5.18).

Despite differences in composition between lower and upper reaches, benthic communities in both upper and lower reaches are diverse, and exhibit similar time trends in composition. There was no evidence of degradation of benthic habitat.

Table 5.30 Habitat characteristics of sampling reaches in the MacKay River, 2003.

Variable	Units	Lower Reach of the MacKay River	Upper Reach of the MacKay River
Sample date	-	Sept 12 -13, 2003	Sept 17, 2003
Habitat	-	Erosional	Erosional
Water depth	m	0.2	0.2
Current velocity	m/s	0.5	0.5
Macrophyte cover	%	5.3	0.3
Benthic algae	mg/m^2	14.1	4.7
Field Water Quality			
Dissolved oxygen	mg/L	9.8	12.6
Conductivity	µS/cm	328	280
pH	-	7.9	7.7
Water temperature	EC	15.1	7.0
Sediment Composition			
Sand/Silt/Clay	%	5.0	0
Small gravel	%	15.7	12.9
Large gravel	%	45.3	14.7
Small cobble	%	33.0	51.3
Large cobble	%	10.0	22.0
Boulder	%	8.3	7.5
Bedrock	%	0	0

Table 5.31 Results of *t*-tests of benthic community indices (abundance, richness, diversity and evenness) between upper and lower reaches of the MacKay River in 2003.

	t	n	p
Abundance	0.507	30	0.616
Richness	-1.516	30	0.141
Diversity	-1.083	30	0.289
Evenness	-0.965	30	0.343

Note: A negative *t* implies that the upper reach was greater than the lower reach, and vice versa.

Table 5.32 Mean, standard deviation (SD), percent abundance and summary statistics for major taxa in the MacKay River, 2003.

Taxon	Lower Reach of the MacKay River			Upper Reach of the MacKay River		
	Abundance no./m2	SD	% Abundance	Abundance no./m2	SD	% Abundance
Hydra	7	0	<1	0	0	0
Nematoda	141	102	1	73	80	1
Erpobdellidae	0	0	0	1	0	<1
Enchytraeidae	625	498	5	227	246	4
Naididae	953	708	8	841	1,068	15
Tubificidae	11	0	<1	16	124	<1
Lumbriculidae	14	0	<1	19	78	<1
Hydracarina	2,179	1,415	18	1,149	1,458	21
Ostracoda	0	0	0	24	33	<1
Bivalvia	300	445	2	224	203	4
Gastropoda	14	50	<1	11	13	<1
Ephemeroptera	2,403	529	19	778	228	14
Plecoptera	161	64	1	194	176	3
Trichoptera	186	116	2	196	63	4
Anisoptera	110	80	1	45	32	1
Coleoptera	7	28	<1	1	<1	<1
Tipulidae	6	0	<1	16	52	<1
Dolichopodidae	0	0	0	1	0	<1
Tabanidae	1	0	<1	1	0	<1
Empididae	186	171	2	101	197	2
Ceratopogonidae	15	56	<1	6	0	<1
Chironomidae	4,994	1,156	40	1,645	236	30
Simuliidae	33	106	<1	1	0	<1
EPT	2,750	448	22	2,337	379	21
Total Abundance	12,347	3,480	100	5,568	4,206	100
Richness	24.5	4.5		27.1	5.0	
Simpson's Diversity	0.85	0.07		0.87	0.05	
Evenness	0.89	0.07		0.91	0.05	

Note: EPT: sum of Ephemeroptera, Plecoptera and Trichoptera taxa

Figure 5.17 Benthic community measures (means ± SD) of abundance, richness, diversity and evenness in the MacKay River from 1998 – 2003.

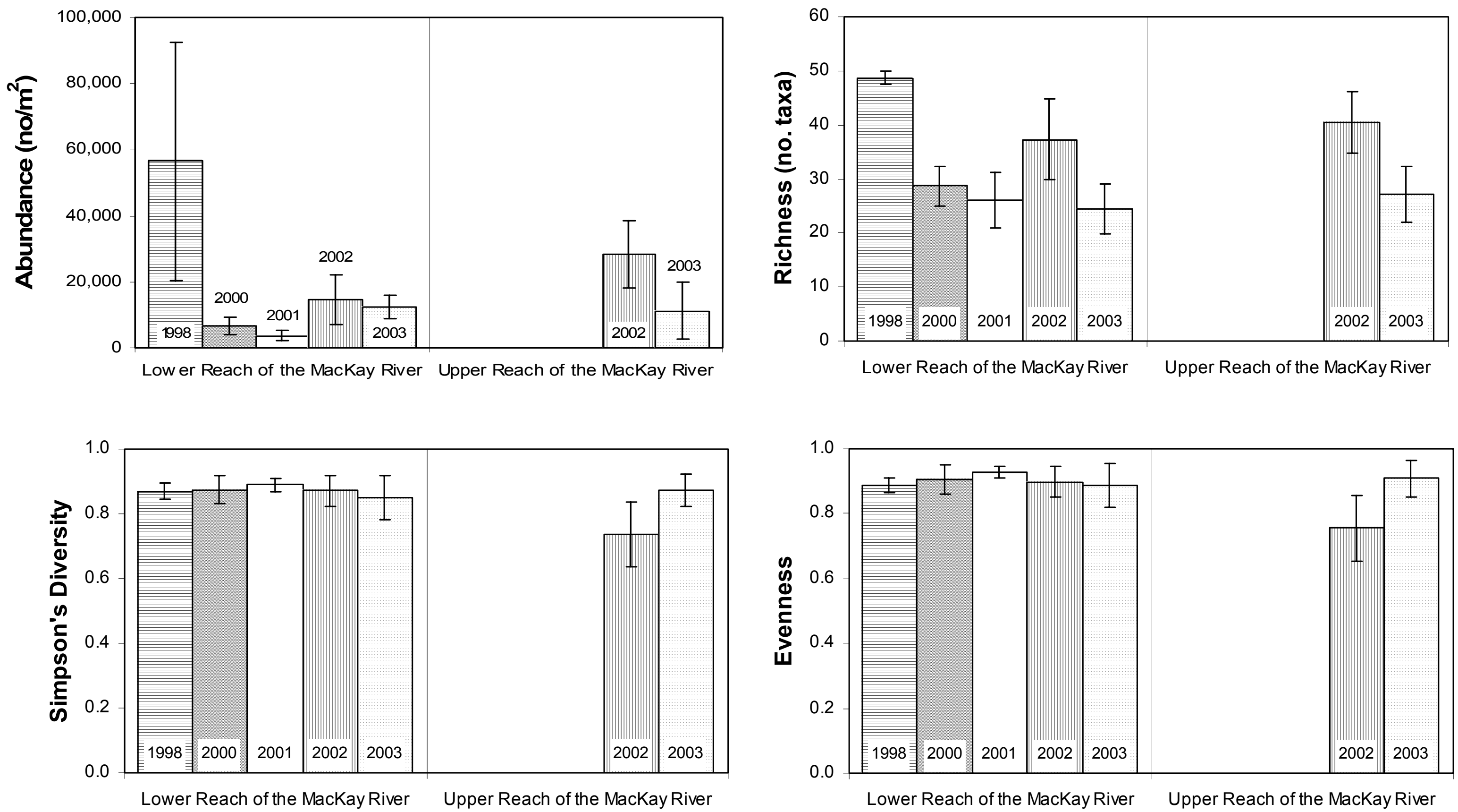
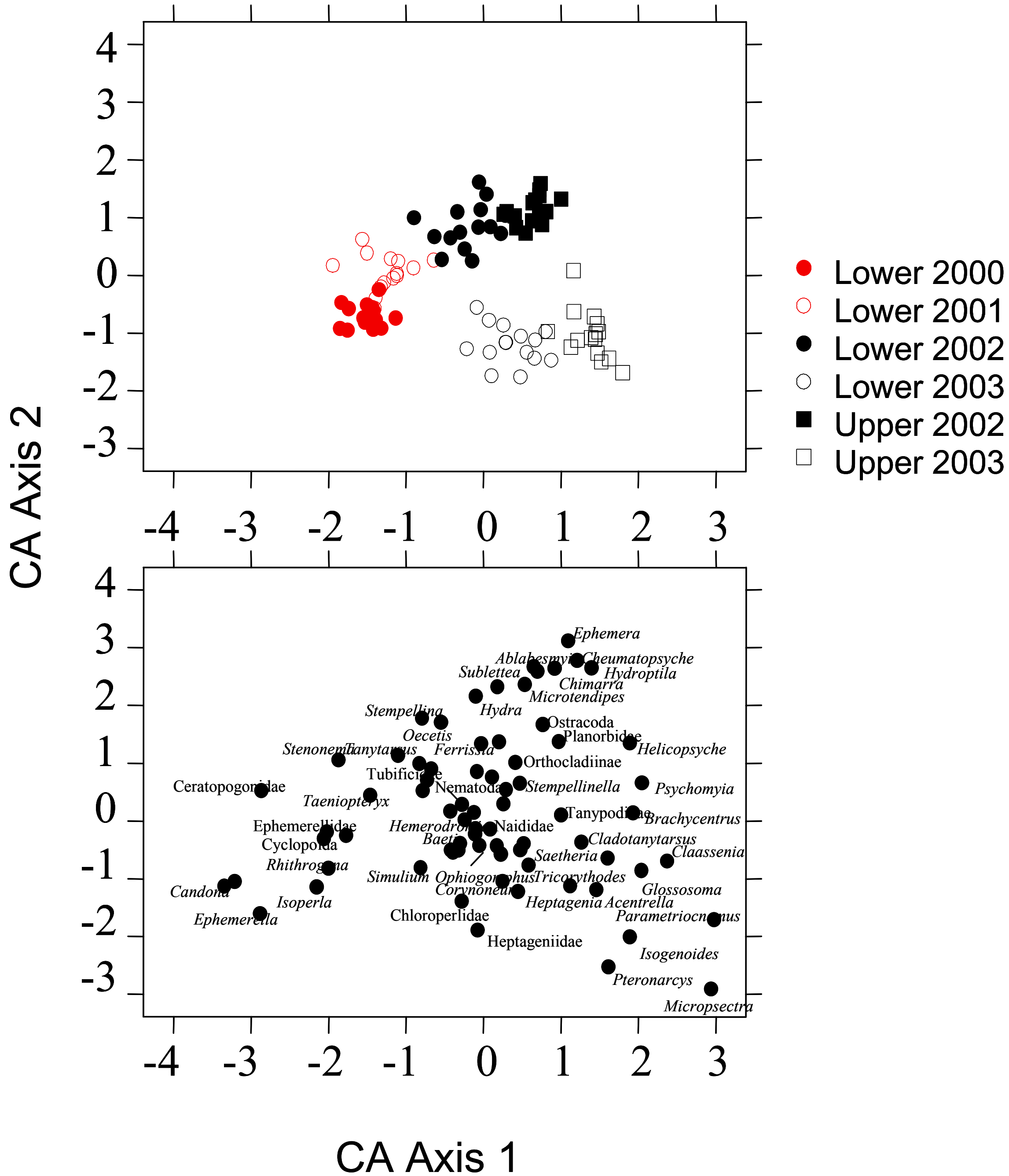


Figure 5.18 Ordination diagrams for the upper and lower reaches of the MacKay River from 2000 to 2003.



Note: The distribution of reaches in ordination space is plotted in the upper panel and taxa in the lower panel.

5.4 DISCUSSION

Over 250 invertebrate taxa were identified by the 2003 RAMP benthic invertebrate program. These taxa ranged from highly tolerant to highly sensitive to effects of pollution (Bode *et al.* 1996). Overall community composition in the different areas reflected this diversity. None of the communities clearly suggested habitat degradation, although none of the communities were composed predominantly of organism extremely sensitive to changes in habitat.

Among the three lakes studied, only one (Shipyard Lake) is located within an active development region and could potentially show impact as a result of oil sands activities within the drainage basin. General indices of benthic community composition (abundance, richness, diversity, and evenness) suggested that, although Shipyard Lake benthic communities have exhibited more variability over time than other lakes sampled, diversity was the only index that differed significantly from Kearl and McClelland lakes. This difference in diversity was reflected in correspondence analysis, where Shipyard Lake tended to separate from the other two lakes with respect to taxonomic composition. Shipyard Lake generally exhibited higher relative abundances of such taxa as *Chaoborus*, *Chironomus*, *Psectrocladius*, *Armiger crista*, and *Valvata* sp. Kearl and McClelland lakes are located in zones of planned or approved development and, therefore, are not currently influenced by development. The most abundant taxa in all three lakes were highly tolerant of pollution (Bode *et al.* 1996).

Invertebrate communities within the three sampled channels of the Peace-Athabasca Delta also were within expected ranges for abundance, richness, diversity, and evenness, although Big Point Channel exhibited lower evenness and diversity than the other two channels. Abundance in Goose Island Channel was considerably lower in 2003 than in 2002, but the 2003 values were comparable to those obtained in the other three channels and therefore not likely to be indicative of environmental change. Although abundance in the Peace-Athabasca Delta declined in 2003 relative to 2002, there were increases in diversity and evenness. Community composition of the three reaches was similar in terms of the level of pollution tolerance, with most taxa having intermediate to high tolerance.

For reaches where there were potential existing or near-future effects of development (i.e., mid-low and lower reaches of the Muskeg River, the MacKay River, the Christina River, and the Clearwater River), there are no clear indications of benthic habitat degradation. Lower reaches of the Clearwater and Christina rivers may have exhibited minor declines in benthic habitat quality relative to upstream reaches in these rivers, although differences between reaches in these rivers also may be attributable to physical habitat characteristics.

The lower reach of the MacKay River exhibited high proportions of taxa considered sensitive to pollution relative to other rivers sampled, despite this reach being located downstream of current oil sands development. Furthermore, differences in taxonomic composition between upper and lower reaches in the MacKay River, as revealed by correspondence analysis, were small relative to inter-annual differences. There was no other evidence of impact in the lower reach of the MacKay River, where abundance, richness, diversity and evenness were all similar to the upper reach in the years where both reaches were sampled.

The lower reach of the Muskeg River exhibited significantly higher richness and diversity in 2003 relative to its upper reach, even though the lower reach is located downstream of oil sands development. The lower-to-mid reach, which also is located in a potentially affected area, did not differ significantly from the upper reach in 2003. Abundances were similar across the three reaches, although they were quite variable over time in the lower-to-mid reach of the river. The potentially affected lower-to-mid reach and unaffected upper reaches of the Muskeg River exhibited similar community composition. Similar to the case of the MacKay River, there were proportionally more pollution-sensitive taxa in the lower reach of the Muskeg River than in its lower-to-mid or upper reaches. However, the habitat of the lower reach of the Muskeg River is erosional and therefore more likely to support pollution-tolerant taxa (i.e., EPT taxa) than the depositional habitats of the lower to mid and upper reaches.

Data collected from the other rivers in the study (two reaches each on Jackpine Creek and the Firebag, Ells, Calumet and Tar rivers) established baseline conditions prior to development. All have upstream reaches that are not currently scheduled for impact from oil sands development. In general, the community composition at the ten pre-development reaches was consistent for the region. Fort Creek is unique among the rivers sampled in RAMP because only one reach was sampled on this stream. The Fort Creek sampling reach is located in a zone of potential development. Three years of data have already been collected for this reach that will provide suitable baseline information for monitoring for post-development changes, when the development occurs. Richness, diversity and evenness were significantly higher in 2003 at the downstream reach of the Firebag River. Richness, diversity and evenness in the Ells River and richness in the Tar River were significantly higher in their respective upper reaches than lower reaches in 2003. There were no significant differences in indices between reaches of the Calumet River in 2003, despite differences in habitat between these reaches.

Temporal and spatial trends observed in 2003 were generally consistent with those reported in the RAMP Five Year Report (Golder 2003a). With the exception of the Christina and Clearwater rivers, there were no clearly identifiable long-term trends in the major tributaries of the Athabasca River, in the channels of the Peace-Athabasca Delta, or in the lakes sampled as part of RAMP. The lower reaches of the Christina and Clearwater rivers may have elicited minor responses to changes in benthic habitat quality, although differences between upstream and downstream reaches in these rivers may also be attributable to habitat differences. Future surveys will be useful for confirming trends in those and other locations.

6.0 FISH POPULATIONS

6.1 OVERVIEW OF 2003 PROGRAM

In 2003, RAMP conducted the following monitoring of fish populations in the oil sands region:

- the operation of a full-span two-way fish counting fence on the lower Muskeg River during the early spring period;
- additional spring fish sampling on the lower Muskeg River, using hoop nets, backpack electrofishing and fish larval traps, to supplement the fish fence program;
- tissue collection and analysis for target fish species in the Athabasca River and several regionally important lakes (Lake Claire and Christina Lake); and
- fish inventory on the Athabasca River (spring and fall sampling), the Clearwater River (spring and fall sampling), and the Firebag River (spring sampling).

Table 6.1 lists the watercourses sampled and the target fish species for each component of the 2003 RAMP fisheries program. Common and scientific names for each fish species noted in this report are listed in Appendix A6.

Table 6.1 Tasks, sampling sites and target species for 2003 RAMP fish program.

Task	Study Period	Waterbody				
		Athabasca River	Muskeg River	Clearwater River	Firebag River	Regional Lakes (Claire*, Christina, Gregoire)
Fish inventory	Spring 2003	fish community		fish community	fish community	
	Fall 2003	fish community		fish community		
Fish tissue collection & analysis	Fall 2003	walleye, lake whitefish and northern pike				walleye, lake whitefish and northern pike
Fish fence program	Spring 2003		migratory fish community			

* Lake Claire opportunistic fish samples were collected in the winter of 2002/2003, but analyzed in the spring of 2003.

6.2 METHODS

6.2.1 Fish Inventory

The RAMP Athabasca River and tributary fish inventory is conducted to provide data on geographic and temporal variations in fish species composition, relative abundance, size and condition factor. In 2003, spring and fall inventories were carried out to augment existing fish presence and abundance data for key fish indicator species (i.e., Key Indicator Resources) in the oil sands region of the Athabasca River. The key fish indicator species are (CEMA 2001):

- walleye (*Sander vitreus*);
- northern pike (*Esox lucius*);
- lake whitefish (*Coregonus clupeaformis*);
- longnose sucker (*Catostomus catostomus*);
- goldeye (*Hiodon alosoides*); and
- trout-perch (*Percopis omyscomaycus*).

Inventories were conducted by personnel from Syncrude, Suncor, CNRL, OPTI/Nexen and Alberta Sustainable Resource Development as an in-kind contribution to RAMP.

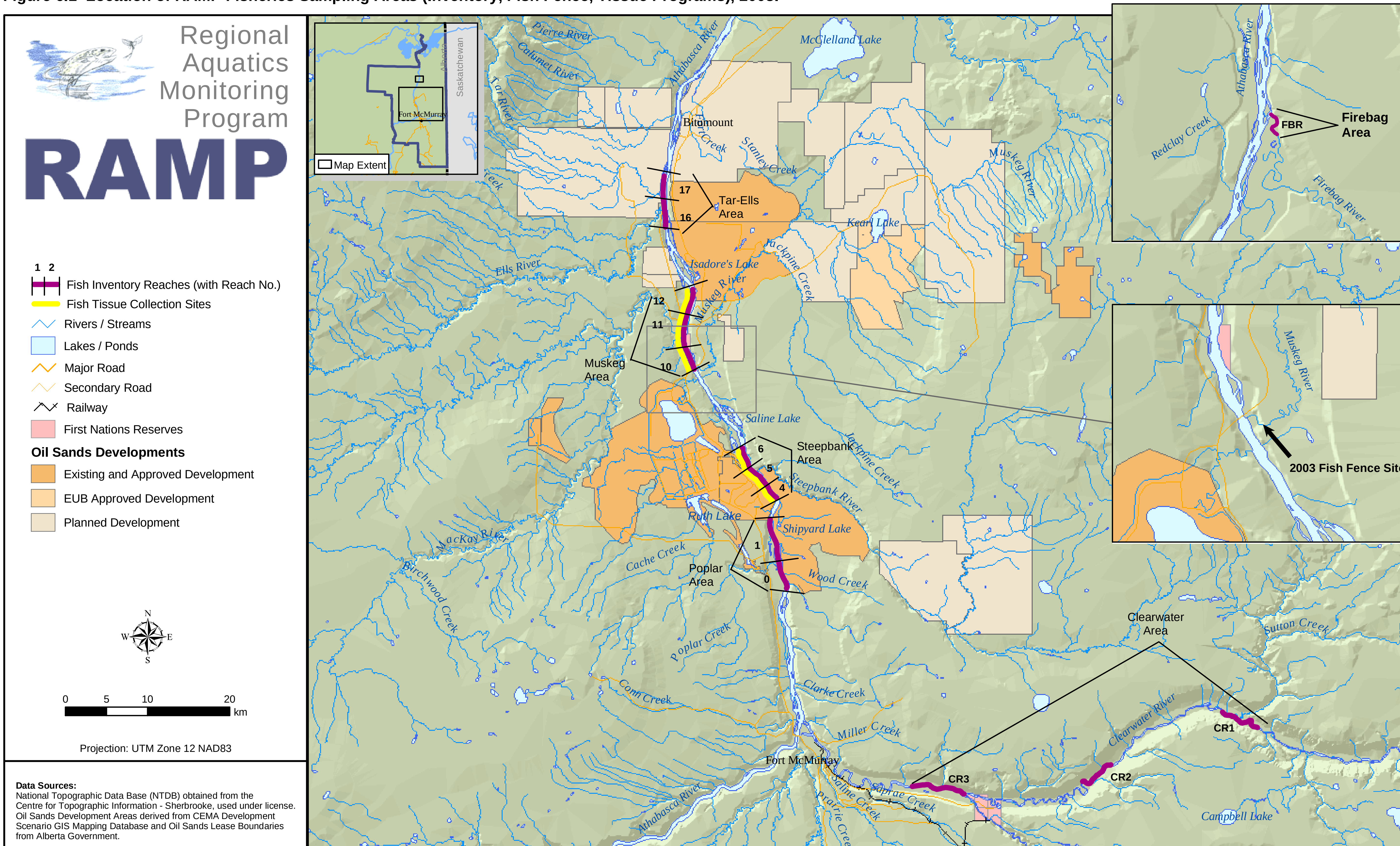
6.2.1.1 Fish Sampling and Handling

Spring sampling was conducted between May 7 and May 30, 2003. The survey focused primarily on the Athabasca River mainstem (6.5 days effort), with secondary efforts on the Clearwater (2 days effort) and Firebag (0.5 days effort) Rivers.

The fall program was implemented from September 24 to October 7, 2003. This survey included nine days of effort on the Athabasca River mainstem and three days on the Clearwater River. No fall sampling was conducted on the Firebag River. Fish captured during the Athabasca River inventory were also used to support fish tissue monitoring studies outlined in Section 6.2.2.

In 2003, Athabasca River sampling focused on 10 reaches specifically established by RAMP for the inventory program (Table 6.2, Figure 6.1). The 10 reaches have been re-sampled each year and are located in four sections of the Athabasca River near major tributary confluences. The four areas are: the Poplar Area (Reaches 0 and 1), Steepbank Area (Reaches 4 to 6), Muskeg Area (Reaches 10 to 12), and the

Figure 6.1 Location of RAMP Fisheries Sampling Areas (Inventory, Fish Fence, Tissue Programs), 2003.



Mxd: G:\DATA\PROJECTS\RAMP1069\GIS\Fig6-1_Fish2003.mxd
Last Modified: 2/11/2004 11:21:15 AM

Tar-Ells Area (Reaches 16 and 17). Sampling in the Clearwater River was conducted at three locations in the Fort McMurray region (Figure 6.1). Sampling in the Firebag River extended from the confluence with the Athabasca River to approximately 2.25 km upstream. Sampling was conducted in areas conducive to boat electrofishing, primarily shallow river margins.

Table 6.2 Athabasca River and tributary fish inventory sampling locations, 2003.

Site Name	Reach Numbers	UTM Coordinates (NAD 83, zone 12V)	
		Upstream Boundary	Downstream Boundary
Poplar Area	0 and 1	474627 E / 6305817 N	473052 E / 6311432 N
Steepbank Area	4, 5 and 6	472838 E / 6317197 N	469314 E / 6322688 N
Muskeg Area	10, 11 and 12	463967 E / 6331391 N	463253 E / 6341314 N
Tar-Ells Area	16 and 17	459859 E / 6350353 N	459913 E / 6356845 N
Clearwater River	na	527711 E / 6290586 N	489943 E / 6281368 N
Firebag River	na	479469 E / 6399453 N	478973 E / 6401264 N

na = not applicable

Fish sampling was carried out using a Smith-Root model SR-18 electrofishing boat with a 5.0 GPP electrofishing unit configured with two anode boom arrays with multiple dropper-cables. The boat hull acted as the cathode. Stunned fish were captured with dip-nets, then held in an on-board flow-through live well. Fish observed, but not captured, were enumerated by species and recorded as observed fish. Seine netting (at select sites in the Athabasca River and Clearwater River) was also conducted during the spring inventory (5-m long net). Seining was conducted where the bottom habitat was deemed suitable for walking.

Large-bodied fish were measured for fork length (±1 mm) and weight (±10 g) and an external pathology examination was conducted to assess the presence of abnormalities, disease and/or parasites. Sex and state of maturity were recorded when discernible by external examination. Small-bodied species (e.g., forage fish) were measured for fork length only. Prior to live release, key indicator species of sufficient size were fixed with RAMP Floy tags; each was inscribed with a contact phone number to encourage anglers to report their catch. Non-lethal ageing structures were collected for captured fish following procedures outlined in MacKay *et al.* (1990). Ageing structures were archived.

6.2.1.2 Data Analysis

All fish captured were summarized by species composition (i.e., percent of total catch) and relative abundance (i.e., catch-per-unit-effort [CPUE]). Data for fish collected by beach seining were included in length-frequency analyses for the 2003 inventory.

Where sample sizes permitted, more detailed analyses were conducted on key fish indicator species. Multi-year comparisons were restricted to data from the Athabasca River. All detailed analyses were conducted using SYSTAT® 10 statistical software (SPSS 2000). The following population parameters were examined:

- length-frequency distribution;
- mean condition factor; and
- mean external pathology index.

Comparison of length-frequency distributions among years (1997-2003) was based on data collected from spring and fall inventories (i.e., no summer data were used). High numbers of lake whitefish are only present in the oil sands region of the Athabasca River during the fall spawning migration. Accordingly, length-frequency analyses for lake whitefish was limited to fall inventory data only. Differences in length-frequency distributions among years for each species were compared separately using the G-test for independence for two-way frequency tables (Sokal and Rohlf 1981). G or the log-likelihood ratio is distributed approximately as X^2. Tables of standardized deviates (year-by-length class) were also examined to identify any obvious pattern in distributions over time.

With the exception of lake whitefish, analysis of condition was restricted to data for fish collected in the spring. Fall data were used for lake whitefish. To be consistent with past years, analyses were restricted to fish of a minimum length: walleye >400 mm; lake whitefish >350 mm; northern pike >400 mm; goldeye >300 mm; and longnose sucker >350 mm. For each species, fish condition was estimated by the relationship of total body weight versus fork length ($\log_{10}$ data). Potential differences in condition among years (1997-2003) were initially tested using Analysis of Covariance (ANCOVA). However, when the full ANCOVA model (i.e., test of slopes) was conducted, there was a high number of fish that exhibited studentized residual values > 4.0. Given these results, the residual values for each fish derived from the ANCOVA model were saved and these data were used to test for differences in condition among years using the non-parametric Kruskall-Wallis test (similar to ANOVA). This approach avoided the potential problems associated with arbitrarily omitting high numbers of fish from the analyses based on residual values, and potentially biasing the results of the test. For graphical purposes, Fulton's Condition Factor was also calculated using the following equation: K=(body weight/fork length^3 x 10^5).

An external pathology index (Golder 2003b) was calculated for each fish (Appendix A6.1). Historical index results were tabulated to assess evidence of trends in external fish health.

6.2.2 Fish Tissue Analyses

The RAMP fish tissue program is conducted to measure the levels of chemicals, including metals and organic tainting compounds, present in fish populations of the Athabasca oil sands region, and to identify any potential risks to humans, fish, and wildlife.

In 2003, fish sampling for tissues was conducted in the Athabasca River, as well as Lake Claire and Christina Lake. Lake collections were conducted under the Regional Lakes component of the RAMP Fish Tissue Program. Regional lake sampling was initiated to address community concerns regarding the safe consumption of fish from recreational, subsistence or commercial fisheries in regionally important lakes connected to the Athabasca River, or located in the zone of airborne oil sands emissions. Tissue collection and analyses occurs on an opportunistic basis, when sampling is conducted by other agencies or programs.

Fish species targeted for the Athabasca River included lake whitefish and walleye. For Lake Claire and Christina Lake, tissues from lake whitefish, walleye and northern pike were analyzed.

6.2.2.1 Fish Collection and Sampling

Athabasca River

Lake whitefish and walleye were collected from fish inventory reaches 4 to 6 (Steepbank Area) and reaches 10 to 12 (Muskeg Area) of the Athabasca River between September 26 and 29, 2003 during the fall fish inventory of the Athabasca River (Section 6.2.1). Fish that met the species and length requirements (described below) were transferred to an onshore sampling location and held in perforated plastic tubs until they were sampled.

Figure 6.2 Fish sampling tent used to sample fish tissues, 2003.

Fish that did not meet the species and length requirements were counted, measured for length and weight, examined for external indicators of sex and maturity, and released; data for these fish are presented in Section 6.3.1 (Fish Inventory).

For each target fish species, up to 25 individuals were selected for tissue analyses on the basis of size. The objective was to collect tissues from five fish from each of five predetermined size classes for each species (Table 6.3). Size classes were used to collect tissue samples from a wide range in fish sizes and ages to obtain a better understanding of tissue concentrations in populations being assessed, and to ensure comparability with data from previous sampling efforts. Size classes were selected based on typical size ranges of fish available in the fall recorded during past fish inventory surveys (Golder 2003). Size classes for lake whitefish were narrower relative to walleye, because most lake whitefish found in the Athabasca River in the fall are adults participating in the annual spawning migration.

Table 6.3 Target fork length classes for the selection of fish for the RAMP fish tissue program, Athabasca River, 2003.

Species	Target Size Classes for Mercury Analysis (mm) (5 fish per class)					Target Size Classes for Composite Samples	
	1	2	3	4	5	Female	Male
Walleye	200-300	301-400	401-500	501-600	601-700	500-550	450-500
Lake whitefish	350-400	401-450	451-500	501-550	551-600	400-450	400-450

The analyses of fish tissues from the Athabasca River included metals, including mercury, and specific tainting compounds (see Section 6.2.2.2 for details). Mercury concentration was measured in each fish (i.e., 25 fish per species). For other metals and tainting compounds, analyses were conducted on composite samples prepared for each species and sex. Composite samples consisted of tissues from five fish per sex and included some fish used for mercury analyses. Composite samples consisted of fish from a narrow size range to minimize within composite variability (Table 6.3).

Each fish was measured for fork length (± 1.0 mm) and total weight (± 1.0 g) prior to dissection. For each fish, muscle tissue was removed for mercury analyses. Additional muscle tissue was were removed from five males and females per species for composite samples. Muscle tissue was removed from the left side of the fish following procedures outlined in the RAMP protocol for fish health assessment for organic chemicals (Golder 1999a), and from the right side of the fish according to the RAMP fish health assessment protocol for metals (Golder 1999b). A minimum of 100 g of muscle tissue was collected per fish; however, for smaller fish, the minimum weight was not always obtained. Muscle samples collected for organics analyses were individually wrapped in solvent-rinsed aluminum foil and samples collected for metals analyses were individually wrapped in plastic wrap. All samples were labeled, stored on dry ice, and shipped to Enviro-Test Labs (ETL; Edmonton) for analysis and compositing.

After dissection, carcass weight (i.e., internal organs removed; ± 1.0 g), liver weight (± 1.0 g) and gonad weight (± 1.0 g) were measured for each fish. Ageing structures, consisting of otoliths and pelvic fin rays for walleye, and otoliths and scales for lake whitefish, were collected. Aging structures were sent to North Shore Environmental Services (Ontario) for analysis.

Liver and gonad somatic indices (LSI and GSI) were calculated as follows:

- Somatic index = (liver or gonad weight (g)/total body weight (g)) X 100.

These indices were used to assess potential contaminant, nutritional, or other environmental stresses on fish health and reproduction.

Fish health was also assessed using the fish health assessment index outlined in Goede (1993). An external and internal pathology examination was conducted for each fish. The percentage of fish with one or more abnormalities was calculated. Observations related to food availability and quality, such as percent mesenteric fat present or fatty livers, were excluded from the calculation. It is important to recognize that this approach was designed to establish base line data for detecting trends in the health and condition of fish populations rather than as a diagnostic tool or to solve specific problems related to fish health or environmental conditions (Goede and Barton, 1990).

Regional Lakes

The Regional Lakes program was conducted to undertake an opportunistic testing program to identify potential mercury, and possibly other chemicals, in fish tissues collected from lakes located within the RAMP study area. The protocol developed by the RAMP Fisheries Sub-group is provided in Appendix A6.

Muscle tissues from lake whitefish, walleye, and northern pike were also collected from Christina Lake and Lake Claire. Fish from Christina Lake were collected using multi-gang gill nets by the Alberta Department of Sustainable Resource Development (ASRD) in September 2003, as part of an annual fall walleye index netting program. Fish from Lake Claire were also collected using gill nets (size unknown) by a member of the Fort Chipewyan community in December 2002. Efforts were made to collect 10 fish of each of the target species. Only large fish were collected to ensure fish were representative of sizes used for human consumption. Fork length and weight were measured for fish collected for both studies; sex and maturity of fish were only reported for fish collected from Christina Lake.

From the three largest fish per species, individual tissue samples were collected for mercury analysis. In addition, two composite samples of five fish per sample were derived from the 10 available fish (including the three largest fish sampled above). Efforts were made to duplicate the size range for each composite. Composite samples were also analyzed for mercury.

The tail sections (between the last rib and end of the caudal peduncle) of fish from Christina Lake were collected and shipped directly to ETL by ASRD for further dissection, compositing, and analysis. Whole fish from Lake Claire were frozen and later shipped to ETL for further dissection, compositing, and analysis.

Sample sizes for lake whitefish and walleye from Lake Claire were limited. Consequently, only two individual tissue samples per species were analyzed.

6.2.2.2 Analyses

Chemical Analyses

Composite samples were prepared at ETL by combining an equal weight of muscle from five fish for each size class. Remaining tissue samples were archived frozen at the testing laboratory pending further analyses.

Individual and composite muscle samples of fish from the Athabasca River, Christina Lake, and Lake Claire were analyzed for mercury. Composite samples from the Athabasca River fish were also analyzed for:

- Metals: aluminum, antimony, arsenic, barium, beryllium, boron, cadmium, chromium, cobalt, copper, iron, lead, lithium, manganese, molybdenum, nickel, selenium, silver, strontium, thallium, tin, titanium, vanadium, and zinc.

- Tainting Compounds (PAHs): thiophene, toluene, M+P-xylenes, o-xylene, 1,3,5-tribmethylbenzene, and naphthalene. There are fourteen compounds that are known to have the potential to taint fish muscle (described in Golder 2002), but only these six analytes can be measured effectively.

Analyses were conducted on a wet weight basis. The methods and detection limits used for chemical analyses are presented in Table 6.4.

Table 6.4 Methods of analyses and detection limits for metals and tainting compounds.

Analyte	Detection Limit (mg/kg)	Method of Analysis
Metals		
Aluminum (Al)	4	EPA 200.3/200.8-ICPMS
Antimony (Sb)	0.04	EPA 200.3/200.8-ICPMS
Arsenic (As)	0.2	APHA 3114 C-AAS – Hydride
Barium (Ba)	0.08	EPA 200.3/200.8-ICPMS
Beryllium (Be)	0.2	EPA 200.3/200.8-ICPMS
Boron (B)	2	EPA 200.3/200.8-ICPMS
Cadmium (Cd)	0.08	EPA 200.3/200.8-ICPMS
Chromium (Cr)	0.2	EPA 200.3/200.8-ICPMS
Cobalt (Co)	0.08	EPA 200.3/200.8-ICPMS
Copper (Cu)	0.08	EPA 200.3/200.8-ICPMS
Iron (Fe)	2	EPA 200.3/200.7-ICPOES

Table 6.4 (cont'd).

Analyte	Detection Limit (mg/kg)	Method of Analysis
Metals		
Lead (Pb)	0.04	EPA 200.3/200.8-ICPMS
Lithium (Li)	0.5	EPA 200.3/200.8-ICPMS
Manganese (Mn)	0.04	EPA 200.3/200.7-ICPOES
Mercury (Hg)	0.01	EPA 200.3/200.8-ICPMS
Molybdenum (Mo)	0.04	EPA 200.3/200.8-ICPMS
Nickel (Ni)	0.08	EPA 200.3/200.8-ICPMS
Selenium (Se)	0.2	APHA 3114 C-Auto Continuous Hydride
Silver (Ag)	0.08	EPA 200.3/200.8-ICPMS
Strontium (Sr)	0.04	EPA 200.3/200.8-ICPMS
Thallium (Tl)	0.04	EPA 200.3/200.8-ICPMS
Tin (Sn)	0.08	EPA 200.3/200.8-ICPMS
Titanium (Ti)	0.05	EPA 200.3/200.7-ICP-OES
Vanadium (V)	0.08	EPA 200.3/200.8-ICPMS
Zinc (Zn)	0.2	EPA 200.3/200.8-ICPMS
Tainting Compounds (PAHs)		
Thiophene	0.02	EPA 5021/8240-Headspace GC/MS
Toluene	0.02	EPA 5021/8240-Headspace GC/MS
M+P-Xylenes	0.02	EPA 5021/8240-Headspace GC/MS
o-Xylene	0.02	EPA 5021/8240-Headspace GC/MS
1,3,5-Trimethylbenzene	0.02	EPA 5021/8240-Headspace GC/MS
Naphthalene	0.02	EPA 5021/8240-Headspace GC/MS

Data were not presented for naturally occurring elements such as potassium, phosphorus, magnesium, and sodium that are not associated with oil sands activities, or with adverse effects on humans, fish, or wildlife through fish consumption.

Statistical Analyses

Scatterplots were used to initially assess the relationships between mercury concentrations in fish and whole-organism parameters. Rank correlations were then used to evaluate relationships between these variables for each species and sex combination. The significance of a correlation was determined using critical values of Spearman's correlation coefficient (r_s). A correlation was described as moderate if $0.50 > r_s < 0.75$ and strong if $r_s > 0.75$. If significant rank correlations were observed, linear regression was used to further evaluate the relationship. Assumptions of regression models were tested and if necessary regressions were performed using $\log_{10}$-transformed or ranked data. All statistical analyses were performed using SYSTAT 10 (SPSS 2000).

6.2.2.3 Screening for Potential Effects

Tissue chemistry data for the Athabasca River, Christina Lake, and Lake Claire were compared to several criteria to assess potential effects on humans, fish, and piscivorous wildlife.

Effects on Human Health

To assess potential effects of ingestion of fish tissue on human health, fish tissue data were screened against the following criteria:

- Health Canada Guidelines for chemical contaminants in fish (CFIA 2003) and for exposure of Indian and Inuit residents to methylmercury in the Canadian environment (Health Canada 1978, as cited in Lockhart et al. 1995);
- Region III USEPA risk-based criteria for consumption of fish tissue for recreational and subsistence fishers (USEPA 2003); and
- National USEPA risk-based screening values for consumption of fish tissue (USEPA 2000).

The Health Canada guidelines for chemical contaminants in fish are designed for the average fish consumer; the only contaminant evaluated in the current study that has a guideline is mercury (as total mercury). The Health Canada guideline for methylmercury for Indian and Inuit residents represents a more stringent criterion for subsistence fish consumers. The regional and national USEPA criteria, which are risk-based criteria that take into account the toxicity (including carcinogenicity) of the contaminant, body weight of the consumer, and exposure rate, include criteria for a larger number of contaminants. The national criteria also provide criteria for several contaminants for different exposure scenarios (e.g., recreational and subsistence fishers). The Health Canada guideline for subsistence fishers is less conservative (four times higher) than the USEPA screening value for subsistence fishers. Because the USEPA criterion for subsistence fishers is based on more recent toxicology data and models, it is the more pertinent of the two criteria.

Effects on Fish and Wildlife

To assess potential effects on fish, fish tissue data were compared to the lowest tissue residue concentrations linked to effects (or a lack of effects). Effects thresholds were derived from laboratory-based studies summarized in Jarvinen and Ankley (1999); these effects thresholds relate tissue residues to sublethal and lethal effects for aquatic organisms exposed to a number of inorganic and organic chemicals. The full range of effects (or no effects) thresholds are presented in Table 6.5, along with information regarding the studies that these thresholds were derived from, including the endpoints evaluated, tissue type, species, life stage, and/or size of fish, exposure route and duration of exposure. Only the most relevant studies were used to generate effects thresholds. Studies for small-bodied fish or tropical fish species, and those that simultaneously evaluated effects of conventional variables on toxicity or maternal transfer studies, were excluded. Data derived from acute exposures were only included for contaminants where there was a paucity of data.

To assess potential effects on wildlife that consume fish, fish tissue data were compared to CCME criteria for avian and mammalian piscivores (CCME 2001b). Mercury (as methylmercury) was the only contaminant analyzed that had a criterion.

Effects on Palatability

Elevated concentrations of tainting compounds can result in decreased palatability of fish due to presence of an undesirable odor or flavor. To assess potential tainting of fish tissues, concentrations of tainting compounds were compared to criteria developed by Jardine and Hrudey (1988). Tainting compounds present at concentrations above 1 mg/kg are believed to result in a detectable undesirable odor or taste.

Table 6.5 **Concentrations of metals that have lethal, sublethal or no effect on freshwater fish (from Jarvinen and Ankley 1999).**

Variable	Endpoint		Effects Concentrations (mg/kg)	Tissue	Species	Life Stage or Size	Exposure Route	Duration (days)
Metals								
Aluminum	Survival	no effects	1.0 - 1.15	muscle	rainbow trout, Atlantic salmon	171 g, alevin	oral, water	30 - 42
		effects	20 - 36.8	whole body	Atlantic salmon	alevin	water	30
Antimony	Survival	no effects	5	whole body	rainbow trout	fingerling (1.2 g)	water	30
		effects	9	whole body	rainbow trout	fingerling (1.2 g)	water	30
Arsenic	Survival	no effects	2.6 - 11.4	carcass, whole body	rainbow trout	juvenile	oral, water	21 - 56
		effects	11.2 - 17.9	carcass	rainbow trout	juvenile	oral	56
	Growth	no effects	0.9 - 6.5	carcass, whole body	rainbow trout	juvenile	oral, water	21 - 56
		effects	3.1	carcass	rainbow trout	juvenile	oral	56
Barium	-	-	-	-	-	-	-	-
Cadmium	Survival	no effects	0.02 - 2.8	muscle	rainbow trout, brook trout	150 -200 g, adult	water, ip injection	210 - 455
		effects	0.14 - 0.7	whole body	rainbow trout, brook trout	5 - 15 g	water	29 - 30
	Growth	no effects	0.09 - 2.8	muscle, whole body	rainbow trout, brook trout	3.1 g, 5 g, adult	water	30 - 455
		effects	0.12 - 0.96	muscle, whole body	rainbow trout, Atlantic salmon	3.1 g, alevin	water	92 - 210
	Reproduction	no effects	0.4	muscle	rainbow trout	adult	water	455
		effects	0.6	muscle	rainbow trout	adult	water	455
Chromium	-	-	-	-	-	-	-	-
Copper	Survival	no effects	0.5 - 3.4	muscle	rainbow trout, brook trout	embryo-adult-juvenile	water	0.33 - 720
		effects	0.5	muscle	rainbow trout	138 g	water	0.33
	Growth	no effects	3.4	muscle	brook trout	embryo-adult-juvenile	water	720
	Reproduction	no effects	3.4	muscle	brook trout	embryo-adult-juvenile	water	720
Iron	-	-	-	-	-	-	-	-
Lead	Survival	no effects	4.0	carcass	rainbow trout	under-yearlings (6.5 g)	water	224
Manganese	-	-	-	-	-	-	-	-

Table 6.5 (cont'd).

Variable	Endpoint		Effects Concentrations (mg/kg)	Tissue	Species	Life Stage or Size	Exposure Route	Duration (days)
Mercury[1]	Survival	no effects	1.91 - 35.0	whole body, muscle	rainbow trout, brook trout	10 - 20 mm, juvenile, fingerling, yearling-adult, adult	ip injection, oral, water	15 -273
		effects	3.7 - 31	whole body, muscle	rainbow trout, brook trout northern pike	10 - 20 mm, subadult (100 - 150 g), yearling-adult, adult	ip injection, oral, water	186 - 273
	Growth	no effects	2.28 - 29.0	whole body, muscle	rainbow trout	fingerling, juvenile	oral, water	24 - 105
		effects	8.6 - 35.0	whole body, muscle	rainbow trout	fingerling	oral	84 - 105
	Reproduction	no effects	9.2	muscle	brook trout	yearling-adult	water	273
		effects	23.5	muscle	brook trout	yearling-adult	water	273
Nickel	Survival	no effects	0.82 - 58.0	muscle	rainbow trout, carp	15 g, 150 - 200 g	water	5 - 180
		effects	118.1	muscle	carp	15 g	water	4
Selenium	Survival	no effects	0.28 - 3.1	whole body, carcass	rainbow trout, chinook salmon, largemouth bass	larvae-swim-up, egg-juvenile, fingerling-juvenile, juvenile	water, oral	28 - 308
		effects	0.92 - 2.5	whole body, carcass	rainbow trout, chinook salmon	larvae-swim-up, .fingerling-juvenile	water, oral	28 - 168
	Growth	no effects	0.08 - 1.08	whole body, carcass	rainbow trout, chinook salmon	larvae-swim-up, egg-juvenile, fingerling-juvenile, juvenile	oral	60 - 308
		effects	0.32 - 2.08	whole body, carcass	rainbow trout, chinook salmon	larvae-swim-up, fingerling-juvenile, juvenile	oral	60 -168
Silver	Survival	no effects	0.003	carcass	largemouth bass	young-of-year	water	180
	Growth	no effects	0.003	carcass	largemouth bass	young-of-year	water	180
Strontium		-	-	-	-	-	-	-
Tin		-	-	-	-	-	-	-
Titanium		-	-	-	-	-	-	-
Vanadium	Survival	no effects	5.33	carcass	rainbow trout	juvenile	oral	84
	Growth	no effects	0.02	carcass	rainbow trout	juvenile	oral	84
		effects	0.41	carcass	rainbow trout	juvenile	oral	84
Zinc	Survival	no effects	60	whole body	Atlantic salmon	juvenile	water	80
	Growth	no effects	60	whole body	Atlantic salmon	juvenile	water	80

\- = no data

[1] methylated forms of mercury

6.2.3 Muskeg River Fish Fence Program

6.2.3.1 General

The Muskeg River has been designated as an important tributary to the Athabasca River system due to its proximity to various existing and proposed oil sands developments and its importance to the local community of Fort McKay. Therefore, accurate information on fish and fish habitat in the watershed is needed to support impact monitoring and to provide any required follow-up measures.

The 2003 fish sampling program on the Muskeg River was conducted in the spring between May 2 and May 27. The main objective of the fish program was to contribute to the ongoing monitoring of resident fish populations in the system, as well as information on the use of the Muskeg by fish from the mainstem Athabasca River. The primary activity under the program was the deployment of a fish counting fence across the Muskeg River, which was used to obtain accurate counts of all species movements into and out of the Muskeg River during the spring season. Tagging of all fish counted through the fence provided additional information regarding patterns of timing of migration by species and by sex. Secondary elements of the Muskeg fish program included a partial fish fence, consisting of two hoop nets, which was used to provide comparative data, larval drift traps to assess their potential usefulness as a tool for estimating fish abundance (particularly grayling), and a limited electrofishing program conducted in the vicinity of the fish fence to provide information on resident and non-resident fish, particularly small-bodied species, which were not captured at the fence. The following sections outline the various methods associated with the fish program on the Muskeg River.

Specifications for the major equipment items used during the Muskeg River fish program are provided in Table 6.6 below. A number of other smaller equipment items, such as dissection tools, fish measuring boards, construction tools, first aid kits, etc. were also used during the field data collection component of the program.

6.2.3.2 Fish Fence

The Muskeg River fish fence was built to capture and enumerate fish species migrating both upstream and downstream in the river, and to acquire a wide range of data on adult spawning populations in the Muskeg watershed. The fish fence, which is a repeatable survey method, provided quantitative and qualitative data on major large-bodied fish species, including Arctic grayling (*Thymallus arcticus*), northern pike, walleye, longnose sucker, and white sucker (*Catastomos commersoni*). Several previous efforts at installing and operating a fish fence in the lower Muskeg River have been carried out under RAMP. Historically, the success of a spring fish fence on the river has been limited, due to a variety of factors including low and high water levels, instability of the fence integrity from scouring and erosion of stream substrate, large beaver dams limiting spawning run movement, and late ice conditions.

Table 6.6 Equipment used during the Muskeg River fish program, spring 2003.

Equipment Item	Model	Specifications
Electrofishing Units	Smith Root Model 12-B POW	100 to 1000 Volts
Global Positioning System (GPS)	Garmin 76	12 Channel
Water Quality measurement	YSI 85	DO, conductivity, temperature
pH Measurement	pHTestr2	pH Range of 0 to 14
Thermometer	Alcohol thermometer	Temperature Range –35 to 50 °C
Portable flow meter	Marsh-McBirney Flow-Mate Model 2000	Electromagnetic flow measurement
Balance	UWE HS-7500	0 kg to 7.5 kg (±5.0 g)
	Kilotech KLB	0 kg to 5 kg (±1.0 g)
	UWE HS-3000	0 kg to 3 kg (±2.0 g)
	AM2501-SPL	0 kg to 12 kg (±25.0 g)
Fish Traps	Gee Minnow Traps	Standard Mesh Size (1/8 “)
Fish fence components	—	
Hoop net	—	Three total (one for backup)
Larval drift traps	—	Five total (one for backup)
Floy tags	—	Specific to the RAMP program

Specific objectives of the 2003 Muskeg River fish fence project were:

- To generate ongoing data on the biology and movement of large-bodied fish species that use the Muskeg River drainage;
- To use these data to assist in the identification and quantification of local and regional environmental impacts/effects in the Muskeg watershed; and
- To document the current use of the Muskeg River by spawning fish populations from the Athabasca River.

A preliminary planning step was first undertaken to predict the spring discharge of the Muskeg River, using a screening level hydrological assessment based on snow pack levels. For planning purposes, it was decided that stream discharge higher than 9 m^3/s would constitute unsuitable conditions for safely deploying a full fish fence. In such cases, two partial fish fences using hoop nets would be employed. If conditions allowed deployment of a full fence program, the partial fence was to be run concurrently for comparative purposes. Decision framework and protocols developed by RAMP for operation of the fish fence are provided in Appendix A6.

The two partial fish fences consisting of hoop nets deployed 500 m apart were designed to evaluate and compare both approaches for quantifying the spawning run. The hoop nets were used to carry out a mark-recapture study to estimate population sizes and migration patterns. Additional detailed explanations on the hoop net operation are provided in Section 6.2.3.4. An initial assessment of the Muskeg River condition in late April indicated that the fish fence could be properly installed; however the deployment of the partial fence program was delayed until a week later due to logistical reasons.

The 2003 Muskeg River fish fence program also included the use of larval drift traps to estimate larval fish numbers (particularly for grayling). Four larval traps were installed upstream of the fish fence on May 18. More details on the larval trap design are provided below in Section 6.2.3.3. Electrofishing and minnow trapping efforts were also undertaken to further support data from the fish fence.

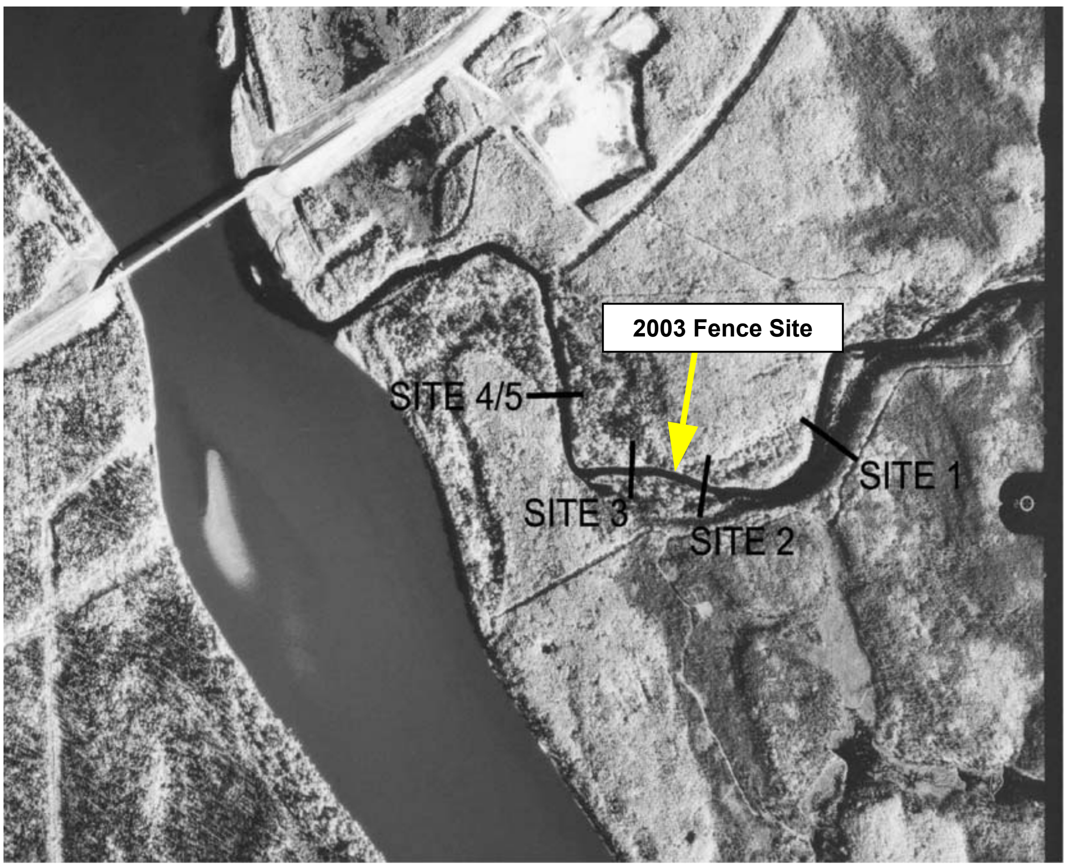
Fish Fence Location and Construction

During a previous reconnaissance study conducted by RAMP in 2002, it was determined that the fish fence should be located at Site 3 as shown on the air photograph in Figure 6.3 (Golder 2003b). However, final siting by the field crew resulted in placement of the fence approximately halfway between Sites 2 and 3. The selected location represented optimal hydraulic conditions, as well as cross-sectional depth profile, acceptable substrate features (e.g., a minimum of bitumen in the substrate mix), and good access and safety characteristics. The site was located on the Muskeg River mainstem approximately 800 m upstream from its confluence with the Athabasca River. UTM coordinates for the site are: Easting 464049 m, Northing 6332081 m, Zone 12, NAD83.

In order to capture the largest possible component of the spring spawning run and to increase the likelihood of capturing migrating Arctic grayling, the fish fence was installed as soon as possible after river ice-out and stream discharge fell below 10 m^3/s. Personnel from the Hatfield office in Fort McMurray monitored ice conditions in the lower Muskeg River daily to assist in determining the earliest date for fence installation. Helicopter support was used to transport equipment to the site on April 30, 2003, and installation of the fish fence began on May 1, 2003. The fence was operational for a 26-day period from May 2 to May 27, 2003.

The fish fence was constructed based on a design developed by Anderson and McDonald (1978), and Kristofferson et al. (1986). Wings of the fence consisted of sections of 96 vertical conduit pipes (1.8 m in height and 1.8 cm in diameter) held in place by two, three meter long, horizontal pieces of aluminum channel. Channels were supported by brackets attached to 2.1 m high x 5 cm diameter aluminum poles and "two by four" wooden A-frames, which were held in place by rock/sand-filled woven polyethylene bags. Conduit were spaced at 3.4 cm centres, leaving 1.6 cm of space between pipes. Upstream and downstream trap boxes, constructed of conduit and spruce "two by fours", were located on opposite sides of the river, and connected by a single centre wing (MacDonell 1991). The traps were anchored in place by driving steel t-bar fence posts into the gravel bed on the upstream and downstream sides of the trap.

Figure 6.3 The Muskeg River, showing potential fish fence sites, and location of the 2003 fence site.



North/South Consultants Inc. oversaw the construction of the fish fence and assisted with the initial on-site deployment of the fence. A view of the installed Muskeg River fish fence is shown in Figure 6.4.

Sampling Procedures

A two-person crew consisting of a Field Manager and a Fisheries Technician (primarily Gary Cooper, Fort McKay Environmental Services Ltd.) monitored the fish fence daily. The two trap boxes were checked for fish every two hours during daylight hours (approximately 07:00 to 19:00 h). Fish captured in the boxes were removed and enumerated by species, date, time, and direction of movement (upstream or downstream). Efforts were made throughout the fish collection program to minimize the impact and stress caused by sampling activities. Table 6.7 lists fish species captured in the fish fence.

Figure 6.4 View of Muskeg River fish fence looking upstream from right bank, May 2003.

Table 6.7 List of common and scientific names of species captured during fish fence operation – Muskeg River, Spring 2003.

Common Name	Scientific Name	Species Code
Lake whitefish	*Coregonus clupeaformis*	LKWH
Mountain whitefish	*Coregonus williamsoni*	MTWF
Longnose sucker	*Catostomus catostomus*	LNSC
White sucker	*Catostomus commersoni*	WHSC
Northern pike	*Esox lucius*	NRPK
Arctic grayling	*Thymallus arcticus*	ARGR
Walleye	*Stizostedion vitreum*	WALL

The following biological indices were recorded from all fish sampled:

- Species, life stage, sex and maturity (e.g. pre-spawning, ripe or post-spawning);
- Direction of capture (downstream trap, upstream trap);
- Fork length (± 1.0 mm);
- Fish weight (± 2.0/5.0 g) using an electronic hanging scale for all 'large' fish (>100 g) captured; and
- Fish weight (± 0.1g) using a calibrated electronic balance for all 'small' fish (< 100 g) captured.

This information was recorded on field data sheets and later transferred to an electronic database for analysis.

All fish were examined for any external abnormalities or pathological conditions, such as deformities, eroded fins, lesions, and tumors to provide an external pathological index (PI). Appropriate non-lethal aging structures (fin clips and scales) were collected from all fish captured (according to MacKay et al. 1990). The aging structures were placed in scale envelopes and dried for future aging. The adipose fins on all (n=2) captured grayling were clipped and archived in individually-labeled envelopes pending future DNA analysis, as required.

Floy tags with a unique identification number (specific to the RAMP program) were inserted into the posterior end of the dorsal fin of all sport fish (i.e., northern pike and walleye, but not Arctic grayling) and the first 50 white sucker and longnose sucker processed each day, the tag number was recorded, and the fish released unharmed in the direction they were moving when captured. Recaptured tagged fish caught in the trap boxes had their Floy tag number recorded and were released in the river in the direction they were moving when they were caught.

Examples of the field data sheets are presented in Appendix A6.

6.2.3.3 Electrofishing

Sampling protocols for the 2003 Muskeg River fish program specified that, depending on the time available to the field crew, a limited electrofishing program was to be conducted in the vicinity of the fish fence. The goal of this sampling was to provide information on resident and non-resident fish, particularly small-bodied species, which would not be captured at the fence.

Fish sampling employed standard multiple pass electrofishing methodology (Bohlin *et al.* 1989) for a given length of stream channel habitat. Electrofishing was conducted by a two-person crew using a Smith-Root 12B-POW battery-powered electrofishing unit.

Given the short time available to the field crew and the poor water flow and clarity conditions in the Muskeg River during the May 2003 sampling period, electrofishing activities were limited to two sampling sites. The first electrofishing pass was conducted in a backchannel of the Muskeg River as well as a 130 m section on the left bank of the river. The second pass was conducted over the same 130 m section of the Muskeg River mainstem. During each pass, captured fish were placed in a 25 L pail and subsequently transferred to a larger holding tub for processing. Specimens were sedated with sodium bicarbonate to enable easier handling during processing.

All captured fish were identified and measured for fork length (± 1.0 mm) and weight (± 0.1 g) using an electronic balance that was calibrated prior to each measurement. The fish were then revived in a bucket of fresh water for eventual release back into the river. All fish were monitored at regular intervals to avoid excessive stress or mortality.

6.2.3.4 Hoop Nets and Minnow Traps

The original purpose for the hoop net program was to provide a back-up fishing method in the event the fish fence failed or stream flows were too high for fence deployment. A secondary goal was to test the feasibility of running a mark/recapture study using two hoop nets in series to estimate spawning run size in the Muskeg River. The sampling design called for the hoop nets to remain in place throughout the entire fish program and to be checked every two hours (Figure 6.5). Any fish captured in the downstream net that were not previously tagged (any fish swimming by the nets would likely have been tagged at the fence) would be tagged and processed as specified in the fish fence protocols.

Figure 6.5 Example of hoop net deployed approximately 60 m downstream from the fish fence location, Muskeg River, May 2003.

A Gee-type minnow trap sampling program was also implemented in the Muskeg River for a limited period during the spring of 2003. The purpose of this activity was to provide supplementary data on small-bodied fish not captured in the fish fence. Overnight trap sets were conducted primarily along the banks and in a back channel of the river in the immediate vicinity of the fish fence.

6.2.3.5 Fish Larval Drift Traps

Trap Location and Installation

Larval drift traps were built and installed in the Muskeg River immediately upstream of the fish fence from April 29, 2003 to May 26, 2003. This location was chosen primarily for ease of access as it was close to the fish fence. The drift traps were set in the thalweg of the river with the top of the trap opening positioned 10 cm below the surface. Steel T-bars were used to secure the traps in the river. A total of four traps were placed in the river at the sampling site.

Sampling Procedure

Prior to sampling from the drift traps, water velocity was recorded. Average velocity for the set was calculated using velocity data recorded when the trap was set and again when the trap was pulled. A catch-per-unit-effort (CPUE) was then calculated as a catch per unit of volume, with total volume sampled equal to the cross-sectional area of trap mouth × mean velocity × duration. Length of time the trap was set was used to determine duration of the set. At the beginning of the fish program, the larval traps were set over a period of 8-10 hours, or during daylight hours. Due to the long set times and the large amount of debris present in the Muskeg River, the traps quickly became clogged. The set times were systematically decreased to a point where the traps did not become overly clogged with debris; the final average set time was one hour.

After each set, the net was carefully cleaned so that any material and larval fish adhering to the mesh was washed into the cod-end bottle. The bottle was then carefully removed so as to ensure that none of the contents spilled out; contents were rinsed onto a metal dissecting tray for sample processing. After processing, the samples were then placed into 500 ml containers and preserved with formalin for future analysis. The sample containers were labeled with the date, trap number, and other site identification information. The cod-end bottle was then replaced on the trap and the process repeated.

The drift trap net was checked daily, to ensure it was clean and that the cod-end bottle was secure. Trap mesh and bottle screens were checked daily to ensure that they were in good shape and had no tears or holes. The traps were adjusted accordingly depending on the height of the river on any given day to ensure that the trap end was positioned properly under the water surface.

Sample Processing

Samples collected from the larval drift traps were sorted and processed in the field immediately after collecting bottles were recovered. Final identification of any fish larvae was carried out in a laboratory. Samples were emptied into plastic sorting trays (approx. 12" x 4" x 2") to identify larval fish. The containers were labeled with the date, trap number, and project code.

6.2.3.6 Water Quality Measurement

Water quality measurements were taken daily throughout the duration of the Muskeg River fish program (April 30 to May 28, 2003) at a site immediately upstream of the fish fence. A YSI 85 meter was used to measure temperature, dissolved oxygen and specific conductance. pH was recorded using a pHTestr2. Other parameters, such as weather conditions and air temperature, were also recorded on a daily basis at the fish fence site. A HOBO Water Temp Pro (H20-001) data logger was deployed immediately upstream of the fish fence site and recorded water temperature for a period of 23 days between May 1 and May 24, 2003. Average readings were generated every three minutes and results were recorded in degrees Celsius (±0.2°C accuracy). A second data logger was used to record air temperatures for a period of 18 days from May 1 to May 20, 2003.

Depth/velocity transects were carried out on four separate occasions (May 3, 11, 18, and 23, 2003) during the Muskeg River fish program. The transects were conducted to calculate total discharge and subsequent fish usage patterns within certain habitat units. Velocity measurements (± 0.01 m/s) were made with a Marsh-McBirney Model 2000 portable flow meter. Parameters such as channel depth and stream velocity were recorded and used to calculate a total discharge volume in cubic metres per second. Manual discharge measurements obtained during the fence operation were used to develop a stage-discharge rating curve for the fence station. Daily discharge measurements for the Muskeg River station were compared with data obtained at a station monitored by Water Survey of Canada S7 (WSC Station #07DA008). The station, called "Muskeg River near Fort Mackay", is located approximately 15 km upstream of the river mouth.

6.2.3.7 Age Determination

Ageing structures were collected from all fish counted at the fish fence; however, only a subsample was submitted for ageing. Due to the high number of white sucker captured, approximately 20 fish were selected from each 25 mm length class within the range of 375 and 550 mm fork length. All white sucker smaller or larger than this range were also submitted for ageing. In total, 179 white sucker (25% of the total) were aged. Similarly, a subsample of 151 longnose suckers were randomly selected from the total sampled population (n=191), following the stratified-random approach described above for white sucker.

Ageing structures were collected from 85 of 96 northern pike and submitted for analysis.

North Shore Environmental Services of Ontario analyzed all ageing structures from the fish fence program. Scales were used for ageing Artic grayling, mountain whitefish, and walleye. For each fish, several scales were cleaned and mounted between two glass sides and the annuli read from the image produced by an Eberbach microprojector.

Pelvic fin rays were used to age northern pike, while white and longnose suckers were aged using pectoral fin rays. Cross sections were acquired from each fin ray sample as described by Beamish and Harvey (1969) and Beamish (1973). After embedding the dried fin rays in epoxy, thin sections (0.5 mm to 1.0 mm) were cut by hand using a jeweller's saw with No. 6 or No. 7 blades. These sections were then mounted in Permount on glass slides and read under a microscope.

A limited number of fish were sacrificed to acquire otoliths for age determination. Otolith samples were first ground by hand on a carborundum. The otoliths were then cleared in a 3:1 mixture of benzyl benzoate and methyl salicylate, and read under a dissecting microscope using reflected light against a black background.

6.2.3.8 External Pathological Index

Fish health was assessed 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 degree of severity and were assigned an index value ranging from 10 to 30; 0 indicated no signs of pathology (see Appendix A6). 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.

6.2.3.9 Data Analysis

For large-bodied fish species captured at the fish fence, the mean and standard error were calculated for fork length, weight, age, condition factor and PI. Fulton's Condition Factor (K) was also calculated according to the formula:

$$K = (\text{body weight [g]} / \text{fork length [mm]}^3) \times 10^5.$$

For large-bodied species with an adequate sample size (i.e., $n \geq 30$), the following parameters were examined:

- size (fork length) frequency distribution;

- age frequency distribution;
- weight versus fork length relationship (i.e., condition); and
- size-at-age (fork length versus age) relationship.

All analyses were performed using SYSTAT 10 statistical software (SPSS 2000). For each species, analysis of Variance (ANOVA) was used to compare fork length between sexes. Estimates of size-at-age (fork length vs. age) and condition (body weight vs. fork length) between sexes were evaluated using analysis of covariance (ANCOVA). An assumption of the ANCOVA model is that the slopes of the regression lines are equal between areas. Therefore, differences in slopes were tested prior to conducting the ANCOVA. Generally, ANCOVA is fairly robust even when slopes are not equal, so slopes were considered different when $p<0.01$ (Paine 1998). Data were $\log_{10}$ transformed where appropriate.

6.3 RESULTS

6.3.1 Fish Inventory

A total of 8,916 fish were captured or observed during fish inventory studies conducted in 2003 (Athabasca River, Clearwater River and Firebag River combined). Over 94% of the total fish were obtained using electrofishing methods; the remainder were captured by beach seining. A total of 20 fish species were collected during the survey. Detailed information describing sampling locations and effort for the 2003 inventory (date, time, electrofishing settings, etc.) are summarized in Appendix A6.2.

6.3.1.1 Athabasca River

Species Composition and Catch-Per-Unit-Effort

A total of 5,546 fish and 20 species were captured during the spring and fall fish inventory on the Athabasca River. Boat electrofishing resulted in the capture/observation of 5,071 fish (spring: 2,566 fish; fall: 2,505 fish) (Table 6.8, Table 6.9) (Appendix A6.3). Species composition (%) and catch-per-unit-effort (#fish/100 seconds) information for electrofishing are shown in Table 6.8 and Table 6.9. Seine netting (spring only) resulted in the capture of an additional 474 fish (Table 6.10).

Table 6.8 Fish inventory results from electrofishing on the Athabasca River, Spring 2003.

Spring Results (total effort = 25,850 s.)					
Species	**Total Captured**	**Total Observed**	**Total (obs.+cap.)**	**Species Composition (% of total)**	**CPUE (#/100 s)**
Arctic grayling	0	0	0	0	0
Burbot	0	1	1	0.04	0
Cisco	1	0	1	0.04	0
Emerald shiner	11	401	412	16.06	1.59
Flathead chub	49	30	79	3.08	0.31
Goldeye	60	38	98	3.82	0.38
Lake chub	3	0	3	0.12	0.01
Lake whitefish	2	5	7	0.27	0.03
Longnose sucker	57	37	94	3.66	0.36
Mountain whitefish	8	4	12	0.47	0.05
Northern pike	20	15	35	1.36	0.14
Pearl dace	0	0	0	0	0
Spottail shiner	1	0	1	0.04	0
Sucker sp.	0	1	1	0.04	0
Trout-perch	60	1,459	1,519	59.20	5.88
Walleye	202	27	229	8.92	0.89
White sucker	47	27	74	2.88	0.29
Yellow perch	0	0	0	0	0
TOTAL	**521**	**2,045**	**2,566**	**100**	

Table 6.9 Fish inventory results from electrofishing on the Athabasca River, Fall 2003.

Fall Results (total effort = 36,195 s.)					
Species	**Total Captured**	**Total Observed**	**Total (obs.+cap.)**	**Species Composition (% of total)**	**CPUE (#/100 s)**
Arctic grayling	3	0	3	0.1	0.01
Burbot	1	0	1	0.0	0.003
Cisco	2	0	2	0.1	0.01
Emerald shiner	3	0	3	0.1	0.01

Table 6.9 (cont'd).

Species	Total Captured	Total Observed	Total (obs.+cap.)	Species Composition (% of total)	CPUE (#/100 s)
Fall Results (total effort = 36,195 s.)					
Flathead chub	11	2	13	0.5	0.04
Goldeye	50	16	66	2.6	0.18
Lake chub	2	0	2	0.1	0.01
Lake whitefish	45	1,551	1,596	63.7	4.41
Longnose sucker	37	43	80	3.2	0.22
Mountain whitefish	16	6	22	0.9	0.06
Northern pike	38	10	48	1.9	0.13
Pearl dace	2	0	2	0.1	0.01
Spottail shiner	0	1	1	0.0	0.003
Trout-perch	41	405	446	17.8	1.23
Walleye	133	45	178	7.1	0.49
White sucker	22	16	38	1.5	0.10
Yellow perch	4	0	4	0.2	0.01
TOTAL	**410**	**2,095**	**2,505**	**100**	

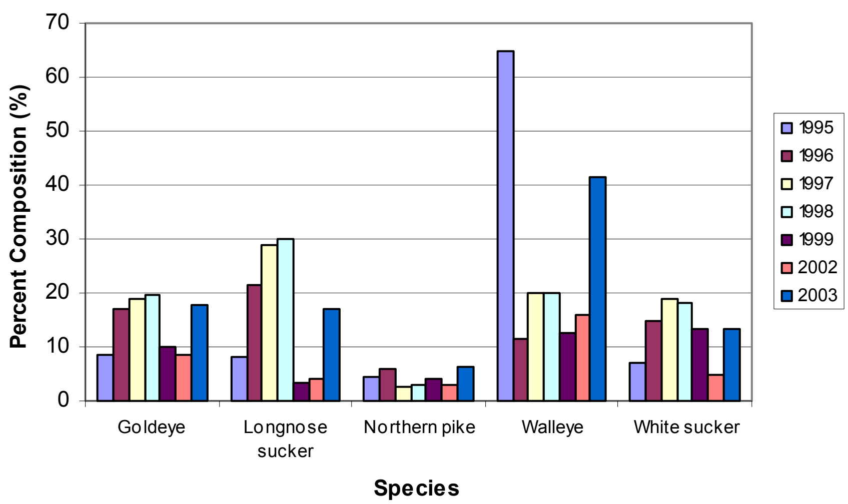
The most abundant large-bodied species captured in 2003 (in declining order) were walleye, goldeye, white sucker, longnose sucker and northern pike (based on electrofishing capture results only; (Table 6.8, Table 6.9). This ranking is identical to that found in 2002, and corresponds to the known characteristics of the fish community utilizing the Athabasca River in the oil sands region (Figure 6.6). Large numbers of trout-perch (total 1,965 individuals) were observed during electrofishing, although only a fraction (<2%) were captured. In dramatic contrast to the spring survey (n=7 fish observed), lake whitefish were highly abundant in the fall (total 1,596 individuals observed; <3% captured to minimize mortality during holding period) in connection with the annual spawning migration for this species.

Percent composition (1995-2003) for select large-bodied species is shown in Figure 6.6. Over the past 7 years, numbers of northern pike have been the most consistent overtime, representing approximately 5% of the fish captured. Goldeye, longnose sucker and white sucker all showed an increase in percent composition relative to 2002. The percent composition of walleye captured in 2003 (>40%) was higher than in all previous years, except 1995 (>65%).

Table 6.10 Fish inventory results from beach seining on the Athabasca River, Spring 2003.

Species	Total Fish Captured	Species Composition (% of total)
Trout-perch	260	54.9
Longnose dace	56	11.8
Lake chub	38	8.0
Spottail shiner	38	8.0
Spoonhead sculpin	32	6.8
Longnose sucker	19	4.0
Pearl dace	19	4.0
Emerald shiner	4	0.8
Brook stickleback	3	0.6
Flathead chub	3	0.6
White sucker	2	0.4
TOTAL	**474**	**100**

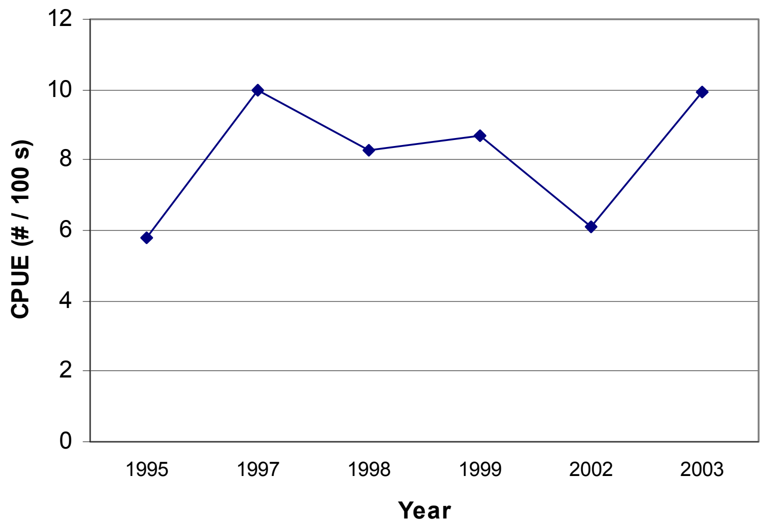
Figure 6.6 Percent composition for common large-bodied species, Athabasca River spring electrofishing inventory, 1995 to 2003.



Note: figure reproduced from (Golder 2003b) with 2003 data added. Figure based on fish captured and observed.

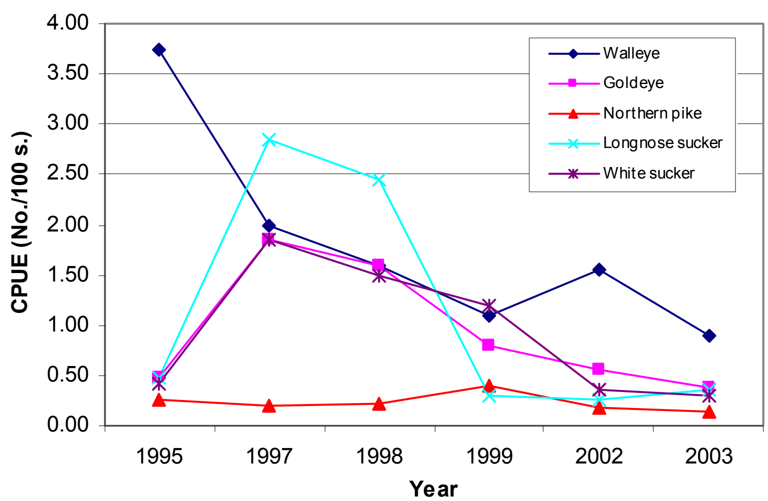
The combined catch-per-unit-effort (CPUE) (captured/observed) increased in 2003 after declining in 2002 (Figure 6.7). Despite a moderate increase in the CPUE of walleye in 2002, results from 2003 indicate a continuation in the decline of walleye captured/observed since 1995 (Figure 6.8). The abundance of longnose sucker, white sucker and goldeye in 2003 continues to be lower relative to previous years, particularly 1997, but similar to results observed in 1995. The CPUE of northern pike has remained consistently low since 1995.

Figure 6.7 Catch-per-unit-effort (CPUE) for all species combined, Athabasca River spring electrofishing inventory, 1995 to 2003.



Note: figure reproduced from (Golder 2003b) with 2003 data added. Figure based on fish captured and observed.

Figure 6.8 Catch-per-unit-effort for key fish indicators, Athabasca River spring electrofishing inventory, 1995 to 2003



Note: figure reproduced from (Golder 2003b) with 2003 data added. Figure based on fish captured and observed

Length-frequency Analysis

Length-frequency histograms (1997-2003) for each key fish indicator species are presented in Figure 6.10 to Figure 6.15.

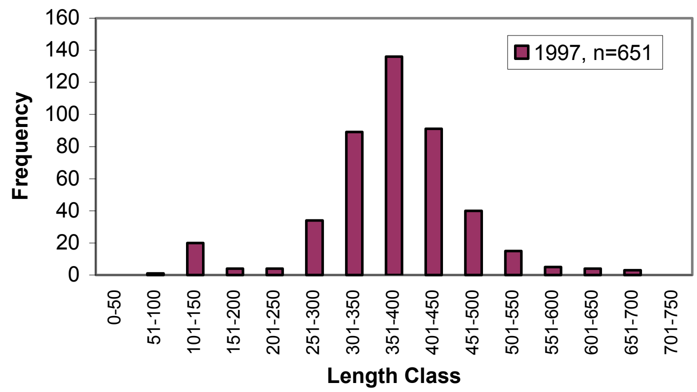
Walleye captured in 2003 were predominantly in the 350-400 mm length class. This class has been the dominant mode in all past inventories with the exception of 1998, where the majority of fish captured were in the 401-450 mm length class (Figure 6.9). Visually, there appeared to be little change in the length-frequency distribution for walleye in the Athabasca River in 2003, relative to historical inventory results. A statistical difference in length-frequency was found among years ($p<0.001$); however, no consistent pattern could be identified over time.

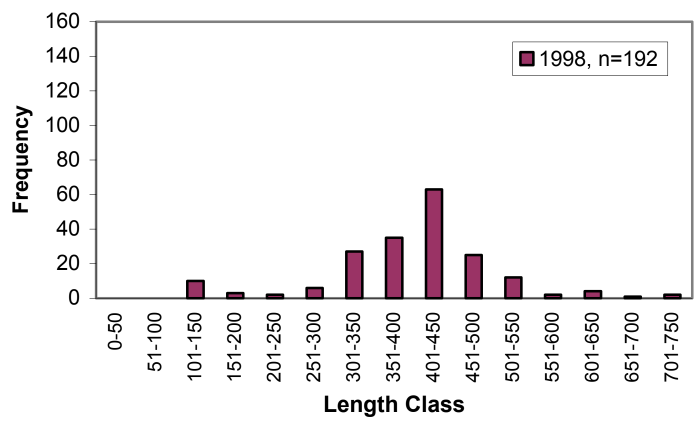
Inventory results for lake whitefish (fall only) in 2003 found the majority to be in the 350-500 m length range, with the peak occurring in the 401-450 mm length class (Figure 6.10). This was also the dominant class in past years. A significant difference in length-frequency data among years was detected ($p=0.001$), however, there was no evidence of a directed shift towards any particular size class in the spawning population.

Goldeye captured during the 2003 spring and fall inventory were dominated by individuals in the 325-350 mm length class (Figure 6.11). Length-frequency distributions for previous survey data have been variable for goldeye, particularly in relation to the number of young fish captured. In 2003, few individuals in smaller length classes were captured. These results are similar to 1999 and 2002 results, but differed from 1997 and 1998 results when greater numbers of small fish were captured. Statistical analysis found a significant difference in length-frequency among years ($p<0.001$).

The length-frequency distribution for longnose sucker has been variable among years (Figure 6.12). Two modes were observed in 2003 (51-100 mm and 401-500 mm length class) suggesting that small, most likely juvenile individuals were present in large numbers. In past years, particularly 1997 and 1998, a single dominant mode was observed ranging from 350-500 mm. Length-frequency distributions were significantly different ($p<0.001$) among years.

Figure 6.9 Length-frequency distributions for walleye captured in the Athabasca River, Spring and Fall, 1997 to 2003.





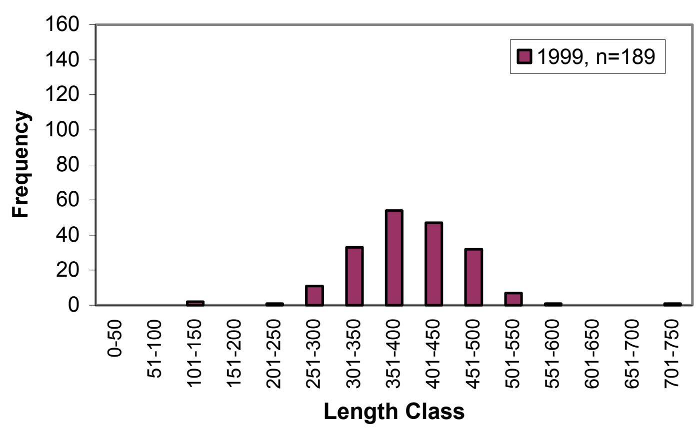
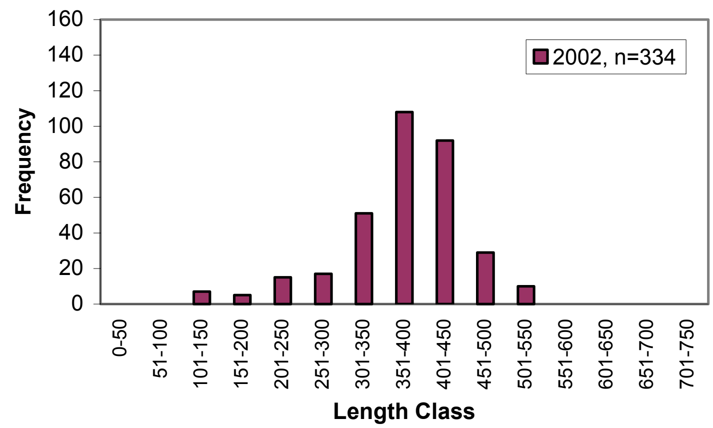
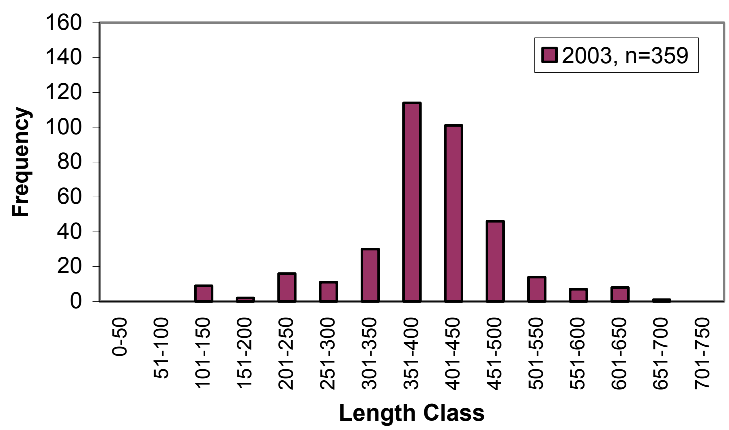


Figure 6.9 (cont'd).

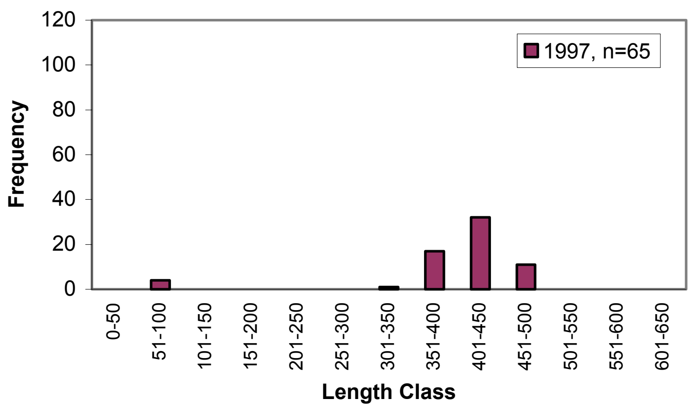




The 2003 length-frequency distribution for northern pike was dominated by fish in the 500-550 mm and 550-600 mm length classes (Figure 6.13). Historically, the majority of individuals captured were between 400 and 600 mm long, with some shifting of the dominant 50 mm class between years (Figure 6.12). Smaller individuals were present in 2003, which contrasts with some years (e.g., 1999) when small fish were not collected. Overall, results from 2003 appear to be within the range of variation in length-frequency distributions seen in recent years. Though the distributions appear variable, there is no indication that the population is changing substantially over time. Statistical analyses found no significant difference (p=0.18) among years.

Trout-perch have been collected during inventory activities in the Athabasca River; however, they have not been included in RAMP monitoring as a key fish indicator until recently. In addition, the size-selective bias inherent in electrofishing limits the comparability of data. Low sample sizes in 1999 to 2002 (<20 fish per year) limited the comparison to results from 1997 (n=63) and 2003 (n=361). The majority of trout-perch collected in 2003 were in the 45-50 mm length class (Figure 6.14). Based on visual observation, it appears that a shift may have occurred towards smaller fish in 2003. In addition, length-frequency relationships were significantly different between years (p<0.001); however, the limited sample size in 1997 relative to 2003, likely strongly influences the comparison.

Figure 6.10 Length-frequency distributions for lake whitefish captured in the Athabasca River, Spring and Fall, 1997 to 2003.



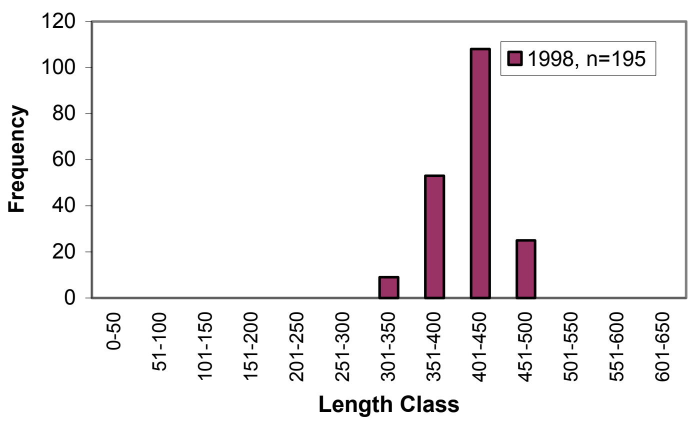
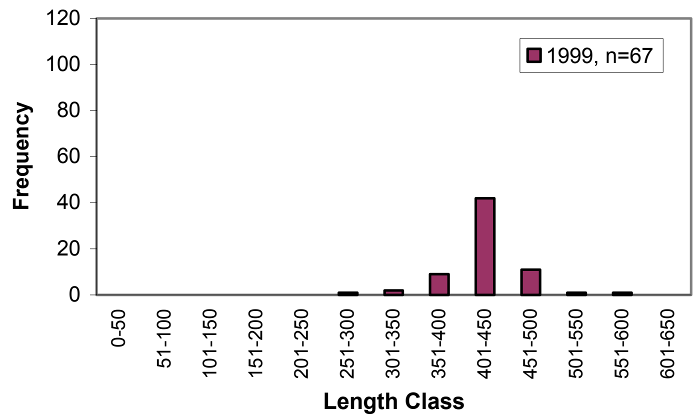


Figure 6.10 (cont'd).



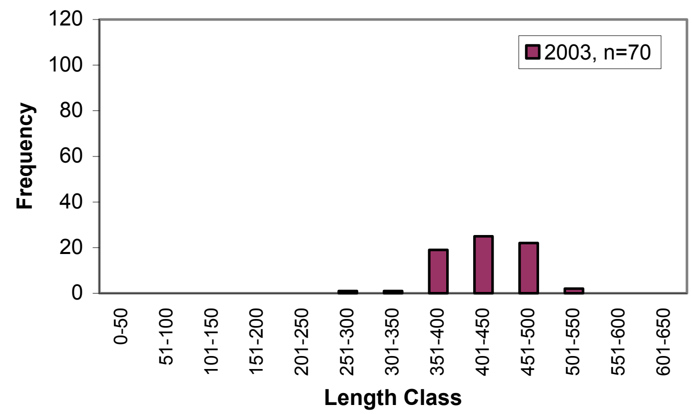


Figure 6.11 Length-frequency distributions for goldeye captured in the Athabasca River, Spring and Fall 2003.

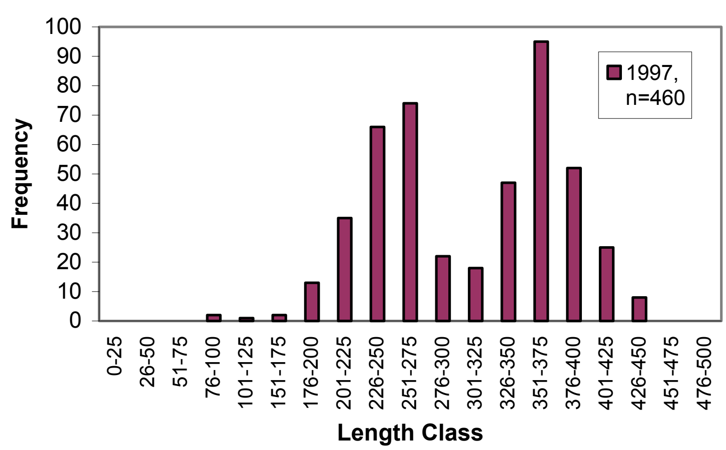
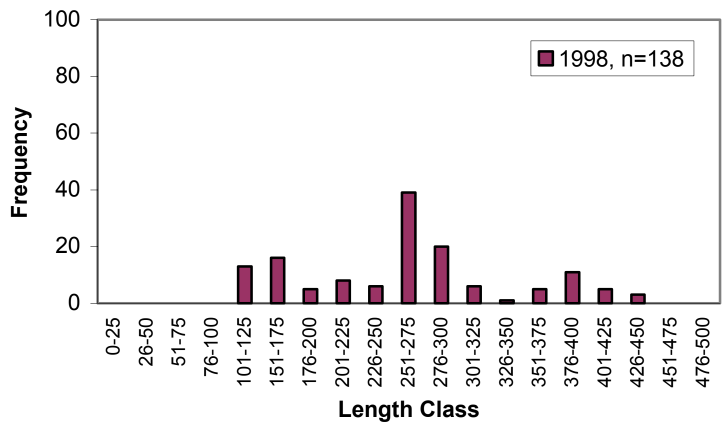
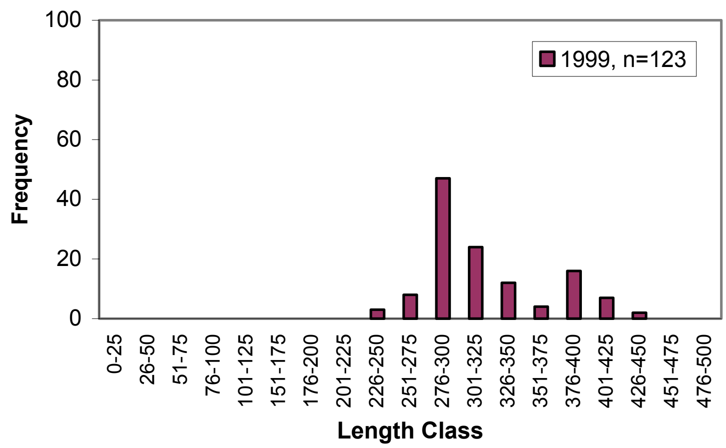


Figure 6.11 (cont'd).





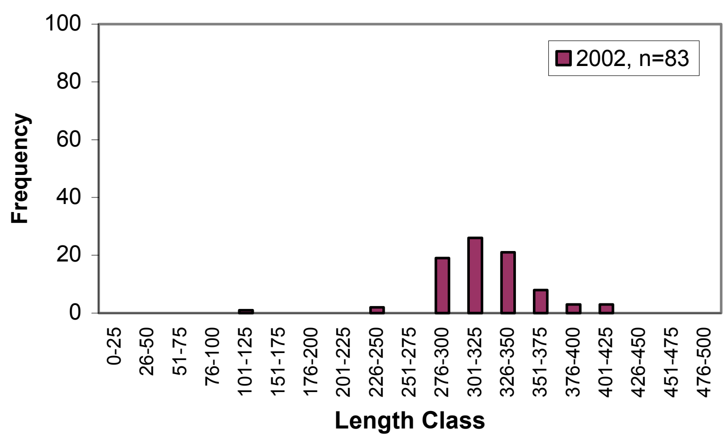


Figure 6.11 (cont'd).

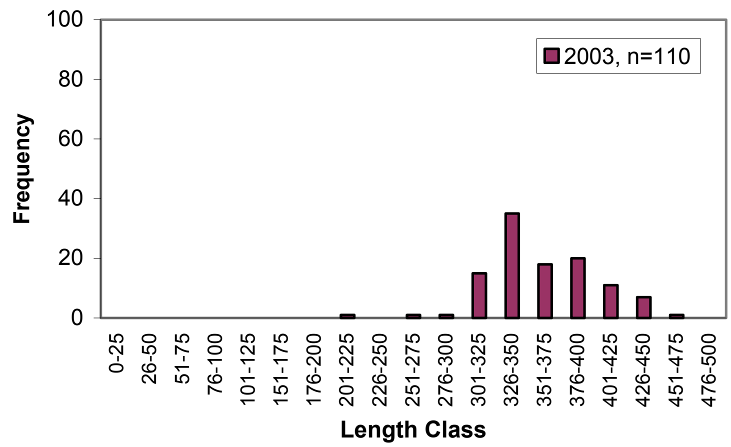


Figure 6.12 Length-frequency distributions for longnose sucker captured in the Athabasca River, Spring and Fall, 1997 to 2003.

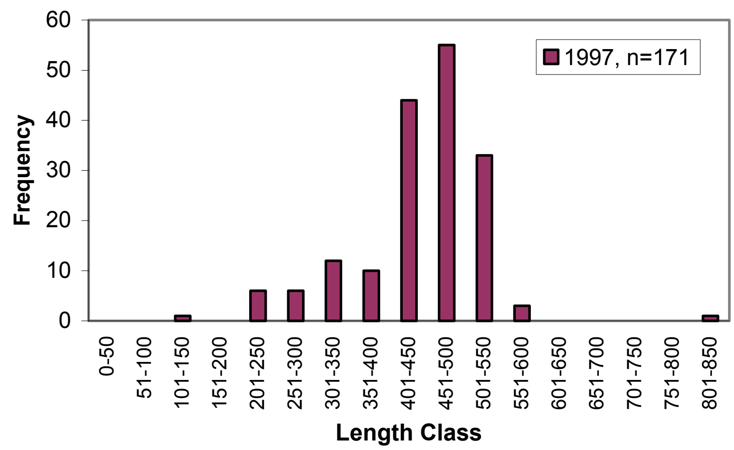
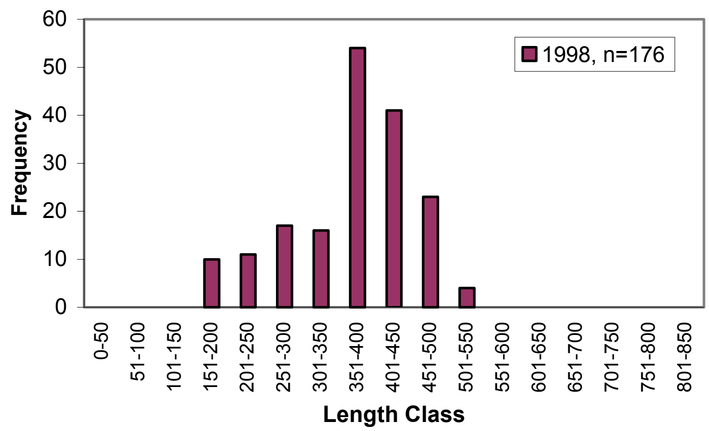
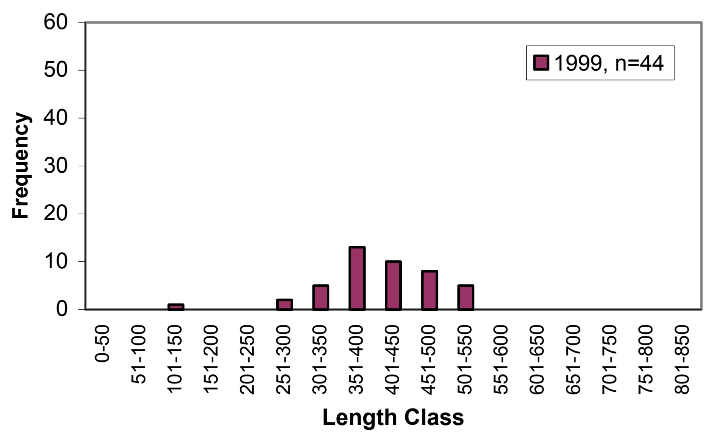


Figure 6.12 (cont'd).





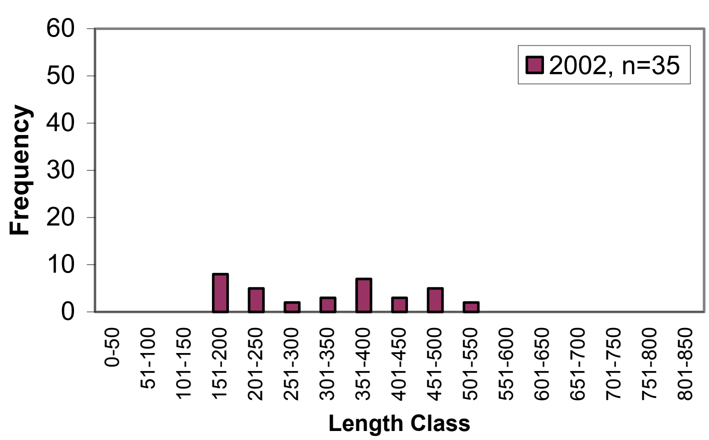


Figure 6.12 (cont'd).

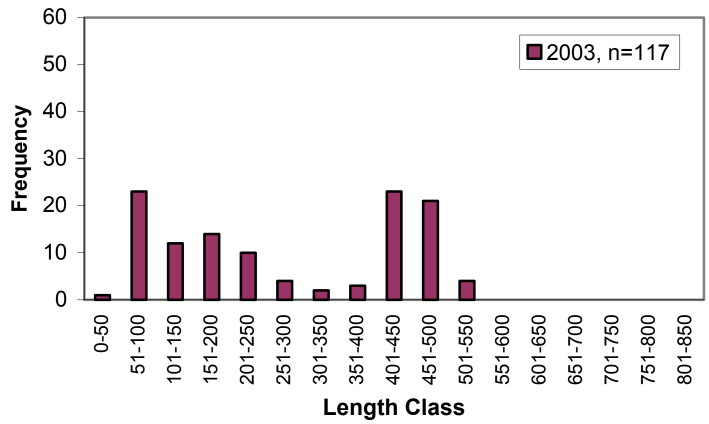
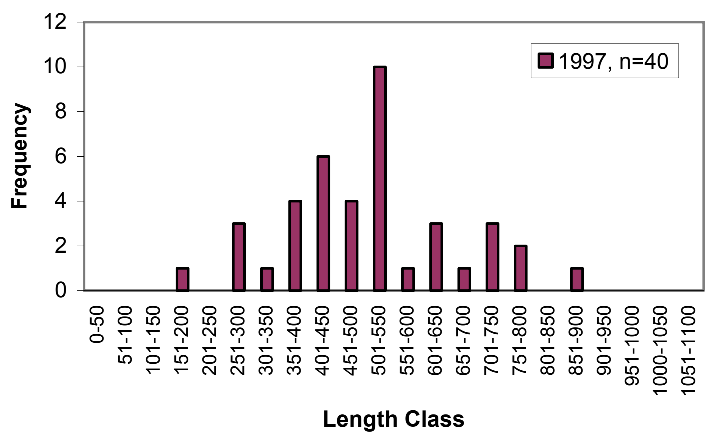


Figure 6.13 Length-frequency distributions for northern pike captured in the Athabasca River, Spring and Fall, 1997 to 2003.



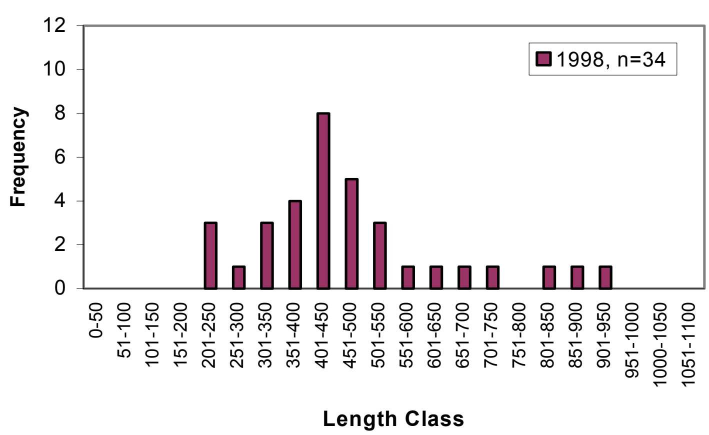
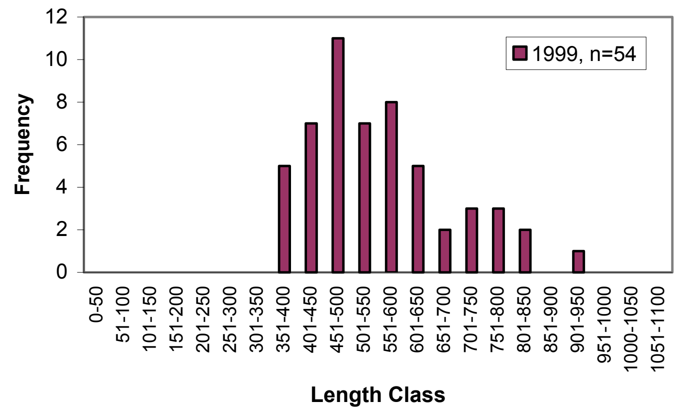


Figure 6.13 (cont'd).



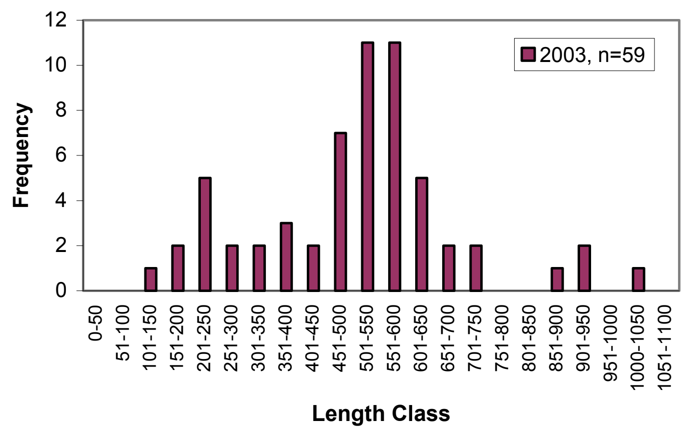


Figure 6.14 Length-frequency distributions for trout-perch captured in the Athabasca River, Spring and Fall 2003.

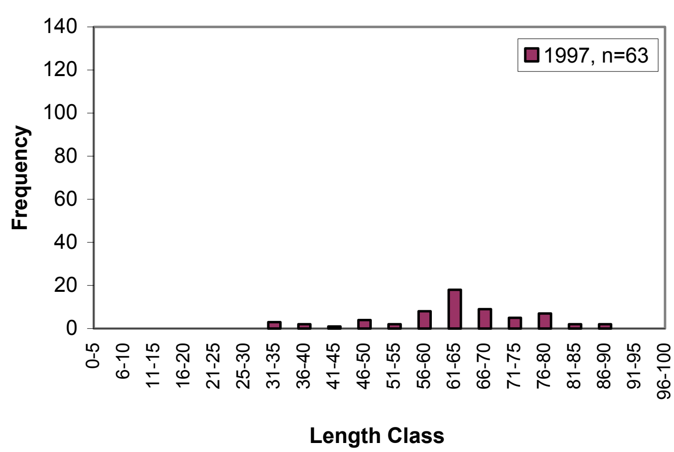
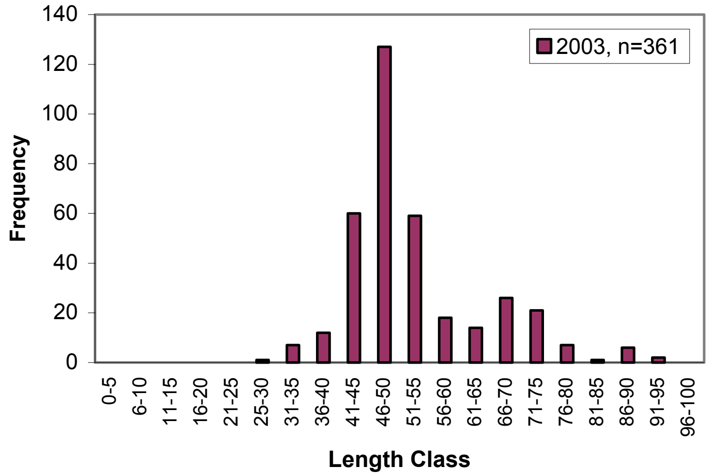


Figure 6.14 (cont'd).



Condition Factor

The relationship between body weight and fork length was examined for five of the six key fish indicators. Trout-perch (which were not weighed prior to release) were not included in this analysis.

Comparisons of mean Fulton's Condition Factor (k) among years are presented for each species of interest in Figure 6.15 to Figure 6.19. There were no significant differences in condition ($p<0.001$) among years for any of the five species evaluated (Table 6.11).

Table 6.11 Results of multi-year (1997-2003) comparisons of weight-length relationship (condition) for key fish indicator species, Athabasca River.

Fish Species	n	df	Kruskal-Wallis test statistic	Chi-square p-value	Result
walleye	476	4	1.073	0.90	ns
lake whitefish	372	4	0.382	0.94	ns
longnose	208	4	0.119	1.00	ns
goldeye	256	4	7.573	0.11	ns
northern pike	70	4	2.635	0.62	ns

Note: n - pooled sample size, df - degrees of freedom based (years), ns - not significant at $p<0.05$

Figure 6.15 Mean condition factor (±SE) and sample size for walleye in the oil sands region of the Athabasca River, 1997-2003.

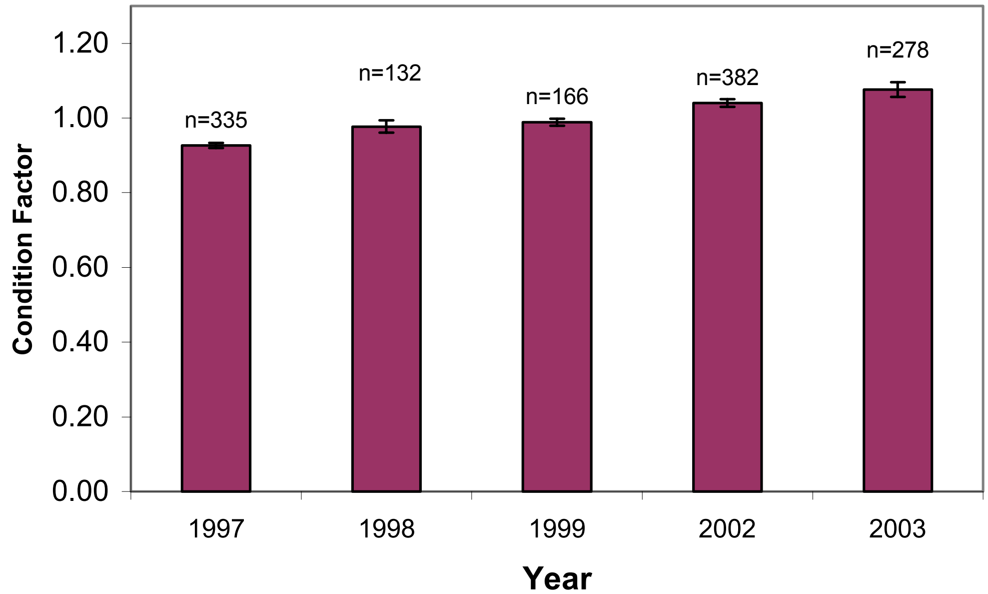


Figure 6.16 Mean condition factor (±SE) and sample size for lake whitefish in the oil sands region of the Athabasca River, 1997-2003.

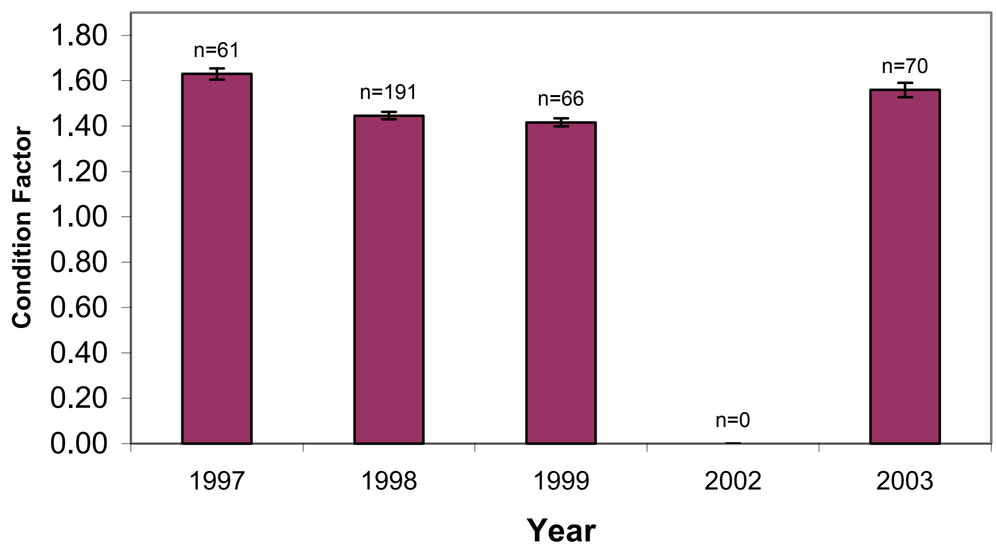


Figure 6.17 Mean condition factor (±SE) and sample size for longnose sucker in the oil sands region of the Athabasca River, 1997-2003.

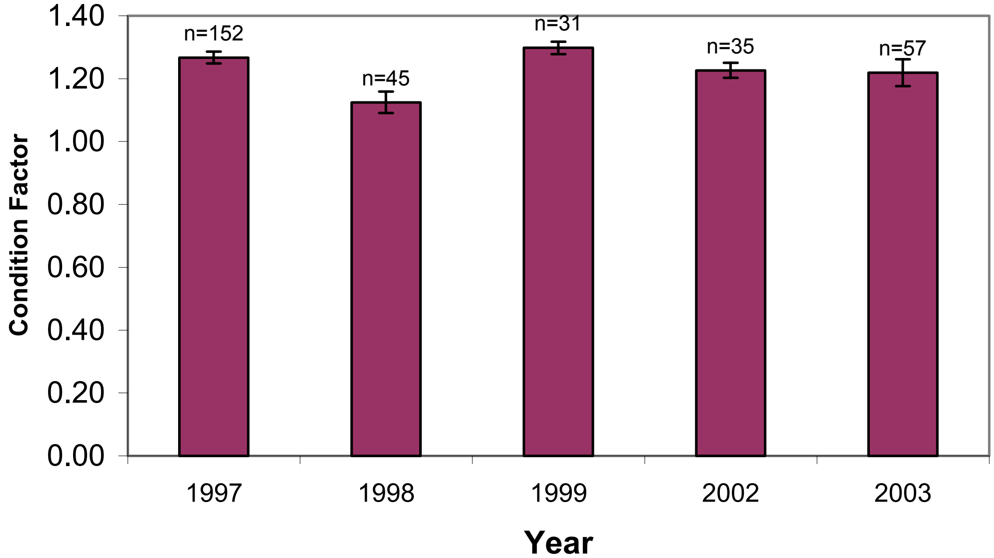


Figure 6.18 Mean condition factor (±SE) and sample size for goldeye in the oil sands region of the Athabasca River, 1997-2003.

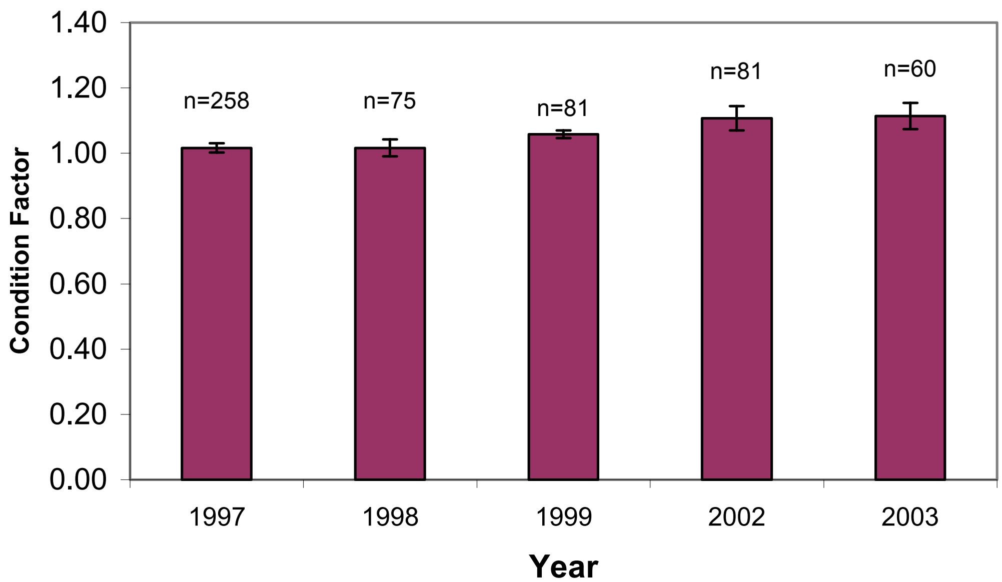
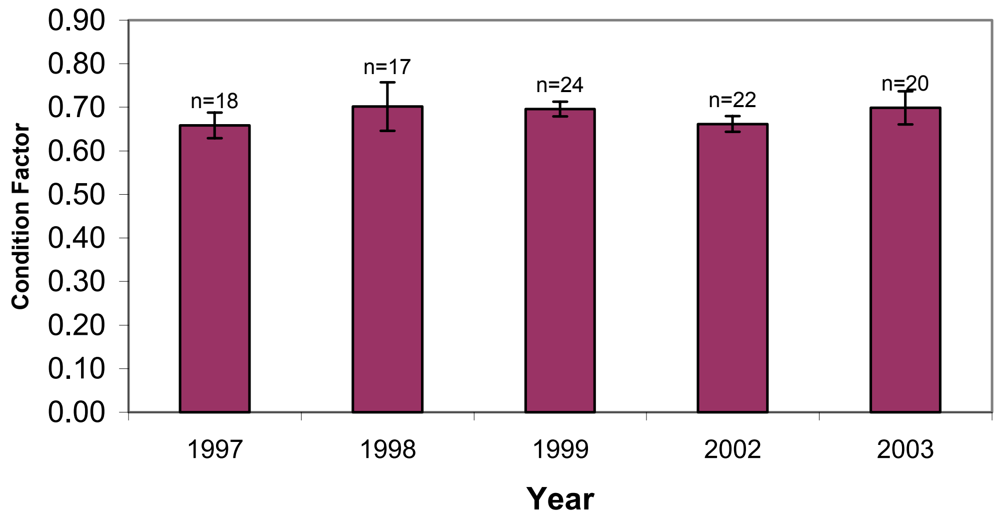


Figure 6.19 Mean condition factor (±SE) and sample size for northern pike in the oil sands region of the Athabasca River, 1997-2003.



External Health

Mean external pathology index values ranged from 0.5% (longnose sucker) to 7.1% (white sucker) (Table 6.12). Abnormalities observed were primarily associated with fin erosion and injuries to the body surface (skin aberrations). The mean index values for fish collected in 2003 were within the range of values documented for previous years (Table 6.12).

Table 6.12 Summary of external pathology indicies, Athabasca River inventories, 1995-2003.

Species	Mean External Pathology Index					
	1995	1997	1998	1999	2002	2003
goldeye	9.6	4.3	0.5	3.7	0.4	1.9
longnose sucker	11	5.8	3.5	4.1	0.9	0.5
walleye	2.8	1.5	2.1	18.3	1.4	1.1
white sucker	18.6	3.2	9.6	5.7	0.6	7.1

6.3.1.2 Clearwater River

A total of 3,350 fish and 19 species were captured during the inventory of the Clearwater River in 2003. Boat electrofishing resulted in the capture/observation of 3,332 fish (spring: 1,443 fish; fall: 1,889 fish) (Table 6.13 and Table 6.14), while beach seining (spring only) resulted in the capture of an additional 18 fish (Table 6.15). Percent species composition and catch-per-unit-effort is provided in Table 6.13 and Table 6.14. Overall, the fish community in the Clearwater River in both seasons was dominated by trout-perch and spottail shiner. Large-bodied fish present (in declining order of abundance) included white sucker, northern pike, walleye and mountain whitefish.

Table 6.13 Fish inventory results from electrofishing on the Clearwater River, Spring 2003.

Spring Results (total effort = 13,987 s.)					
Species	**Total Captured**	**Total Observed**	**Total (obs.+cap.)**	**Species Composition (% of total)**	**CPUE (#/100 s)**
Arctic grayling	1	0	1	0.07	0.01
Burbot	0	3	3	0.21	0.02
Cisco	1	0	1	0.07	0.01
Flathead chub	8	1	9	0.62	0.06
Goldeye	16	10	26	1.80	0.19
Lake chub	4	4	8	0.55	0.06
Lake whitefish	0	3	3	0.21	0.02
Longnose sucker	17	3	20	1.39	0.14
Mountain whitefish	13	5	18	1.25	0.13
Northern pike	52	24	76	5.27	0.54
Pearl dace	0	0	0	0	0
Slimy sculpin	1	0	0	0	0
Spoonhead sculpin	0	0	1	0.07	0.01
Spottail shiner	7	178	185	12.82	1.32
Sucker sp.	0	45	45	3.12	0.32
Trout-perch	8	773	781	54.12	5.58
Walleye	27	6	33	2.29	0.24
White sucker	80	153	233	16.15	1.67
Yellow perch	0	0	0	0	0
TOTAL	**235**	**1208**	**1443**	**100**	

Table 6.14 Fish inventory results from electrofishing on the Clearwater River, Fall 2003.

Fall Results (total effort = 12,450 s.)					
Species	**Total Captured**	**Total Observed**	**Total (obs.+cap.)**	**Species Composition (% of total)**	**CPUE (#/100 s)**
Arctic grayling	12	4	16	0.85	0.13
Burbot	0	0	0	0	0
Cisco	0	0	0	0	0
Flathead chub	0	0	0	0	0
Goldeye	2	3	5	0.26	0.04
Lake chub	12	23	35	1.85	0.28
Lake whitefish	0	0	0	0	0
Longnose sucker	4	2	6	0.32	0.05
Mountain whitefish	13	3	16	0.85	0.13
Northern pike	88	50	138	7.31	1.11
Pearl dace	4	0	4	0.21	0.03
Slimy sculpin	5	0	5	0.26	0.04
Spoonhead sculpin	0	0	0	0	0
Spottail shiner	37	119	156	8.26	1.25
Sucker sp.	0	0	0	0	0
Trout-perch	24	1276	1300	68.82	10.4
Walleye	32	9	41	2.17	0.33
White sucker	87	78	165	8.73	1.33
Yellow perch	2	0	2	0.11	0.02
TOTAL	**322**	**1567**	**1889**	**100**	

Table 6.15 Fish inventory results from beach seining on the Clearwater River, Spring 2003.

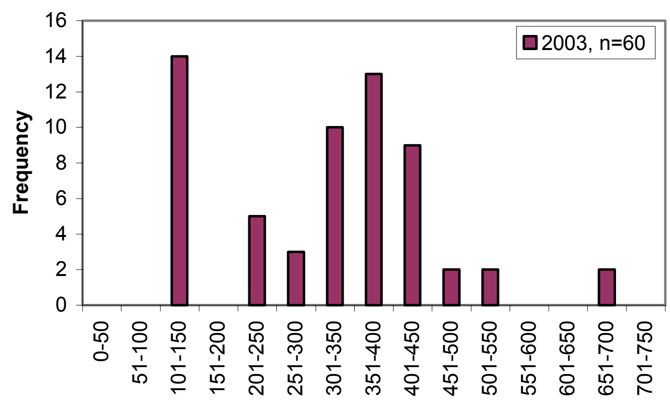
Species	**Total**	**Species Composition (% of total)**
Longnose sucker	4	22.2
Pearl dace	9	50.0
Trout-perch	2	11.1
White sucker	3	16.7
TOTAL	**18**	**100**

Length-frequency analysis

Length-frequency distributions for key fish indicators in the Clearwater River are shown in Figure 6.20 to Figure 6.24. Data were pooled to include fish captured in the spring and fall.

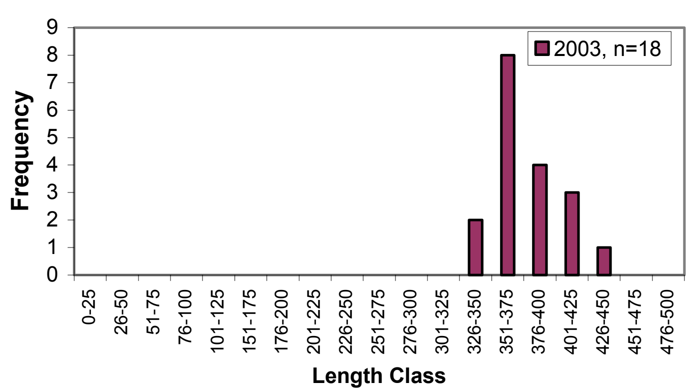
For walleye, the dominant length class was 350-400 mm. An additional group of fish were found in the 100-150 mm class (Figure 6.20). With the exception of the outlying group, the dominant mode was similar to lengths for walleye observed (1997-2003) in the Athabasca River (Figure 6.9).

Figure 6.20 Length-frequency distribution for walleye captured by electrofishing in the Clearwater River, Spring and Fall 2003.



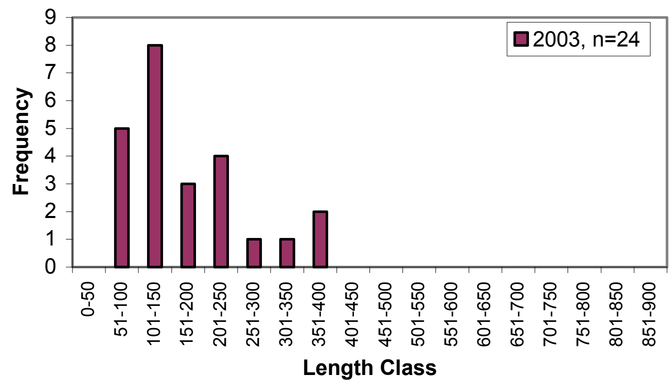
The dominant mode for goldeye was 351-375 mm (Figure 6.21), which is similar to Athabasca River results for 2003, but slightly larger than historical results (Figure 6.11). However, the comparison is weak given the small sample size of goldeye in 2003 (n=18).

Figure 6.21 Length-frequency distribution for goldeye captured by electrofishing in the Clearwater River, Spring and Fall 2003.



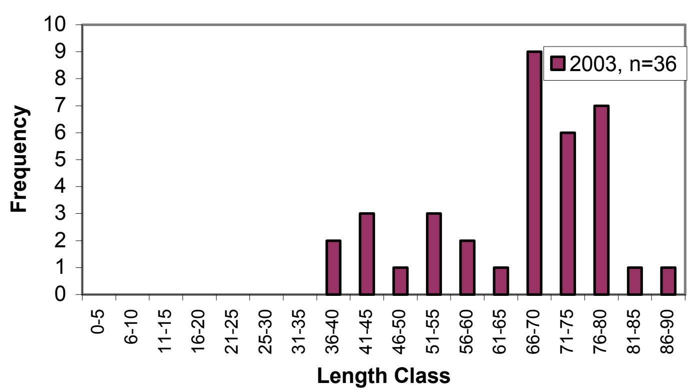
Longnose sucker captured in the Clearwater River were primarily small individuals (dominant mode 100-150 mm; Figure 6.22). This contrasts with historical results (1997-1999) for the Athabasca River where the dominant length class was typically 350-450 mm (Figure 6.12).

Figure 6.22 Length-frequency distribution for longnose captured by electrofishing in the Clearwater River, Spring and Fall 2003.



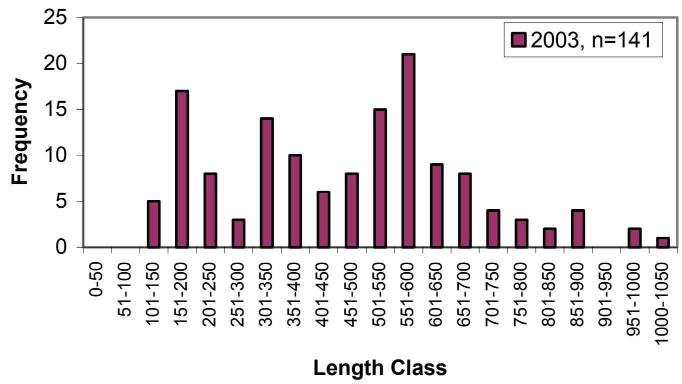
The majority of trout-perch captured in the Clearwater River were 65-80 mm in length (Figure 6.23). Historical inventory results in the Athabasca River have trout-perch populations to be dominated by fish ranging from 45-65 mm (Figure 6.14); however, the sample size of trout-perch from the Clearwater River was limited.

Figure 6.23 Length-frequency distribution for trout-perch captured by electrofishing in the Clearwater River, Spring and Fall 2003.



Northern pike sampled were predominantly in the 550-600 mm length class, with a smaller peak in the 150-200 mm length class (Figure 6.24). These results were similar to 2003 inventory results for the Athabasca River (Figure 6.13).

Figure 6.24 Length-frequency distribution for northern pike captured by electrofishing in the Clearwater River, Spring and Fall 2003.

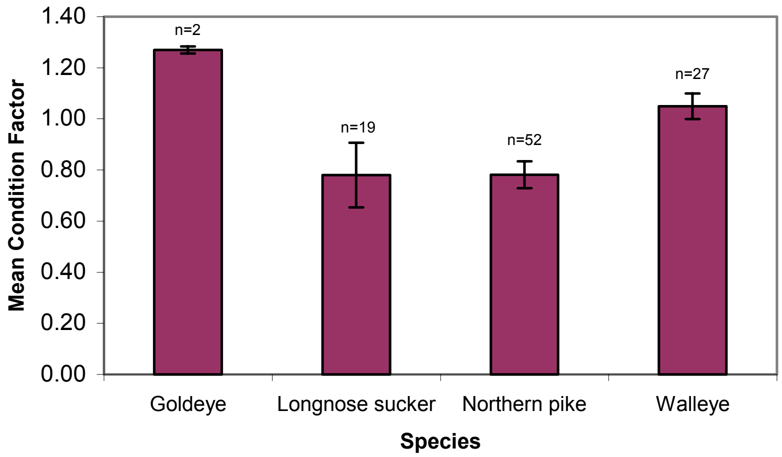


Very few (n=3) lake whitefish were captured in the Clearwater River during spring and fall inventories in 2003. Fall capture success of whitefish is markedly different from results observed for the Athabasca River, where large numbers of lake whitefish are consistently observed in the fall during their annual spawning migration.

Condition Factor

Mean condition factor for key fish indicators captured in the Clearwater River in 2003 is shown in Figure 6.25. Lake whitefish (few captured in 2003) and trout-perch (body weight not measured) are not included.

Figure 6.25 Mean condition factor (±SE) and number analyzed for key fish indicators in the Clearwater River, Spring 2003.



Mean condition factor for walleye and northern pike sampled in the Clearwater River in spring 2003 were similar to results from the Athabasca River (1997-2003) (Figure 6.15 to Figure 6.19). Results for goldeye were inconclusive due to the low sample size. Longnose sucker from the Clearwater River had a lower mean condition factor relative to historical inventory results from the Athabasca River (Figure 6.17).

6.3.1.3 Firebag River

A total of 20 individuals and 7 species were captured/observed during fish inventory studies in the Firebag River in spring 2003 (Table 6.16). All fish were caught by boat electrofishing. The proportion of each species (% relative abundance) captured and the catch-per-unit-effort are shown in Table 6.16. Emerald shiner and trout-perch were most abundant species captured. All species captured have been previously reported in the lower Athabasca River and tributaries. Detailed analysis of inventory results in the Firebag River were not conducted due to limited sample sizes.

Table 6.16 Fish inventory results from electrofishing in the Firebag River, Spring 2003.

Spring Results (total effort = 1,984 s.)					
Species	**Total Captured**	**Total Observed**	**Total (obs.+cap.)**	**Species Composition (% of total)**	**CPUE (#/100 s)**
Arctic grayling	1	0	1	5.0	0.05
Emerald shiner	5	0	5	25.0	0.25
Goldeye	2	1	3	15.0	0.15
Northern pike	2	0	2	10.0	0.10
Trout-perch	5	1	6	30.0	0.30
Walleye	1	0	1	5.0	0.05
White sucker	2	0	2	10.0	0.10
TOTAL	**18**	**2**	**20**	**100**	

6.3.2 Fish Tissue Analyses

6.3.2.1 Athabasca River

Whole-Organism Parameters

Whole-organism parameters for lake whitefish and walleye are summarized in Table 6.17.

Of the 25 lake whitefish caught in the Athabasca River, 9 were females and 16 were males. Male and female whitefish were similar in mean size; however, the mean age of males was higher relative to females. As expected for pre-spawning whitefish, relative gonad size (i.e., GSI) of females was approximately 10-fold higher than for males. Mean LSI was moderately smaller for males compared to females.

Of the 25 walleye caught, 6 were female, 14 were male, and 6 were immature (unsexed). Mean ages between males and females were similar, although the mean length and weight of females was greater than males. The fish collection also included a few smaller immature walleye ranging in age from 2 to 4 years. Mean GSI and LSI for females was approximately 2-fold greater than for males.

Adult fish selected for chemical analyses (composite samples) Table 6.17 were chosen based on size classes presented in Table 6.3 and are highlighted in Table 6.17; all fish selected were adults.

Results from the external and internal fish health assessment for lake whitefish and walleye are summarized in Table 6.18. However, these data should be interpreted with caution because of the small sample sizes employed and lack of a reference population of fish to characterize natural variability in the frequency of abnormalities.

External abnormalities, such as fin erosion and skin abrasions, and internal abnormalities, including enlarged or granular spleens, granular hearts, discoloration of the liver, and presence of parasites, were observed at low frequencies in both species. Mild hindgut inflammation was only observed in one male lake whitefish. Other observations, such as percent mesenteric fat and fatty livers, which are reflective of the food availability and storage, occurred at a similar frequency in both species.

To provide an overall picture of fish health, the percent of fish affected by abnormalities was calculated; this estimation included all abnormalities with the exception of those related to food availability and storage, such as levels of mesenteric fat, presence of fat deposits on the heart, and fatty livers. Male lake whitefish (100%) and female walleye (67%) and whitefish (44%) exhibited the highest percentage of abnormalities. The most prevalent abnormalities were scars on the surface of the skin, general liver discoloration, presence of parasites in the body cavity, and granular deposits on the surface of the heart.

Mercury

Mercury concentrations in muscle of individual lake whitefish and walleye from the Athabasca River are presented in Table 6.17. The highest concentrations of mercury were observed in walleye; concentrations ranged from 0.15 mg/kg in a small 2-year old immature fish to 0.72 mg/kg in a large 16-year old male. Mean mercury concentrations were higher in females (0.43 mg/kg) and males (0.45 mg/kg) than in immature fish (0.20 mg/kg). Mercury concentrations were lower in lake whitefish, ranging from 0.04 to 0.26 mg/kg; mean mercury concentrations were similar in males (0.10 mg/kg) and females (0.12 mg/kg).

Mercury concentrations in composite samples, which ranged from 0.05 to 0.10 mg/kg (Table 6.19), fell within the lower range of the concentrations observed in individual fish.

Scatterplots of fork length, total weight, GSI, LSI and age against mercury concentrations in muscle of individual fish are presented in Figure 6.26 and Figure 6.27. There appears to be a weak positive relationship between fish age and size and mercury concentrations for lake whitefish, and a stronger correlation for walleye.

Table 6.17 Sex, maturity, fork length, total weight, carcass weight, GSI, LSI, and mercury concentrations in lake whitefish and walleye collected from the Athabasca River (September, 2003).

Species	Sex	Fish ID	Maturity	Fork Length (mm)	Total Weight (g)	Carcass Weight (g)	GSI	LSI	Age (years)	Mercury Concentration (mg/kg)
Lake whitefish	Female	**ATR-MR-003**	Adult	378	826.0	680.6	9.2	1.5	7	0.11
		ATR-MR-006	Adult	422	1,304.2	992.3	16.5	1.6	7	0.09
		ATR-MR-004	Adult	433	1,547.5	1,179.3	17.4	2.2	7	0.09
		ATR-MR-016	Adult	436	1,293.8	991.1	16.1	1.5	12	0.26
		ATR-MR-027	Adult	438	1,512.6	nd	14.1	2.8	8	0.12
		ATR-SR-032	Adult	442	1,532.0	1,194.9	16.9	1.5	8	0.07
		ATR-MR-018	Adult	454	1,797.7	1,118.2	19.7	1.8	7	0.10
		ATR-SR-042	Adult	483	2,098.5	1,568.0	18.4	2.2	16	0.14
		ATR-SR-050	Adult	483	2,073.7	1,525.5	19.9	2.0	12	0.12
	Mean			**441**	**1,554.0**	**1,156.2**	**16.5**	**1.9**	**9.3**	**0.12**
	SD			**32**	**401.3**	**290.3**	**3.3**	**0.4**	**3.2**	**0.06**
	Male	ATR-MR-014	Adult	363	665.5	607.8	0.8	0.3	6	0.07
		ATR-MR-022	Adult	370	775.4	715.7	1.6	0.8	4	0.04
		ATR-MR-007	Adult	384	798.1	712.3	1.5	0.7	7	0.08
		ATR-MR-029	Adult	392	892.3	823.6	0.9	1.1	5	0.05
		ATR-MR-017	Adult	413	1,108.8	983.0	2.3	0.8	12	0.11
		ATR-MR-021	Adult	425	1,263.6	1,143.4	2.0	0.9	9	0.07
		ATR-MR-020	Adult	437	1,341.5	1,242.6	1.5	0.8	8	0.13
		ATR-MR-005	Adult	439	1,206.5	1,078.7	1.5	1.0	14	0.16
		ATR-MR-026	Adult	440	1,568.0	1,447.2	1.3	1.0	8	0.08
		ATR-MR-028	Adult	456	1,368.7	1,232.4	1.6	1.4	21	0.07
		ATR-MR-001	Adult	459	1,634.5	1,265.5	2.4	0.8	15	0.08
		ATR-SR-041	Adult	486	2,180.2	2,014.9	2.7	0.8	12	0.16
		ATR-MR-030	Adult	494	1,964.8	1,704.6	2.4	0.7	24	0.05
		ATR-MR-015	Adult	497	1,956.1	1,792.4	1.9	0.9	18	0.12
		ATR-SR-036	Adult	510	1,890.2	1,745.1	1.1	1.1	23	0.10
		ATR-SR-035	Immature	520	2,028.8	1,903.5	0.1	0.7	18	0.18
	Mean			**443**	**1,415.2**	**1,275.8**	**1.6**	**0.9**	**12.8**	**0.10**
	SD			**50**	**493.1**	**452.2**	**0.7**	**0.2**	**6.5**	**0.04**

Table 6.17 (cont'd).

Species	Sex	Fish ID		Fork Length (mm)	Total Weight (g)	Carcass Weight (g)	GSI	LSI	Age (years)	Mercury Concentration (mg/kg)
Walleye	Female	**ATR-SR-047**	Immature	474	1,178.1	1,089.6	0.4	0.9	8	0.32
		ATR-SR-037	Adult	514	1,595.6	1,383.3	5.4	2.0	7	0.32
		ATR-SR-039	Adult	520	1,383.9	1,237.1	4.0	1.7	9	0.34
		ATR-MR-023	Adult	555	1,934.9	1,716.6	3.4	1.9	8	0.27
		ATR-SR-040	Adult	590	2,492.5	2,101.0	5.9	2.3	13	0.65
		ATR-MR-019	Adult	620	2,894.9	2,408.8	6.0	2.5	14	0.67
	Mean			**546**	**1,913.3**	**1,656.1**	**4.2**	**1.9**	**9.8**	**0.43**
	SD			**54**	**666.5**	**517.5**	**2.1**	**0.6**	**2.9**	**0.18**
	Male	ATR-MR-031	Immature	370	532.0	nd	1.0	1.0	6	0.28
		ATR-SR-045	Immature	376	528.3	487.9	0.4	1.1	5	0.44
		ATR-SR-034	Adult	377	547.3	496.4	2.6	0.9	6	0.35
		ATR-MR-024	Adult	387	605.8	549.4	2.3	1.0	8	0.37
		ATR-SR-043	Adult	395	672.0	602.8	2.5	1.1	7	0.47
		ATR-MR-011	Adult	411	793.9	688.8	2.3	1.4	7	0.33
		ATR-MR-013	Immature	416	707.3	659.5	0.3	0.8	5	0.16
		ATR-SR-048	Adult	421	810.6	741.1	2.4	1.1	8	0.53
		ATR-MR-010	Adult	429	919.1	833.5	1.9	1.0	8	0.42
		ATR-MR-012	Adult	432	821.3	761.5	1.7	0.7	10	0.53
		ATR-MR-009	Adult	492	1,383.2	1,237.5	2.7	1.0	16	0.72
		ATR-SR-044	Adult	501	1,377.4	1,254.5	3.0	1.0	10	0.59
		ATR-MR-002	Unknown	509	1,561.0	nd	2.2	1.2	12	0.60
		ATR-MR-008	Adult	511	1,568.8	1,414.5	3.2	1.2	13	0.48
	Mean			**431**	**916.3**	**810.6**	**2.0**	**1.0**	**8.6**	**0.45**
	SD			**52**	**386.4**	**316.8**	**0.9**	**0.2**	**3.2**	**0.15**
	Unknown (immature)	ATR-SR-033	Immature	296	236.1	222.2	nd	1.1	2	0.20
		ATR-SR-049	Immature	299	271.3	240.1	nd	1.5	2	0.15
		ATR-SR-046	Immature	302	278.1	256.1	0.1	0.9	2	0.18
		ATR-MR-025	Immature	370	457.6	413.5	0.3	1.1	4	0.25
		ATR-SR-038	Immature	370	470.7	441.7	nd	0.7	3	0.21
	Mean			**327**	**342.8**	**314.7**	**0.2**	**1.1**	**2.6**	**0.20**
	SD			**39**	**112.0**	**104.2**	**0.1**	**0.3**	**0.9**	**0.04**

bold = fish were used for composite samples.
nd = no data
GSI = gonad somatic index; LSI = liver somatic index

Table 6.18 External and internal observations for lake whitefish and walleye from the Athabasca River (September, 2003).

			Lake Whitefish		Walleye		
			Female	Male	Female	Male	Immature
Exam	Observation		n=9	n=16	n=6	n=14	n=5
External	Fin Erosion	light	1	2	0	1	0
		moderate	0	0	0	0	0
		severe	0	2	0	0	0
	Skin Aberration	scar	2	7	0	3	0
		wound	0	1	1	0	0
	Skin Lesion	tumor/growth	0	0	0	0	0
	Eye	opaque	0	0	0	0	0
	Opercles	shortened	0	0	0	0	0
	Gills	parasites	0	0	0	0	0
		tumor/growth	0	0	0	0	0
	Thymus	moderate hemorrhage	0	0	0	0	0
		severe hemorrhage	0	0	0	0	0
Internal	Mesenteric Fat	50%	0	2	0	2	2
		>50%	0	1	5	8	0
	Parasites	few	0	4	0	0	1
		moderate	0	2	0	0	0
		numerous	0	0	0	0	0
	Liver	focal discoloration	0	0	0	0	0
		tumor/growth	0	1	0	0	0
		fatty	2	5	5	9	2
		general discoloration	0	4	1	0	1
	Hindgut	inflammation	0	1	0	0	0
	Spleen	granular	1	1	2	0	0
		enlarged	0	1	1	0	0
	Other:						
	Heart	fat deposits on surface	2	4	0	0	0
		granular deposits on surface	2	4	0	0	0
# of different types of abnormalities observed[1]			4	10	4	3	1
% fish with one or more abnormalities[1]			44%	100%	67%	29%	20%

[1]Level of mesenteric fat, presence of fat on the heart, and occurrence of fatty liver were excluded from the calculation of abnormalities. An individual fish may exhibit more than one type of abnormality.

Table 6.19 Screening of metals and tainting compounds in lake whitefish and walleye collected from the Athabasca River (September, 2003) against risk-based criteria for fish consumption for the protection of human health.

	Health Canada Criteria		National USEPA Screening Values		Region III USEPA	Concentration (mg/kg)			
	General Consumer	Subsistence Fisher	Recreational Fishers[1]	Subsistence Fishers[2]	Risk-based	Lake whitefish		Walleye	
Analyte	(mg/kg)	(mg/kg)	(mg/kg)	mg/kg)	Criteria[3] (mg/kg)	Female	Male	Female	Male
Metals									
Aluminum	nc	nc	nc	nc	1,400	<4	<4	<4	<4
Antimony	nc	nc	nc	nc	0.54	<0.04	<0.04	<0.04	<0.04
Arsenic	nc	nc	0.026	0.00327	0.002	***<0.2***	***<0.2***	***<0.2***	***<0.2***
Barium	nc	nc	nc	nc	95	0.21	0.22	0.25	0.22
Beryllium	nc	nc	nc	nc	2.7	<0.2	<0.2	<0.2	<0.2
Boron	nc	nc	nc	nc	120	<2	<2	<2	<2
Cadmium	nc	nc	4.0	0.491	1.4	<0.08	<0.08	<0.08	<0.08
Chromium	nc	nc	nc	nc	4.1[4]	<0.2	<0.2	<0.2	<0.2
Cobalt	nc	nc	nc	nc	27	<0.08	<0.08	<0.08	<0.08
Copper	nc	nc	nc	nc	54	0.20	0.29	0.41	0.30
Iron	nc	nc	nc	nc	410	3	4	3	4
Lead	nc	nc	nc	nc	nc	<0.04	<0.04	<0.04	<0.04
Lithium	nc	nc	nc	nc	27	<0.5	<0.5	<0.5	<0.5
Manganese	nc	nc	nc	nc	190	0.11	0.14	0.05	0.06
Mercury	0.5	0.2	0.4	0.049	0.14[5]	0.09	0.05	0.07	0.10
Molybdenum	nc	nc	nc	nc	6.8	<0.04	<0.04	<0.04	<0.04
Nickel	nc	nc	nc	nc	27	<0.08	0.08	<0.08	<0.08
Selenium	nc	nc	20	2.457	6.8	0.3	0.4	0.4	0.3
Silver	nc	nc	nc	nc	6.8	<0.08	<0.08	<0.08	<0.08
Strontium	nc	nc	nc	nc	810	0.16	0.38	0.48	0.17
Thallium	nc	nc	nc	nc	0.09	<0.04	<0.04	<0.04	<0.04
Tin	nc	nc	nc	nc	810	<0.08	<0.08	<0.08	<0.08
Titanium	nc	nc	nc	nc	5,400	0.21	0.15	0.24	0.31
Vanadium	nc	nc	nc	nc	0.41	<0.08	<0.08	<0.08	<0.08
Zinc	nc	nc	nc	nc	410	6.7	6.0	7.7	6.6
Tainting Compounds (PAHs)									
Thiophene	nc	nc	nc	nc	nc	<0.02	<0.02	<0.02	<0.02
Toluene	nc	nc	nc	nc	270	<0.02	<0.02	<0.02	<0.02
M+P-Xylenes	nc	nc	nc	nc	270[6]	<0.02	<0.02	<0.02	<0.02
o-Xylene	nc	nc	nc	nc	270[6]	<0.02	<0.02	<0.02	<0.02
1,3,5-Trimethylbenzene	nc	nc	nc	nc	68	<0.02	<0.02	<0.02	<0.02
Naphtalene	nc	nc	nc	nc	27	<0.02	<0.02	<0.02	<0.02

value = exceeds USEPA screening value for subsistence fishers.
value **=** exceeds Region II risk-based criteria.
value = exceeds USEPA screening value for recreational fishers.
n=5 fish/composite sample
[1]Screening values for recreational fishers are based on a 70 kg individual consuming 17.5 g of fish per day over a 70-year period (USEPA 2000).
[2]Screening values for subsistence fishers are based on a 70 kg individual consuming 142.4 g of fish per day over a 70-year period (USEPA 2000).
[3]Region III USEPA risk- based criteria for fish consumption are based on a 70 kg individual consuming 54 g of fish per day over a 30-year period (USEPA 2003)
[4]criterion is for hexavalent chromium
[5]criterion is for methylmercury
[6]criterion is for xylenes
nc = no criterion

Rank correlations were used to further evaluate the relationship between mercury concentrations in muscle and whole-organism parameters (fork length, total weight, GSI, LSI, and age) for individual and combined sexes for both species (Table 6.20). For walleye (both sexes combined), mercury concentrations were most strongly correlated with age (0.86). Moderately positive correlations (0.52 to 0.63) were also observed with fork length, total weight, and GSI. Mercury concentrations in male walleye were strongly positively correlated with age, and moderately positively correlated with fork length and total weight. For lake whitefish, no correlation was observed between age and mercury concentrations. Correlations with other whole-organism parameters were statistically insignificant.

Linear regression was used to further evaluate relationships between mercury concentrations and length, weight, GSI, and age in male walleye. As noted above, the strongest relationship was observed between mercury concentrations and age; age accounted for 79% of the variability in mercury concentrations (Figure 6.28). The remaining metrics accounted for 43 to 49% of variation in mercury concentrations. Results from the non-parametric and parametric analyses demonstrate that for both species, age is the best predictor of mercury concentrations.

Other Chemicals

Concentrations of other chemicals in composite muscle samples of walleye and lake whitefish from the Athabasca River are presented in Table 6.19. Concentrations of 16 of 24 metals and all six tainting compounds were below analytical detection limits. Concentrations of the remaining metals, including barium, copper, iron, manganese, selenium, strontium, titanium and zinc were low, and varied little between sexes and species.

6.3.2.2 Regional Lakes

Whole-Organism Parameters

In Christina Lake, 13 fish of each species (3 individual fish and 5 fish x 2 composite samples) were collected. Lengths and weights for individual fish and those comprising composite samples are presented in Table 6.21.

In Lake Claire, two lake whitefish, eight northern pike (three individual fish and 5 fish x 2 composite samples), and two walleye were collected. Length and weight of each fish analyzed is presented in Table 6.22. Northern pike were the largest fish caught and lake whitefish and walleye were similar in size.

Figure 6.26 Scatterplots of mercury concentrations in lake whitefish muscle versus length, total weight, GSI, LSI, and age, Athabasca River, 2003.

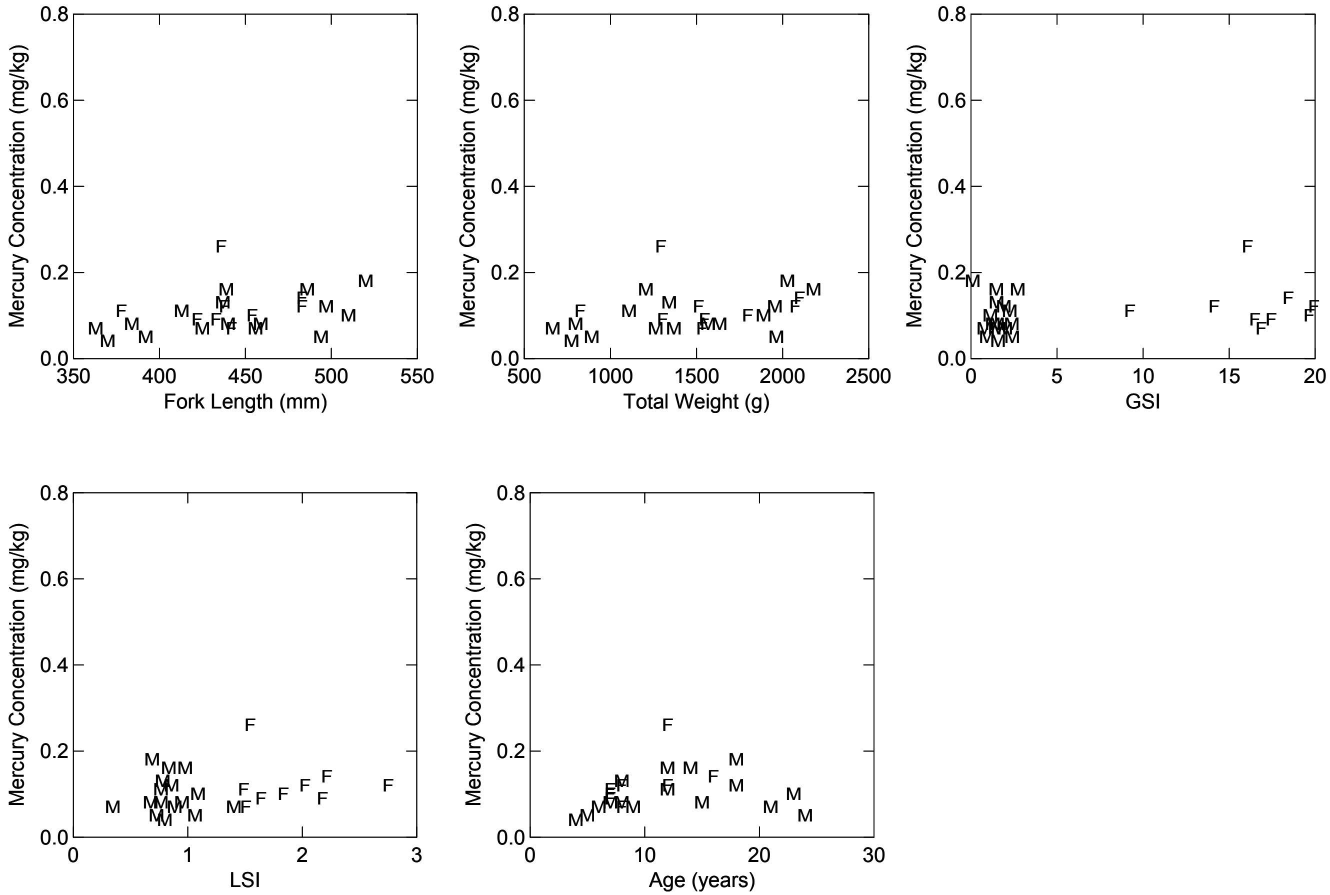


Figure 6.27 Scatterplots of mercury concentrations in walleye muscle versus length, total weight, GSI, LSI, and age, Athabasca River, 2003.

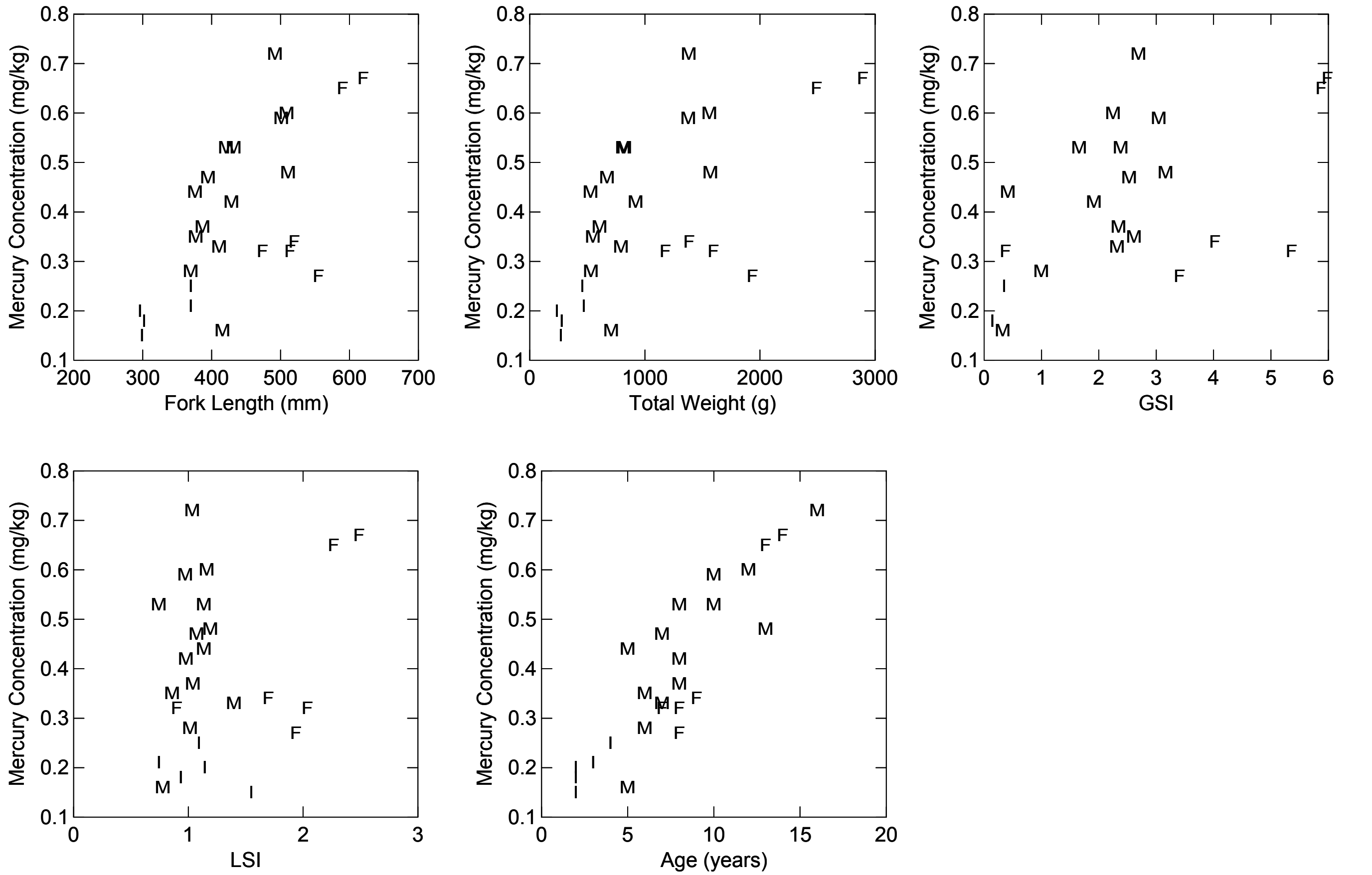
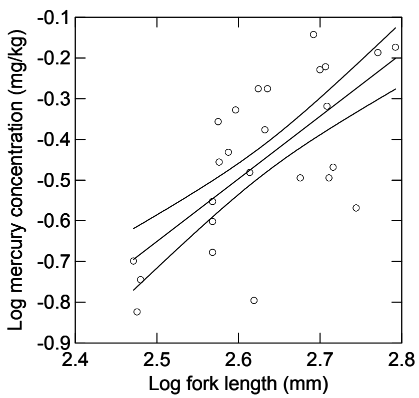
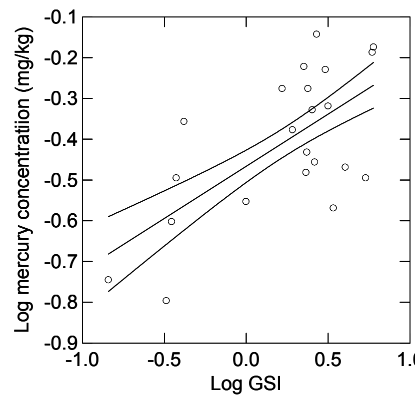


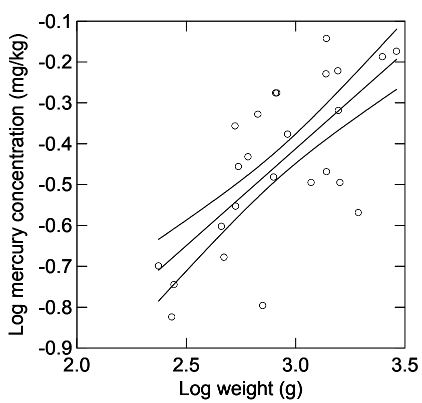
Figure 6.28 Regression plots of mercury concentrations in Athabasca River walleye muscle versus length, total weight, GSI, and age (with 95% CI).



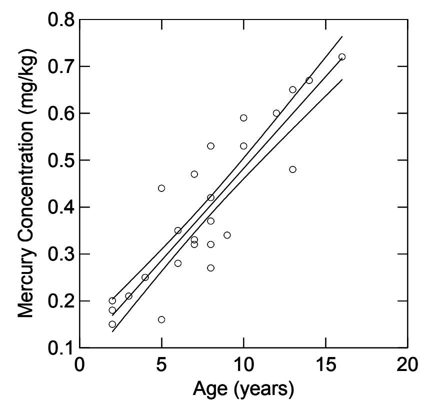
$r^2 = 0.46$, p = < 0.001
log [Hg] = 1.54*log fork length-4.49



$r^2 = 0.43$, p = 0.001
log [Hg] = 0.26*log GSI-0.47



$r^2 = 0.49$, p = < 0.001
log [Hg] = 0.47*log total weight-1.83



$r^2 = 0.79$, p = < 0.001
[Hg] = 0.039*age+0.091

Table 6.20 Rank correlations between mercury concentrations in muscle of Athabasca River walleye and lake whitefish versus length, weight, GSI, and LSI.

	Rank Correlation with Mercury Concentrations (r_s)						
	Lake whitefish			Walleye			
Organism Metric	Male n=16	Female n=9	Combined n=25	Male n=14	Female n=6	Immature n=5	Combined n=25
Fork Length	0.496	0.308	0.373	0.711	0.638	0.667	0.622
Total Weight	0.480	0.059	0.391	0.686	0.551	0.600	0.634
GSI	-0.074	-0.059	0.181	0.497	0.812	1.000	0.515
LSI	-0.050	0.303	0.233	0.150	0.638	-0.500	0.180
Age	0.318	0.700	0.353	0.814	0.868	0.894	0.864

Bolded values represent significant correlation (alpha = 0.05)

Table 6.21 Sex, maturity, fork length, total weight, and mercury concentrations in lake whitefish, walleye, and northern pike collected from Christina Lake (September, 2003).

Species	Sex/Maturity[1]	Fork Length (mm)	Weight (g)	Mercury Concentration (mg/kg)
Lake whitefish Individual samples				
	F	515	2,200	0.20
	M	517	1,830	0.06
	F	557	2,275	0.07
Composite samples				
(n=5)	M, F, and IF	357 - 496	498 -1,650	0.09
	M, F, and U	383 - 505	700 - 2,004	0.09
Walleye Individual samples				
	F	616	2,920	0.56
	F	620	3,250	0.61
	F	635	3,150	0.31
Composite samples				
(n=5)	M, F, IF, and U	432 -589	900 - 2,740	0.26
	M, F, and U	451 - 611	920 - 3,150	0.29

Table 6.21 (cont'd).

Species	Sex/Maturity[1]	Fork Length (mm)	Weight (g)	Mercury Concentration (mg/kg)
Northern Pike Individual samples				
	F	790	3,800	0.27
	F	991	8,700	0.37
	F	1,004	7,250	0.66
Composite samples				
(n=5)	F	531 - 713	1,100 -2,570	0.38
	F	570 -722	1,430 - 2,550	0.44

[1]F=adult female; M=adult male; IF=immature F; U=unknown

Table 6.22 Sex, maturity, fork length, total weight, and mercury concentrations in lake whitefish, walleye, and northern pike collected from Lake Claire (December, 2002).

Species	Sex/Maturity	Fork Length (mm)	Weight (g)	Mercury Concentration (mg/kg)
Lake Whitefish Individual samples				
	U	60	648	0.07
	U	83	1,479	0.15
Northern Pike Individual samples				
	U	44	1,729	0.14
	U	60	1,885	0.63
	U	80	3,460	0.49
Composite samples				
(n=5)	U	U	U	0.55
	U	U	U	0.30
Walleye Individual samples				
	U	39	877	0.18
	U	50	1,385	0.21

U = unknown

Mercury

Mercury concentrations in muscle of individual fish and composite samples from Christina Lake are presented in Table 6.21. Mercury concentrations were highest in walleye (0.26 to 0.61 mg/kg) and northern pike (0.27 to 0.66 mg/kg) and lower in lake whitefish (0.06 to 0.20 mg/kg).

Mercury concentrations in muscle of individual fish and composite samples from Lake Claire are presented in Table 6.22. In Lake Claire, the highest mercury concentrations were observed in northern pike (0.14 to 0.63 mg/kg). Concentrations in walleye (0.18 and 0.21 mg/kg) and lake whitefish (0.07 and 0.15 mg/kg) were lower in comparison. Because of the small sample sizes, statistics were not performed on these data.

6.3.3 Muskeg River Fish Fence Program

6.3.3.1 Environmental Data

Environmental conditions during the period of fish fence operation are presented in Table 6.23 (Appendix A6). Table 6.23 includes discharge data supplied by Environment Canada for the flow monitoring station S7 located approximately 15 km upstream of the river mouth (Water Survey Canada Station 07DA008).

To characterize stream flow conditions near the fence site, a stage-discharge rating curve was calculated at a staff gauge station located approximately 60 meters upstream from the fence location. The depth and velocity profile for the transect at the station location is presented in Figure 6.29.

Manual discharge measurements used to develop the rating curve for the Muskeg River Fence recording station are presented in Table 6.24. Estimated stream discharge values obtained at the Muskeg River fence station were consistently lower (0.3 to 1.5 m^3/s) than those at S7 (Table 6.24). The narrow window of operation for the fence program limited the opportunity to cover a wider range of discharge measurements.

Table 6.23 Environmental data collected at the Muskeg River fish counting fence, May 2003.

Date	Time	Water Temp. (°C)[a]	Daily Air Temp. Range (°C)		Daily Water Temp. Range (°C)		Dissolved Oxygen (mg/l)	pH	Conduc-tivity (µS/cm)	Staff Gauge (m)	Discharge (m^3/s)	
			Min.	Max.	Min.	Max.					Fence	S7
30	08:40	4.6	–	–	5.2	7.5	11.6	7.5	92.0	–	–	9.7
1	19:45	8.2	3.6	13.2	6.7	8.5	11.0	7.5	104.2	0.720	7.7	9.2
2	08:00	5.5	-2.1	3.5	4.2	6.7	10.3	7.6	97.5	0.690	6.9	8.6
3	08:00	4.0	-3.5	-0.3	3.1	4.7	12.1	7.5	93.3	0.680	6.7	8.1
4	07:15	2.5	-3.7	2.3	2.9	4.9	12.8	7.6	99.2	0.670	6.4	7.7
5	08:00	2.5	-1.6	1.9	2.7	3.6	12.2	7.6	95.1	0.655	6.0	7.5
6	08:00	2.2	-0.2	2.6	2.3	3.4	12.5	7.6	92.1	0.668	6.3	7.6
7	08:30	2.2	-0.5	8.3	2.3	4.8	12.9	7.7	94.4	0.688	6.9	8.0
8[b]	08:00	3.1	-0.1	11.2	3.4	6.1	12.2	7.8	97.9	0.702	7.2	8.6
9	07:30	3.2	-3.8	13.9	3.6	7.8	15.0	7.7	98.1	0.756	8.6	8.9
10	08:00	5.0	-1.9	18.4	4.9	9.4	12.8	7.8	96.9	0.760	8.7	9.0
11	08:00	6.5	-0.3	23.9	6.4	11.2	10.7	8.0	102.8	0.755	8.6	9.1
12	07:30	8.0	3.2	25.9	8.3	13.0	11.0	7.9	115.4	0.757	8.6	9.0
13	07:20	9.5	4.8	22.8	10.1	14.2	10.1	7.9	115.6	0.755	8.6	8.9
14	07:30	11.0	7.2	22.4	11.3	13.9	9.2	7.9	122.0	0.755	8.6	8.7
15	07:45	11.1	5.7	16.7	11.6	14.8	9.6	8.0	126.0	0.721	7.7	8.3
16	08:05	11.0	1.6	12.0	10.7	12.3	9.7	8.1	127.4	0.699	7.1	8.0
17	08:00	8.5	-3.0	3.7	6.7	10.6	9.1	8.0	120.0	0.700	7.2	7.8
18	08:30	5.5	-3.7	7.9	5.7	8.9	10.8	8.1	113.0	0.682	6.7	7.6
19	08:00	5.8	-3.0	14.6	5.6	9.7	10.8	8.1	115.1	0.703	7.3	7.8
20	07:50	6.2	-1.3	7.5	6.1	10.2	10.6	8.1	114.0	0.728	7.9	8.4
21[c]	08:00	7.2	–	–	7.1	10.5	–	8.1	–	0.774	9.1	8.8
22	08:15	8.5	–	–	8.4	11.2	10.6	8.1	120.2	0.783	9.3	8.9
23	08:30	9.5	–	–	9.3	13.9	12.4	8.1	117.1	0.770	9.0	8.9
24	08:30	11.5	–	–	11.5	16.2	12.7	8.0	125.7	0.780	9.2	8.9
25	13:30	17.0	–	–	14.2	18.0	11.6	8.1	143.5	0.770	9.0	9.1
26	11:00	15.6	–	–	15.6	17.8	9.9	8.0	140.4	0.785	9.4	9.3
27	11:15	16.0	–	–	15.2	17.2	10.1	8.2	144.4	0.775	9.1	10.3
28	12:25	16.5	–	–	16.5	14.6	11.6	n/a	142.4	0.795	9.6	11.0

[a] Water Temperature measured using small hand-held thermometer. Time of collection found in column to the left.

[b] Fence down overnight (sometime between 18:00 and 08:00);

[c] Interrupted recording of air temperature using data logger (HOBO) – subsequently, air temperature was measured using a small hand- held thermometer;

S7 = Water Survey Canada (WSC) Station 07DA008

Figure 6.29 Depth and velocity profiles for the Muskeg River fence gauging station. Data collected at a stream discharge of 6.12 m³/s, May 18, 2003.

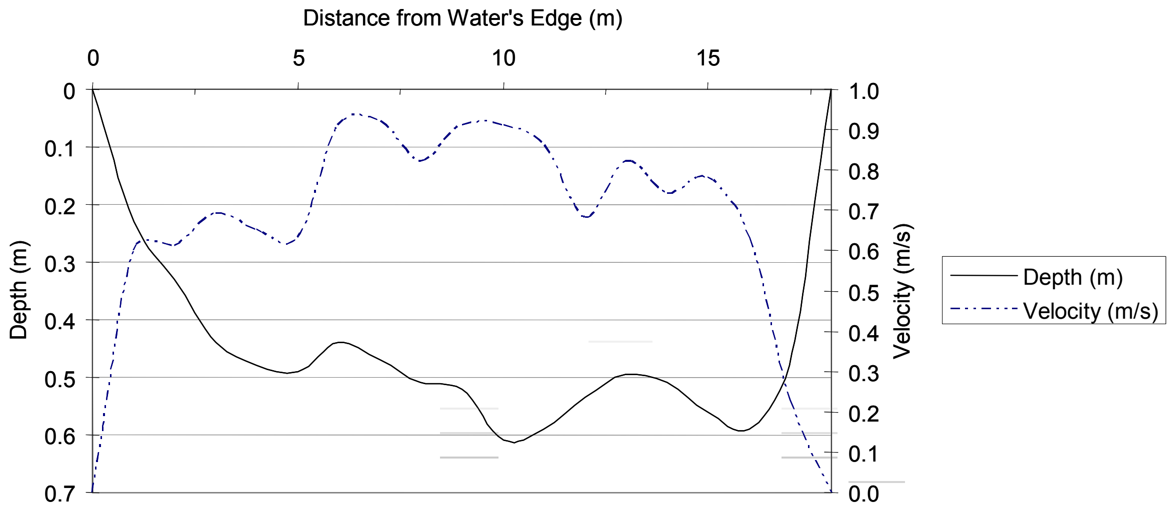


Table 6.24 Manual discharge measurements for the Muskeg River fence station, May 2003.

Date	Time	Height (m)	Discharge (m^3/s)	Discharge S7 [a] (m^3/s)	Diff [b]
3-May	14:00	0.680	7.097	7.997	0.900
11-May	18:30	0.745	8.340	9.004	0.664
18-May	11:00	0.675	6.116	7.648	1.532
23-May	11:35	0.754	8.533	8.853	0.320

(a) Discharge measurements from Water Survey of Canada station S7

(b) Difference between stream discharge measurements from S7 and the Muskeg River Fence Station

Estimated daily stream discharge at the fence site was compared with S7 provisional results (Figure 6.30). The figure also presents water temperature data obtained from the data logger (HOBO) installed at the site between May 2 to 24, 2003 and from RAMP hydrology station S5A.

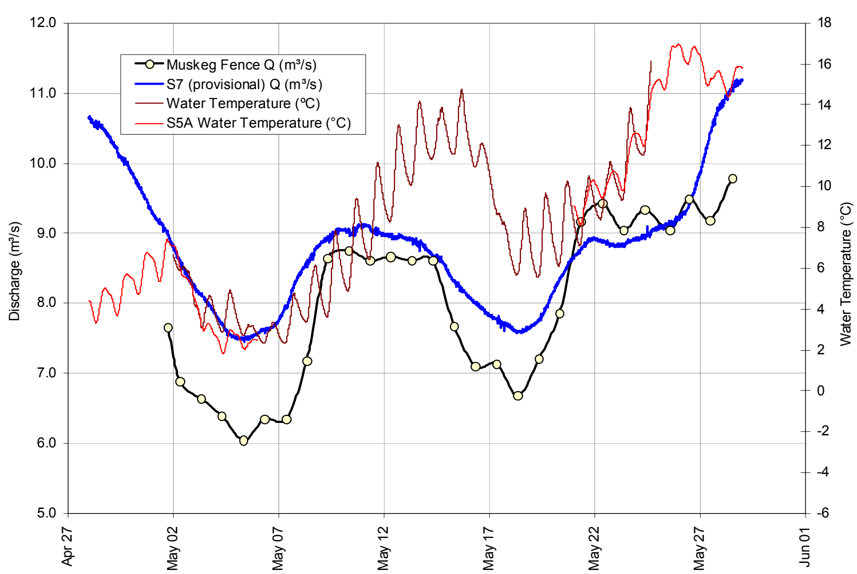
A summary of water quality measurements collected during the fence monitoring period is presented in Table 6.25. Environmental conditions were variable in May 2003, with alternating warm and cold cycles. This pattern continued throughout the period the fence was operation.

The amount of precipitation experienced in May 2003 was normal for the region. Overall, mean discharge values for the Muskeg River near Fort McKay (Water Survey of Canada Station 07DA008) were close to the long-term mean value. In an average year, the Muskeg River discharge at the WSC station in May ranges from 8 to 13 m^3/s. During the fence monitoring period, discharges ranged from 7.5 to 10.5 m^3/s. Discharge values were highest at the beginning, and at the end of the month. Lower stream discharges were closely followed with a marked drop in water temperature.

Table 6.25 Summary of water quality measurements, Muskeg river fence study, May 2003

Field Parameter	Mean ±SD	Range
Temperature (°C)	7.8 ± 3.4	2.3–16.2
Dissolved oxygen (mg/L)	11.3 ± 1.37	9.1–15.0
Conductivity (µS/cm)	113.1 ± 16.7	92.0–144.4
pH	7.9 ± 0.22	7.5–8.1

Figure 6.30 Discharge and water temperature recorded in the Muskeg River in Spring, 2003. Flow data are shown for the fence station and WSC S7.



6.3.3.2 Fish Species in the Muskeg River

The fish fence was operational from May 2 to May 27, 2003. The fence partially collapsed during the night of May 7, and was not operational for a short time on May 8. However, the fence was re-established by the end of the day. The impact of the event on accurate monitoring of fish migration was considered to be small, because the collapse occurred during a time of reduced fish movement and falling water temperatures (<5°C). Soon after this event, the number of fish moving upstream increased substantially with the highest daily counts reported between May 11 and 14.

Nine fish species representing six families were captured in the Muskeg River watershed during the spring fisheries program in 2003. Table 6.26 presents the most common fish species recorded in spring migration movements upstream and/or downstream of the fish fence. Of the six species listed in Table 6.26, longnose sucker, white sucker and northern pike accounted for over 99% of all the fish counted. Only two Arctic grayling were captured at the fence (one upstream, one downstream). In addition, surveys of quiet waters in the vicinity of the fish fence (using backpack electrofishing gear) yielded low numbers of small-bodied forage species, including emerald shiner, trout-perch, and pearl dace.

Table 6.26 Daily fish counts at the Muskeg River counting fence, May 2003.

Date	Upstream Trap						Downstream Trap						
	ARGR	MNWH	NRPK	LNSC	WHSC	Total	ARGR	LKWH	WALL	NRPK	LNSC	WHSC	Total
2	–	–	3	–	–	3	–	–	–	–	–	–	0
3	–	–	3	–	3	6	–	2	–		8	6	16
4	–	–	–	–	–	0	–	–	–	9	4	7	20
5	–	–	1	–	–	1	–	–	–	4	7	3	14
6	–	–	–	–	–	0	–	–	–	2	–	2	4
7	–	–	–	–	–	0	–	–	–	–	–	–	0
8[a]	–	–	–	–	–	0	–	–	–	2	4	1	7
9	–	–	3	–	–	3	–	–	–	1	1	–	2
10	–	–	5	3	2	10	–	–	–	–	–	–	0
11	–	2	15	18	38	73	–	–	–	1	–	1	2
12	–	–	11	29	41	81	–	–	–	–	–	–	0
13	–	–	3	23	76	102	–	–	–	–	–	–	0
14	–	–	5	5	100	110	–	–	–	–	–	–	0
15	–	–	7	7	93	107	–	–	–	1	7	4	12
16	–	–	4	11	89	104	–	–	–	–	–	2	2
17	–	–	–	2	25	27	–	–	2	–	1	5	8
18	–	–	1	1	2	4	–	–	–	3	7	20	30
19	–	–	1	–	6	7	–	–	–	3	2	15	20
20	–	–	4	1	31	36	–	–	–	–	–	16	16
21	–	–	4	3	56	63	–	–	–	–	–	34	34
22	–	–	2	6	14	22	–	–	–	–	1	44	45
23	–	–	1	11	33	45	–	–	–	–	–	15	15

Table 6.26 (cont'd).

Date	Upstream Trap						Downstream Trap						
	ARGR	MNWH	NRPK	LNSC	WHSC	Total	ARGR	LKWH	WALL	NRPK	LNSC	WHSC	Total
24	–	–	2	19	27	48	–	–	–	1	3	15	19
25	1	–	3	18	9	31	–	–	–	–	1	7	8
26	–	–	–	4	2	6	–	–	–	–	1	21	22
27	–	2	1	1	–	4	1	–	–	–		6	7
Total	1	4	79	**162**	**647**	**893**	**1**	**2**	**2**	27	**47**	**234**	**303**

) Overnight fence down; "–" = No captures;

pecies legend: ARGR = Arctic grayling; LKWH = Lake whitefish; MNWH = Mountain whitefish; NRPK = Northern pike; NSC = Longnose sucker; WHSC = White sucker; WALL = Walleye

lote: from the total 1,206 fish enumerated at the fence, 1035 were caught for the first time, 174 were recaptured, ıcluding 2 fish previously tagged by Golder, and 10 fish were found dead (8 recaptured).

In total, 1,206 fish were counted at the fish fence site. Table 6.26 presents the number of large-bodied species captured during each day of trap operation, and for each direction of migration. Small numbers of mountain whitefish (n=4), lake whitefish (n=2) and walleye (n=2) were also recorded at the fence.

6.3.3.3 Life History Characteristics of Dominant Fish Species

Life history characteristics of white sucker, longnose sucker and northern pike sampled at the fish fence are presented in this section. Population parameters were analyzed in detail, including timing of migration, length-weight (i.e., condition) data and length-at-age relationships.

Size, age and health data for fish captured at the fish fence are summarized in Table 6.27 and Appendix A6. Almost all fish captured during the fence program were adults; a small number of juveniles were also captured (<1%), the majority of which were white sucker.

Table 6.27 Mean (±SE) length, weight, condition factor, and External Pathology Index (EPI) for the three dominant species captured at the Muskeg River fence, May 2003.

Species	Statistics	Fork length (mm)	Weight (g)	Condition Factor (K)	Age	External Pathology Index
White Sucker	Range	222–560	120–3,100	1.0–2.0	3–20	10–50
	Mean	453.4 ± 2.0 (728)	1,481.4 ± 21.1 (727)	1.50 ± 0.005 (727)	10.2 ± 0.3 (179)	3.78 ± 0.31 (725)
Longnose Sucker	Range	335–639	446–1,660	1.0–1.55	7–19	10–30
	Mean	411.8 ± 2.6 (191)	888.4 ± 16.7 (191)	1.26 ± 0.01 (191)	11.4 ± 0.2 (151)	1.63 ± 0.38 (172)

Table 6.27 (cont'd).

Species	Statistics	Fork length (mm)	Weight (g)	Condition Factor (K)	Age	External Pathology Index
Northern Pike	Range	328–1,000	232–9,480	0.45–0.97	2–11	10–30
	Mean	627.0 ± 13.8 (96)	2,086.2 ± 160.6 (96)	0.72 ± 0.01 (96)	6.2 ± 0.2 (85)	2.47 ± 0.69 (93)

Note: (n) = sample size; NRPK = northern pike; WHSC = white sucker; LNSC = longnose sucker

Mark/recapture data obtained at the fence provided information regarding the time each fish species spent in the upper reaches of the Muskeg River (Table 6.28). During the first week of fence operation, downstream migration of fish exceeded upstream migration (upstream n=10; downstream n= 63). All three dominant species were found among the early downstream migrants, with longnose sucker comprising the largest group (n=24). The daily catch per species was often less than 50 individuals; therefore, almost all adult fish counted at the fence were tagged. All three dominant species were found upstream of the fence after its installation. Northern pike comprised the highest proportion of individuals tagged in the downstream trap (23%). Based on downstream counts, a portion of the spawning population of both white (18%) and longnose (12%) sucker had migrated upstream before the fence program started. The percentage of recapture was highest for white sucker (20%). Recapture rates for longnose sucker and northern pike were approximately 9% and 8%, respectively. For all species, females were more likely to be recaptured than males.

Table 6.28 Summary of mark/recapture data for dominant fish species captured at the Muskeg River fish fence, May 2003.

Species		Direction of Migration	No. of fish			Total
			Male	Female	Unknown	
White Sucker	Tagged	Upstream	189	443	3	635
		Downstream	11	67	4	82
		Total Tagged [a]	200 (28%)	510 (71%)	7 (1%)	717
	Recaptured	Downstream	27	112	–	139
		Upstream	–	4	–	4
		Total Recaptured	27	116	–	143
		% Recaptured	13%	23%	–	20%
	Total Counted					717

Table 6.28 (cont'd).

Species		Direction of Migration	No. of fish Male	Female	Unknown	Total
Longnose Sucker	Tagged	Upstream	47	110	–	157
		Downstream	9	25	–	34
		Total Tagged	56 (29%)	135 (71%)	–	191
	Recaptured	Downstream	4	9	–	13
		Upstream	1	4	–	5
		Total Recaptured	5	13	–	18
		% Recaptured	9%	13%	–	9%
	Total Counted					191
Northern Pike	Tagged	Upstream	21	45	7	73
		Downstream	6	13	3	22
		Total Tagged	27 (28%)	58 (61%)	10 (10%)	95
	Recaptured	Downstream	1	4	–	5
		Upstream	–	3	–	3
		Total Recaptured	1	7	–	8
		% Recaptured	4%	12%	–	8%
	Total Counted					95

[a] Percent of total fish tagged

Residency time data (time between upstream and downstream capture) are shown in Table 6.29. On average, both sucker species spent approximately 4.5 days in the Muskeg River upstream of the fence location. Residency time for suckers ranged from 0.5 to 13 days. Data for northern pike was limited but residency time ranged from one to 10 days. For all three dominant species, a small number of fish returned to the fence after having spent between 2 to 21 days downstream of the fence.

Table 6.29 Summary of estimated residency time of fish counted at the Muskeg River fish fence, May 2003.

Species	Residence Time	Male	Female	Reverse Migrant [a]
White Sucker	Range (day)	1 – 13	0.5 – 13	2 – 21
	Mean (day)	4.7 (27)	4.6 (112)	11.8 (4)
Longnose Sucker	Range (day)	1 – 14	0.5 – 13	5 – 21
	Mean (day)	4.5 (4)	4.3 (8)	17 (5)
Northern Pike	Range (day)	1	1 – 20	17 – 20
	Mean (day)	1 (1)	10 (4)	18.5 (3)

[a] "Reverse Migrant" describes fish that were first caught, tagged, and released downstream, then later recaptured at the fence while moving upstream. In total, 12 fish were recaptured in the upstream trap; all these were female with the exception of one male longnose sucker.

Based on external pathology examinations conducted on the dominant fish species, the incidence of abnormalities ranged from 12% to 25% (Table 6.30). External pathology index (EPI) values ranged from 10 to 50 for fish exhibiting some form of abnormality. The EPI value for fish showing no signs of pathology was 0 (Table 6.27, Table 6.30). Mean EPI values were calculated by species, based on the entire population of fish examined for pathologies/abnormalities. Most abnormalities reported were associated with some level of fin erosion or skin aberration. The incidence of other abnormalities was generally low, considering the high number of fish examined.

White sucker had the highest incidence of abnormality/pathology and the highest mean EPI value. Longnose sucker had the lowest incidence of abnormalities among the dominant fish species.

Table 6.30 Number of fish with specific external abnormalities for the three dominant fish species encountered at the Muskeg River fish fence, May 2003.

External Examination	Observation (EPI Value)	White sucker	Longnose sucker	Northern Pike	Total
Fin Erosion	Light (10)	69	12	5	86
	Moderate (20)	24	4	3	31
	Severe (30)	19	1	1	21
Skin Aberration /Lesion	Mild (10)	40	2	2	44
	Moderate (20)	6	0	2	8
	Severe (30)	12	1	1	14
Eyes	Swollen/Growth (30)	1	0	0	1
Opercles shortening	Mild (30)	0	0	0	0
	Severe (30)	2	0	0	2
Body Deformities	Presence (30)	2	0	0	2
Ectoparasites	Mild (n/a) [b]	6	1	0	7
	Severe (n/a)	1	0	0	1
Sample Size		725	172	93	990
% affected by abnormalities		25%	12%	15%	22%
EPI Mean Value		3.78	1.63	2.47	3.28

Note: An individual fish may exhibit more than one type of abnormality

(b) Incidence of ectoparasite infestation was not included as part of the EPI calculation

White Sucker

Timing of Migration

White sucker comprised the largest group of migrant fish enumerated at the Muskeg River fence.

The majority of upstream white sucker migrants were sampled at the fence when daily maximum water temperatures reached approximately 10°C (Figure 6.31). This temperature threshold occurred around May 10-11, 2003. Daily counts of white sucker jumped from 2 to 38 fish at that time and remained above 40 fish per day for five continuous days until temperatures dropped below <10°C. A second wave of upstream migration occurred between May 20 and 25. This wave was less intense than the previous one and appeared to end just as the fence was dismantled (May 27). While a steady stream of new arrivals kept moving upstream of the fence, an equal number of out-migrating fish passed through the downstream trap. It should be noted that more than 35% of downstream migrants were untagged fish, indicating that a significant proportion of the white sucker spawning run entered the Muskeg River before the fence was deployed. It is possible that warmer water temperatures (e.g., 6 to 7 °C) recorded in late April (see Chapter 2, Figure 2.42) may have triggered these fish to enter the river prior to water temperatures reaching 10 °C.

In total, 735 white sucker (not including recaptures) were enumerated at the fence, 86% were tagged while moving upstream, and 11% were tagged while moving downstream. By the time the fence was removed, 234 sucker had been released downstream (221 of which were recaptures), representing 30% of total number of fish tagged. As of May 27, the remaining 517 tagged fish had not yet left the upper reaches of the Muskeg River.

Residency Time in the Muskeg River

There appears to be a negative relationship between the date at which a fish moved upstream of the fence, and the number of days it spent in the upper Muskeg (presumably on the spawning grounds Figure 6.32) these data suggest early migrants remained in the river longer than late migrants. The general relationship is consistent for both sexes; however, it is important to note that a majority of fish still had not returned to the fence before the fence was dismantled, and the number of males that were recaptured was small. Extending the duration of the study would have provided a clearer picture of the white sucker migration pattern.

Figure 6.31 Timing of white sucker migration and its relation with water temperature in the Muskeg River, May 2003.

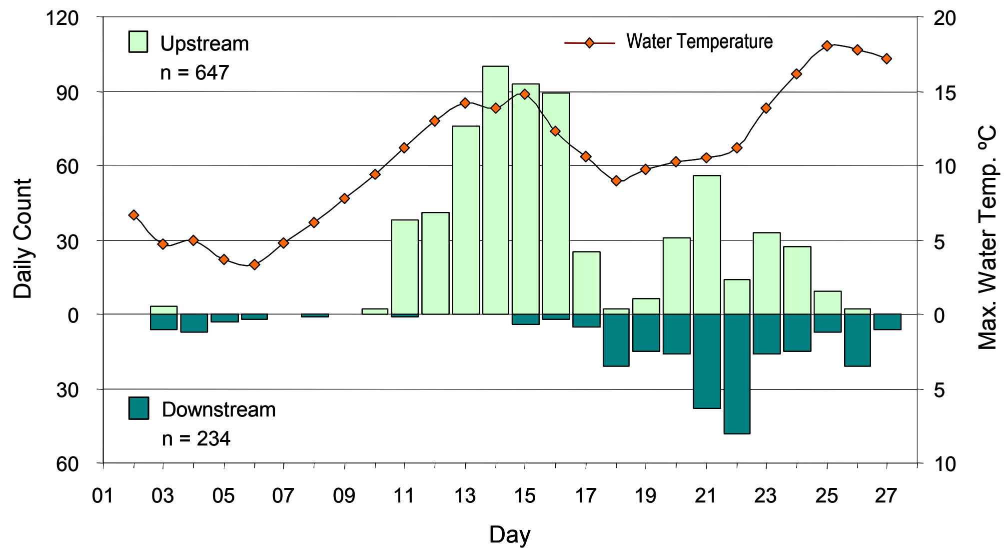
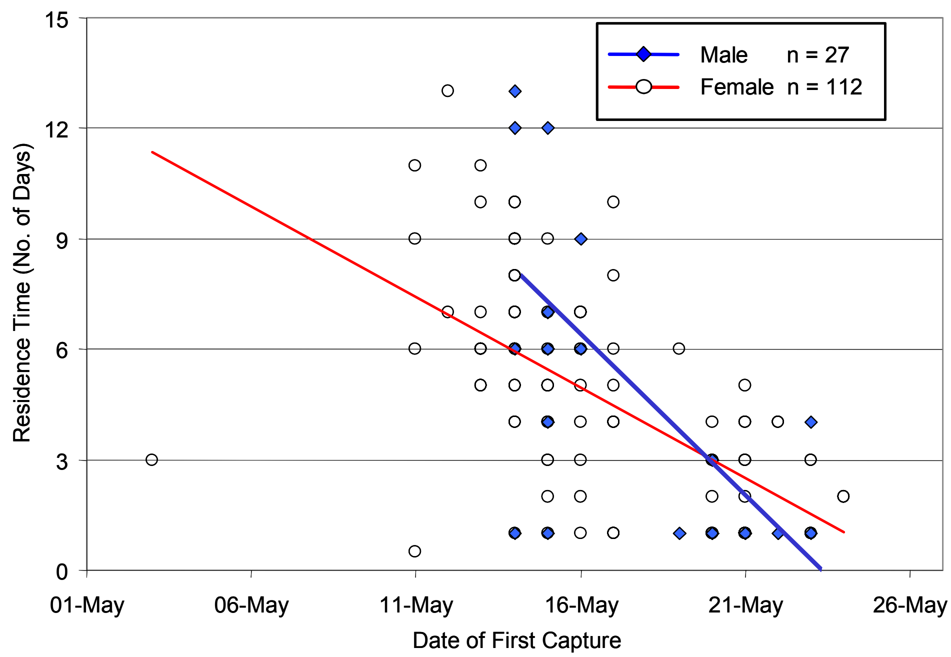


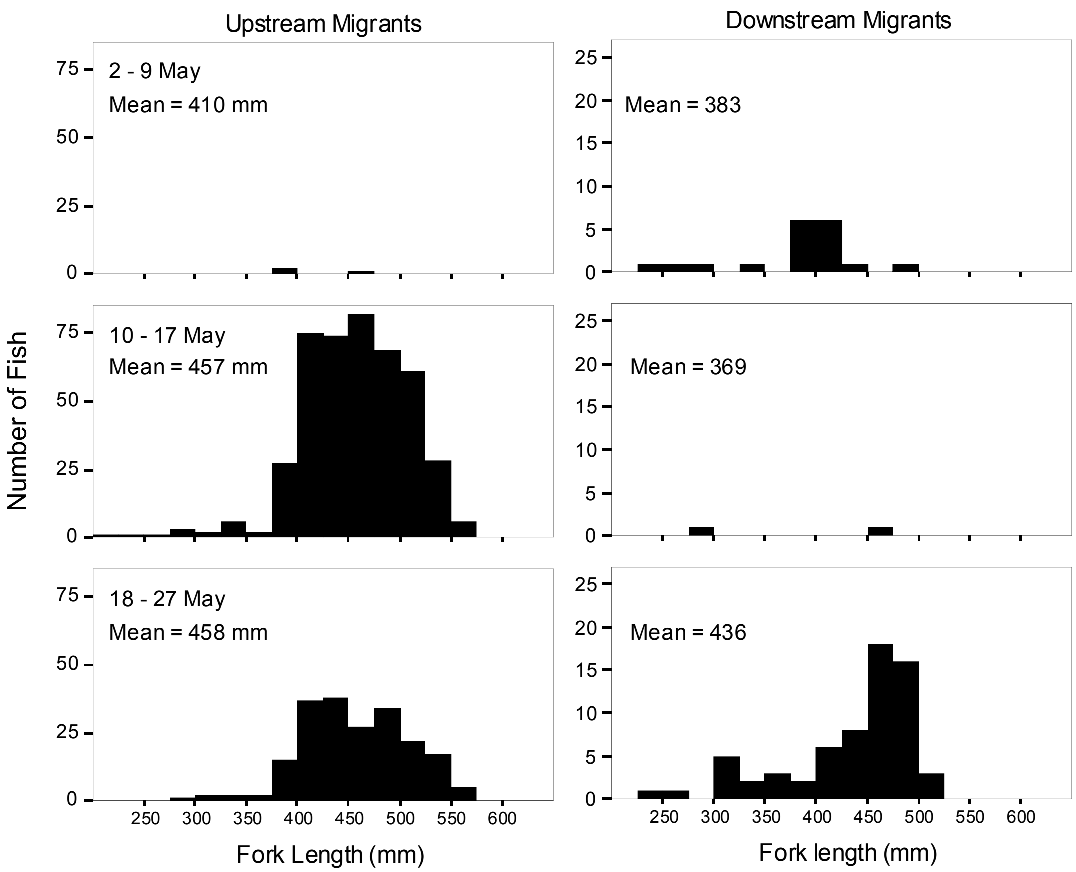
Figure 6.32 Return time (number of days elapsed between first capture and recapture) for white sucker at the Muskeg River fish fence, May 2003.



Size and Age Composition of Migrant White Suckers

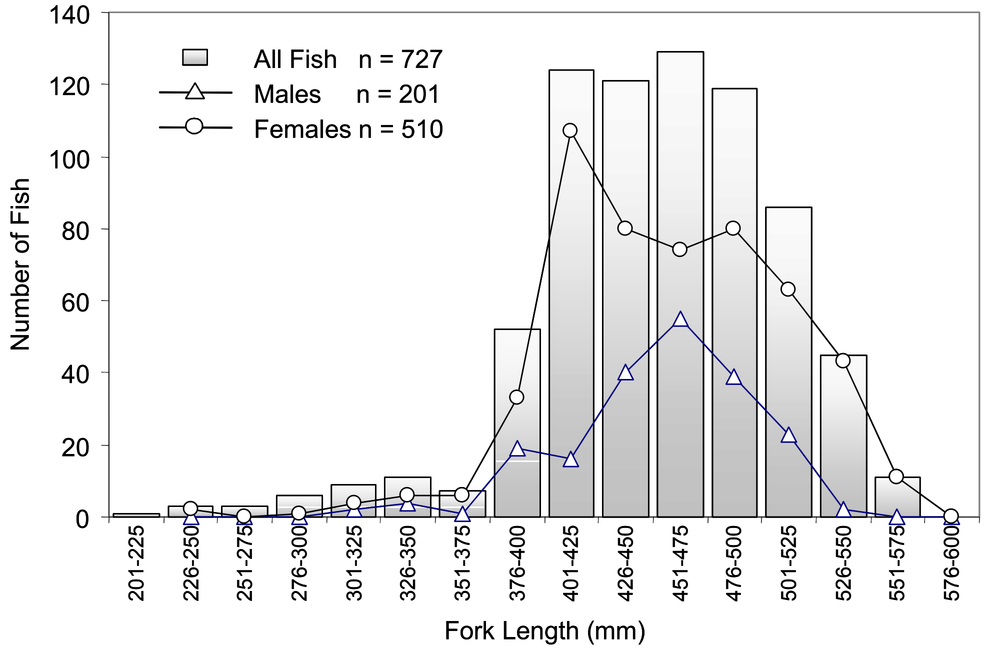
Length-frequency distributions over time for upstream and downstream white sucker migrants are shown in Figure 6.33. Downstream migrants caught in mid to late May were generally larger than earlier migrants. The peak mode for upstream migrants included fish ranging from 375 to 575 mm fork length. The mean size of downstream migrants was similar, particularly during the latter week of May when a greater proportion of white sucker participated in the out-migration.

Figure 6.33 Seasonal changes in length-frequency distribution for white suckers during the spring migration in the Muskeg River, May 2003.



Length-frequency distribution by sex is presented in Figure 6.34. There was no difference (p=0.25) in mean length between male (454 ± 42 mm) and female (458 ± 52 mm) white suckers in the spawning migration. The ratio of male to female white sucker was 1:2.5 during the operation of the fish fence.

Figure 6.34 Length-frequency distribution of white suckers caught at the Muskeg River fish fence, May 2003.



The relationship describing condition (i.e., weight vs. length) of male and female white sucker (r^2=0.96) is shown in Figure 6.35. There were no significant differences in slopes (p=0.22) or intercepts (p=0.88) between the regression lines for males and females. Length and weight data for both sexes were pooled to generate a length-weight relationship for the Muskeg River white sucker migrant population, as follows:

$$Log_{10}\ Body\ weight\ (g) = -6.08 + 3.47 \cdot Log_{10}\ Fork\ Length\ (mm)$$

The age composition for white sucker by sex is presented in Figure 6.36. Ages ranged from 5 to 16 years old for males and 4 to 20 years old for females; the median age for both sexes was 10 years. Fifty percent of the female population was between the ages of 8 to 10 years; 60% of males were between ages of 8 to 12 years.

Length-at-age relationships for male and female white sucker are presented in Figure 6.37 and Figure 6.38. The increase in length with age was similar for both males and females (i.e., no difference in slope, p=0.75); however, female sucker were significantly longer at a given age relative to males (i.e., difference in intercept, p=0.038).

Combining length and age data for both sexes, the resulting length-at-age relationship for the Muskeg River white sucker migrant population is:

$$Log_{10}\ Fork\ Length\ (mm) = 2.24 + 0.408 \cdot Log_{10} Age\ (year)$$

Figure 6.35 Weight-length relationships for male and female white sucker, Muskeg River fish fence, May 2003.

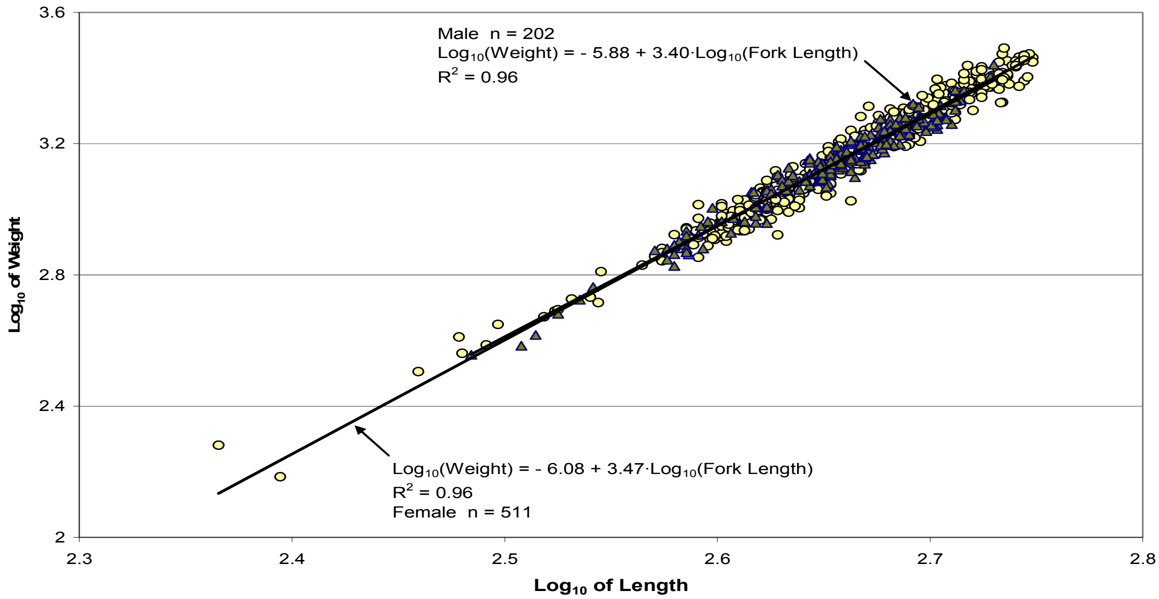


Figure 6.36 Age composition of white sucker sampled at the Muskeg River fish fence, May 2003.

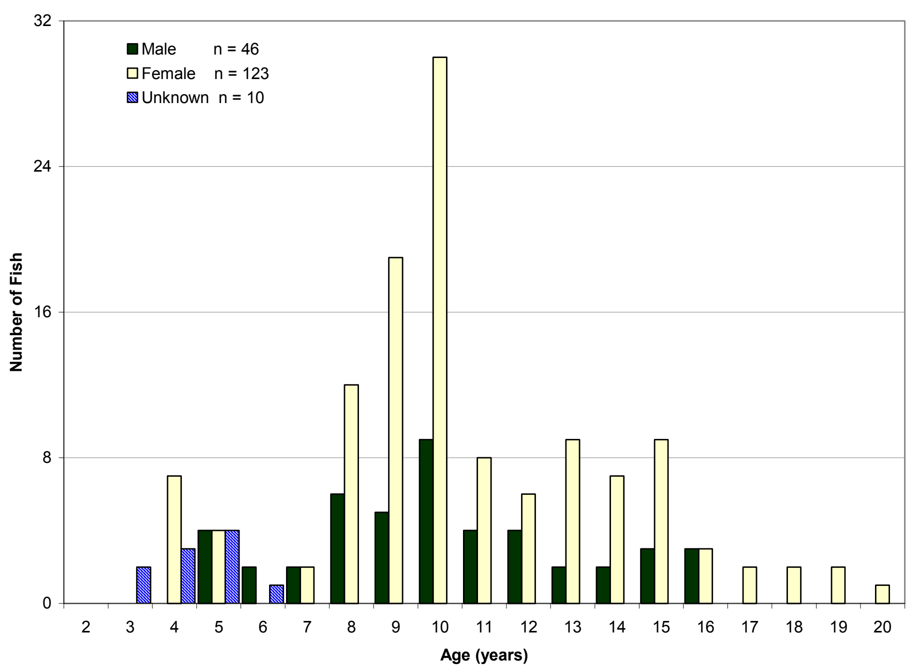


Figure 6.37 Length-at-age relationships for white sucker sampled at the Muskeg River fish fence, May 2003 (Mean ± SE).

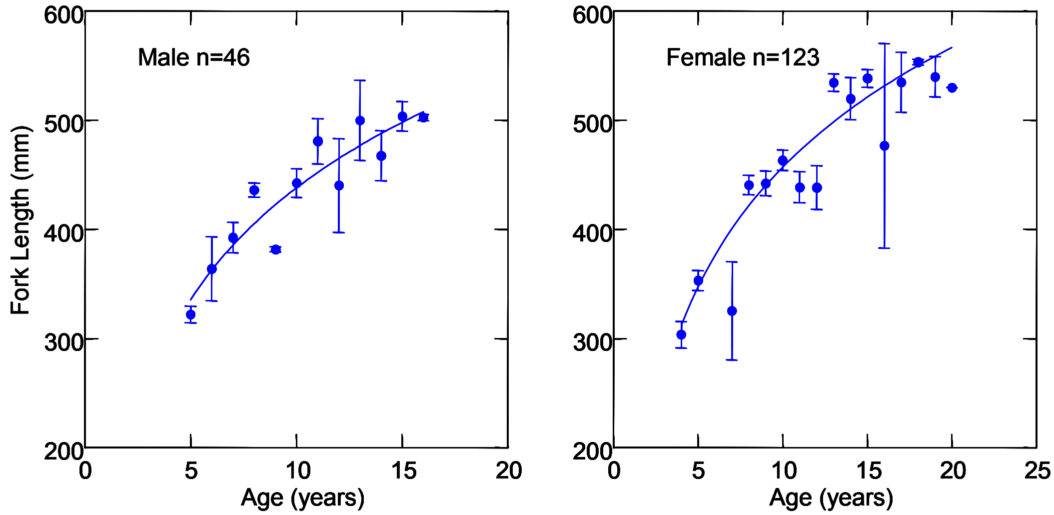
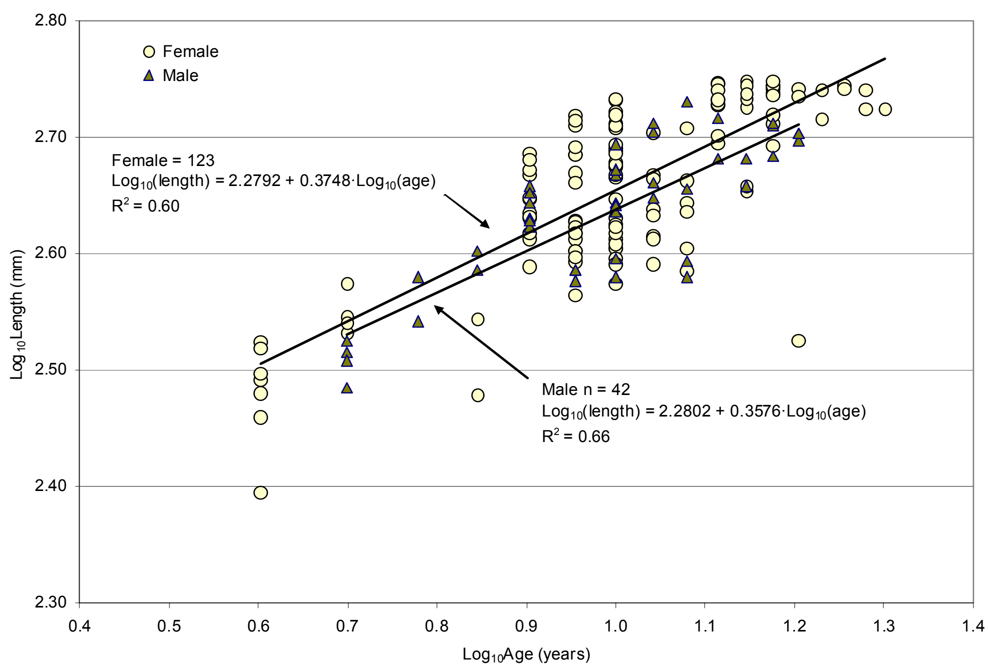


Figure 6.38 Length-at-Age relationship by sex for white sucker sampled at the Muskeg River fence, May 2003.



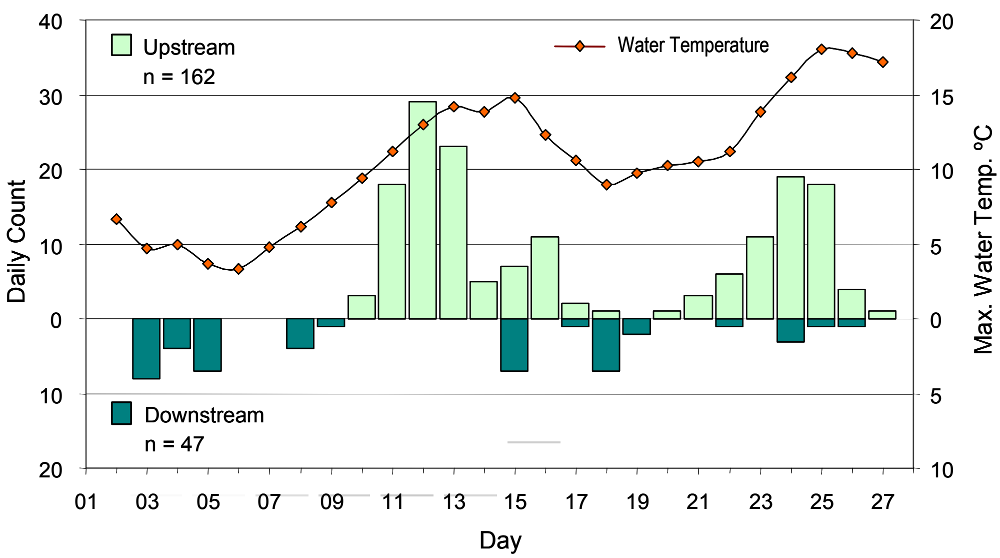
Longnose Sucker

Timing of Migration

Data collected during the monitoring period suggest that the upstream migration of longnose sucker was underway prior to the deployment of the fish fence (Figure 6.39). Of the total of 191 longnose sucker caught at the fence, 18% were already present in the system before the fence was deployed. By the time the fence was removed, only 13 recaptured fish had moved downstream, and 149 tagged fish upstream. More than 72% of the fish sampled in the downstream trap had been captured for the first time, and had not been observed previously by the field team.

Upstream migration for longnose sucker followed a similar pattern as for white sucker. Fish moved upstream in two distinct waves, which follow closely the rise and fall of water temperatures. The first wave started after May 10, subsided after approximately one week, then regained momentum near the end of the month. By then, maximum daily water temperature had reached >15 °C.

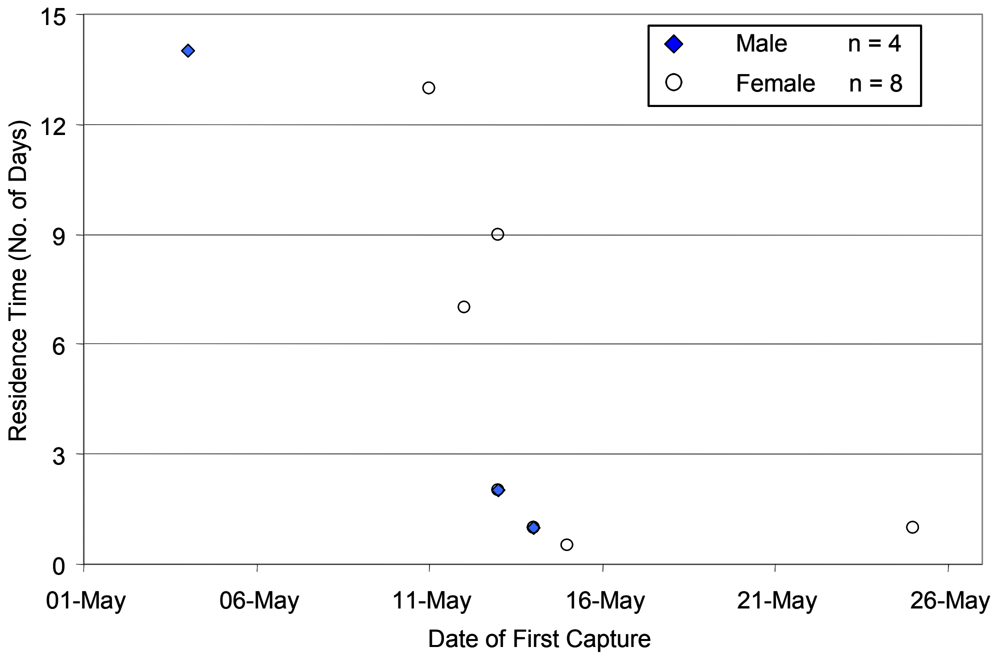
Figure 6.39 Timing of the longnose sucker migration in the Muskeg River, May 2003.



Residency Time in the Muskeg River

The estimated residency time of longnose sucker in the Muskeg River was comparable to white sucker. Average residency time was approximately 4 to 5 days for both sexes, although variability was high as individual residency time ranged from 0.5 to 14 days. As with white sucker, longnose sucker that had entered the river earlier in the month appeared to spend more time upstream of the fence than those that arrived later. However, this relationship was weak due to the small sample size (Figure 6.40).

Figure 6.40 Return time (number of days elapsed between first capture and recapture) for longnose sucker at the Muskeg River fish fence, May 2003.



Size and Age Composition of Migrant Longnose Suckers

The length-frequency distribution of longnose sucker is presented in Figure 6.41. Female longnose sucker migrating up the Muskeg River were significantly longer (420 mm, SD=27) than male sucker (388 mm, SD=26)($p<0.001$). Mean body weight for females (960 g, SD = 206) was also greater than males (704 g, SD = 157). The spawning run of longnose sucker was composed entirely of adult fish, 80% of which were in spawning or ripe condition. The remaining 20% of the run consisted of pre-spawning (8%), maturing (2%) or spent (10%) fish.

The sex ratio of migrant longnose suckers was approximately 1 male to 2.4 females, which was similar to that observed for white suckers.

The relationship describing condition (i.e., weight vs. length) of male and female longnose sucker is shown Figure 6.42. There was no significant difference in slopes of the length- weight relationship between males and females ($p=0.96$). For a given length of fish, females were significantly heavier than males ($p<0.001$); however, the difference in weight was <5%. Overall, there was a strong relationship between body weight and fork length ($p<0.001$, $r2=0.88$).

Figure 6.41 Length-frequency distribution of longnose suckers caught at the Muskeg River fish fence, May 2003.

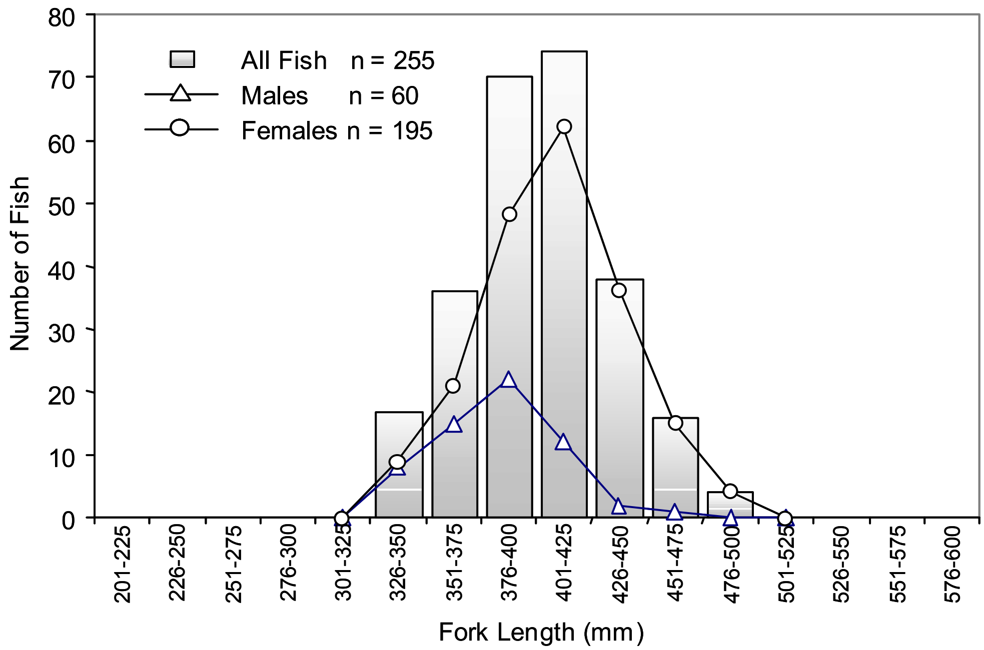
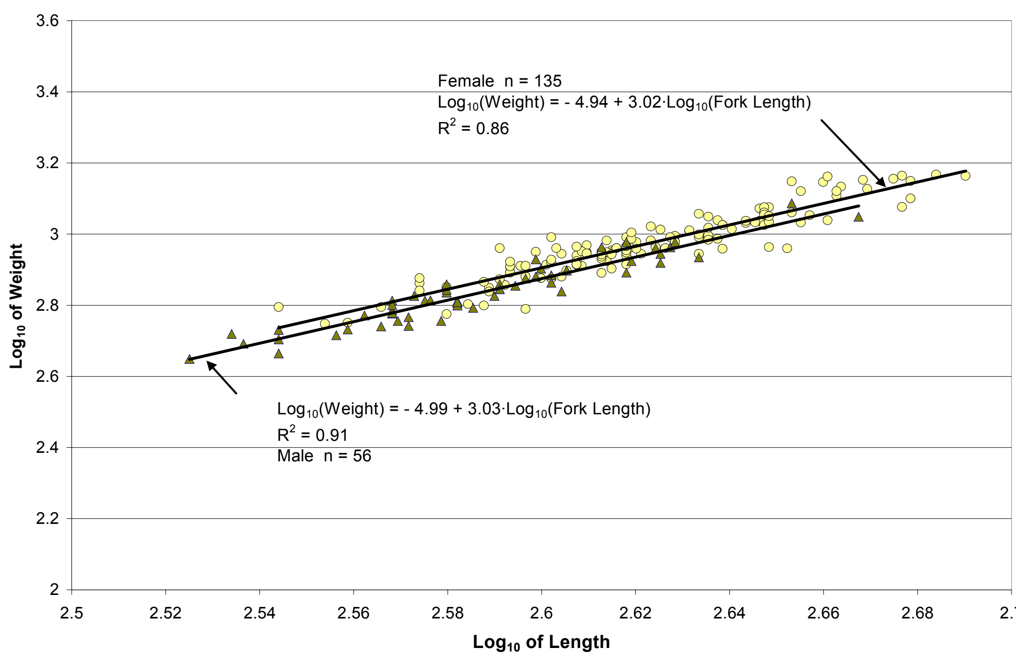
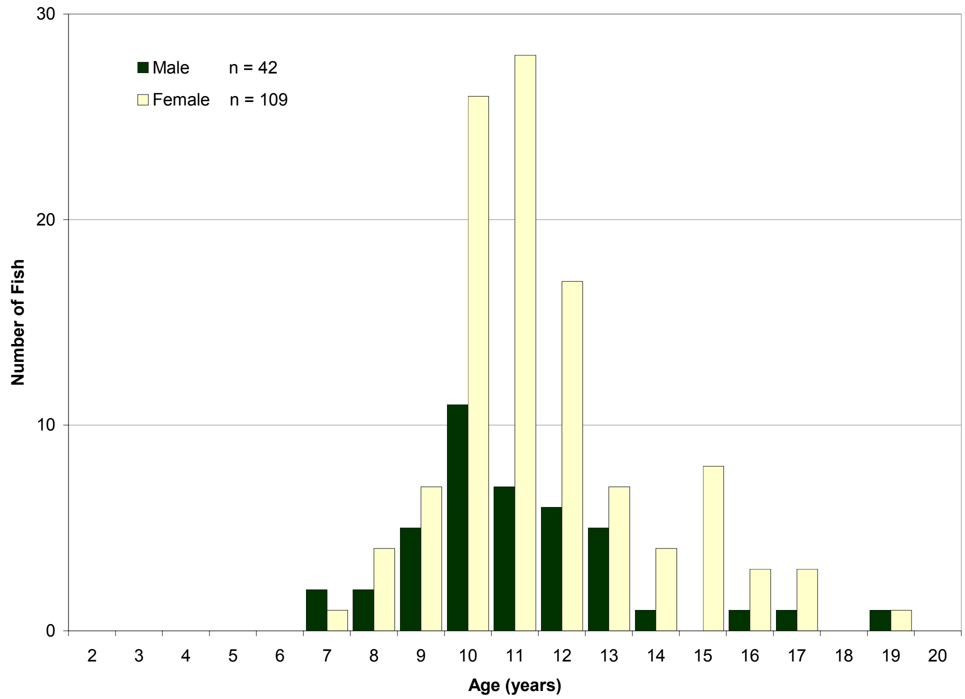


Figure 6.42 Weight-length relationship for male and female longnose sucker, Muskeg River fish fence program, May 2003.



The age composition for male and female longnose sucker is presented in Figure 6.43. Migrant longnose sucker ranged in age from seven to 19 years for both sexes. The median age was 10-11 years old. Over 78% of all females and 81% of all males were between nine and 13 years old.

Figure 6.43 Age composition for longnose sucker sampled at the Muskeg River fish fence, May 2003.



Female longnose sucker appear to reach a larger size with age than males (Figure 6.44), although there was substantial variability in length for younger male sucker. The oldest female sampled was 19 years old and measured 483 mm. Two older males sampled at the fence (17 and 19 years old) measured over 450 mm in fork length, and more closely matched the size range observed for females. Although variability in fish size is common, it is important to note that the sex of longnose sucker was determined externally by the presence/absence of secondary sex characteristics, and it is possible these fish mis-identified.

The length-at-age relationship for male and female longnose sucker (Figure 6.45) indicated no significant difference between sexes ($p=0.95$); however, female sucker were significantly longer at given ages ($p<0.001$) relative to male sucker.

Figure 6.44 Mean length-age relationship by gender for longnose sucker sampled at the Muskeg River fish fence, May 2003 (Mean ± SE).

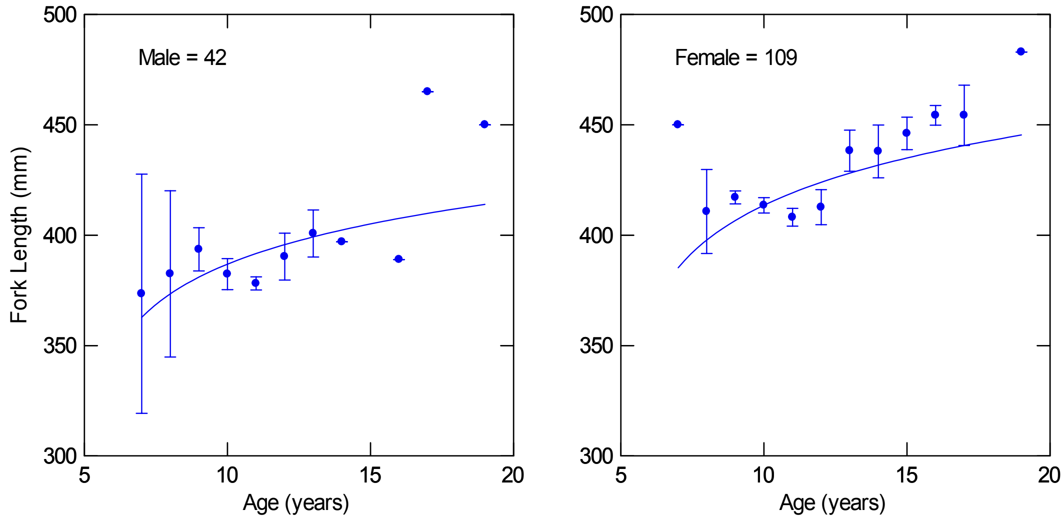
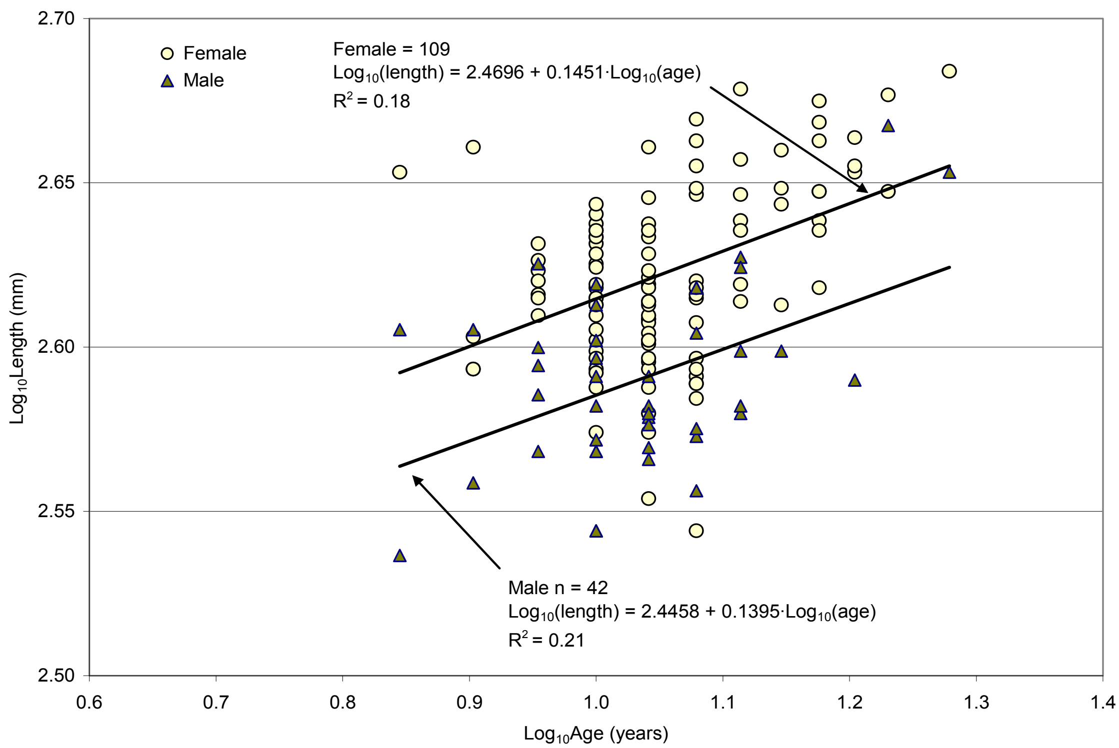


Figure 6.45 Length-at-age relationship by gender for longnose sucker sampled at the Muskeg River fish fence, May 2003.



Northern Pike

Timing of Migration

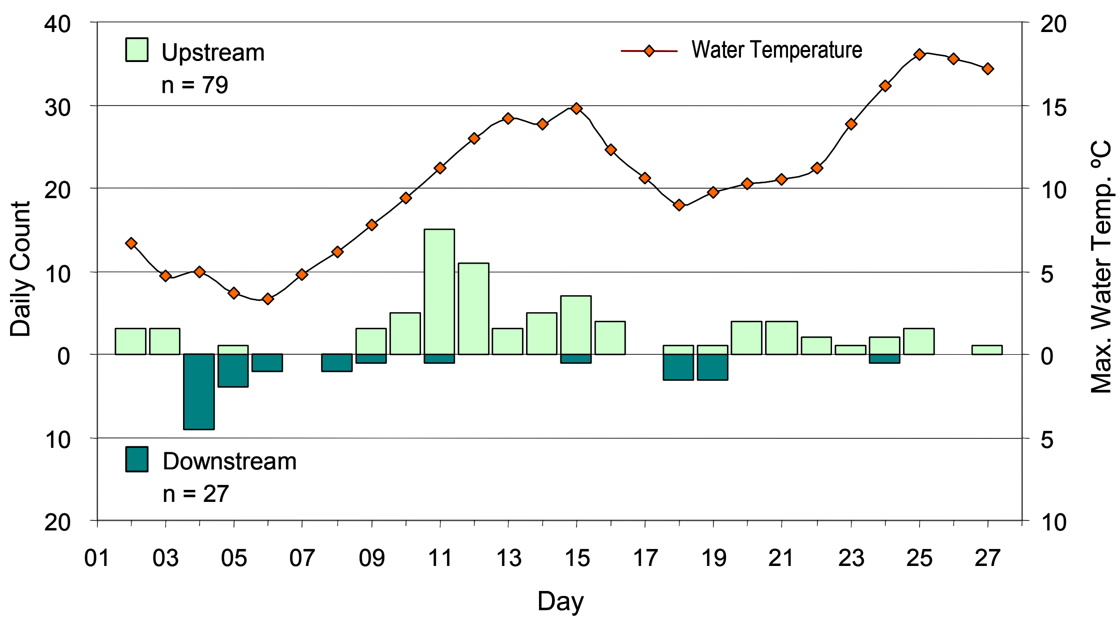
Northern pike captured at the fence throughout the study period (Figure 6.46). However, fewer pike were recorded at the fence than sucker species, with daily counts averaging 3-5 fish. A single wave of downstream migrants occurred after the second week of operation, and coincided with a general "burst" of out-migrating Muskeg River fish.

A total of 106 northern pike were counted at the fence. Approximately 23% were already in the system before the fence was deployed (tagged in downstream trap). By the time the fence was removed, over 5% of pike tagged during their upstream migration had moved downstream. Approximately 71 tagged fish remained upstream at the end of the fence monitoring period.

Only 8 pike were recaptured at the fence, of which were tagged fish returning to the fence after a prolonged visit downstream (17-23 days). Detailed analysis of residency time for northern pike was not conducted, due to small sample sizes.

Approximately 50% of the pike sampled at the fence was considered "ripe". Maturing and spent fish comprised 18% and 13%, respectively. The sex ratio of migrant pike was approximately 1 male to 1.8 females.

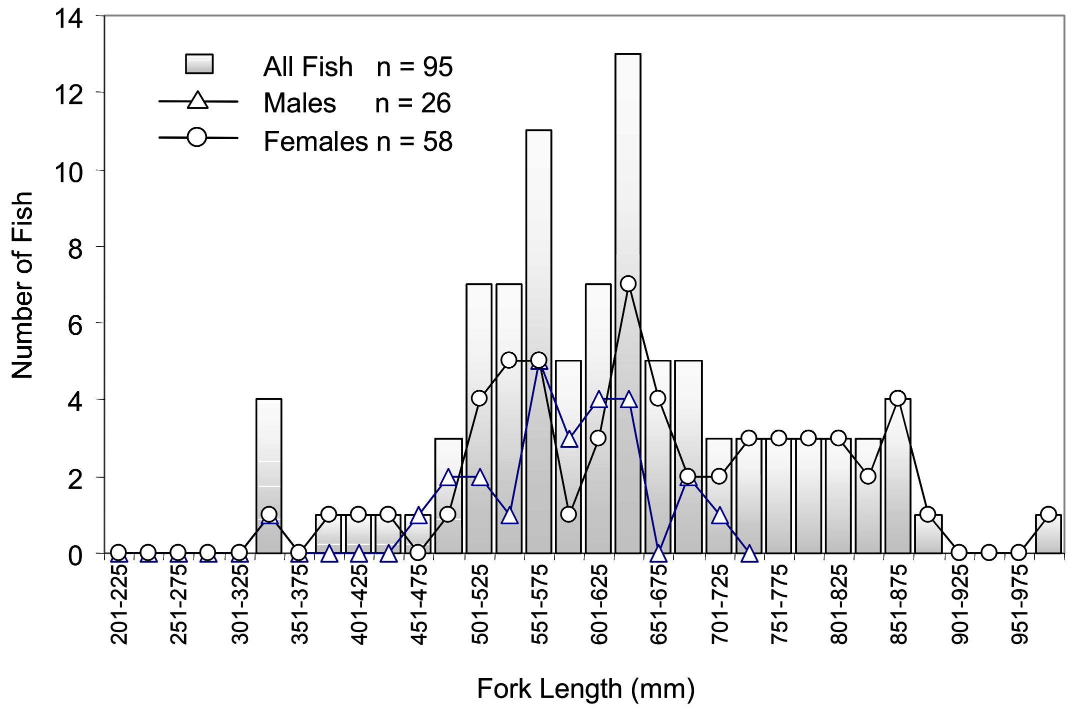
Figure 6.46 Timing of the northern pike migration in the Muskeg River fish fence, May 2003.



Size and Age Composition of Migrant Northern Pike

The size distribution of northern pike sampled at the Muskeg River fish fence is presented in Figure 6.47. The largest pike caught at the fence was a female measuring 1.0 m in fork length; the largest male captured was 702 mm. The mean length of female northern pike was significantly longer (661 mm, SD=139) than male sucker (574 mm, SD = 80)(p=0.003). Mean body weight for females (2,492 g, SD=1,753 g) was also markedly greater than males (1,392 g, SD= 523 g).

Figure 6.47 Length-frequency distribution for northern pike caught at the Muskeg River fish fence, May 2003.



The length-weight relationships for male and female pike are presented in Figure 6.48. Female body weight increased at a significantly higher rate than males with increasing fork length (p<0.001). As shown in Figure 6.48, the regression lines cross at a approximately 560 to 570 mm in fork length, indicating the condition of female pike is greater than males beyond this length.

The age composition of migrating northern pike is presented in Figure 6.49. Pike ranged in age from two to 11 years for both sexes. The median age for males was 6 years (41% of all males) and 6-7 for females (49% of all females).

Mean fork length for each age group of male and female northern pike is presented in Figure 6.50. The linear relationship between fork length and age ($\log_{10}$ transformed) is shown in Figure 6.51.

Based on the pike growth curves (Figure 6.50), females appears to grow at a faster rate than males; however, there is substantial variability in length among 9 and 10 year old female pike. Accordingly, there was no significant difference in growth curves between sexes (p=0.71), but female fish were significantly longer at any given age relative to males (p=0.005).

Figure 6.48 Weight-length relationships for male and female northern pike, Muskeg River fish fence, May 2003.

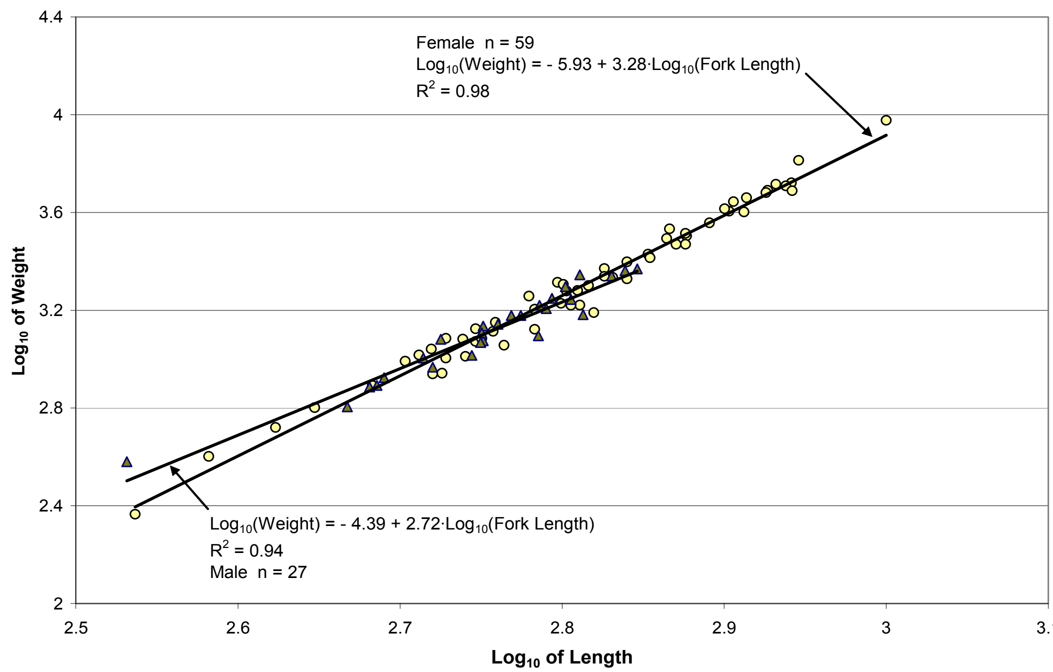


Figure 6.49 Age composition for northern pike sampled at the Muskeg River fish fence, May 2003.

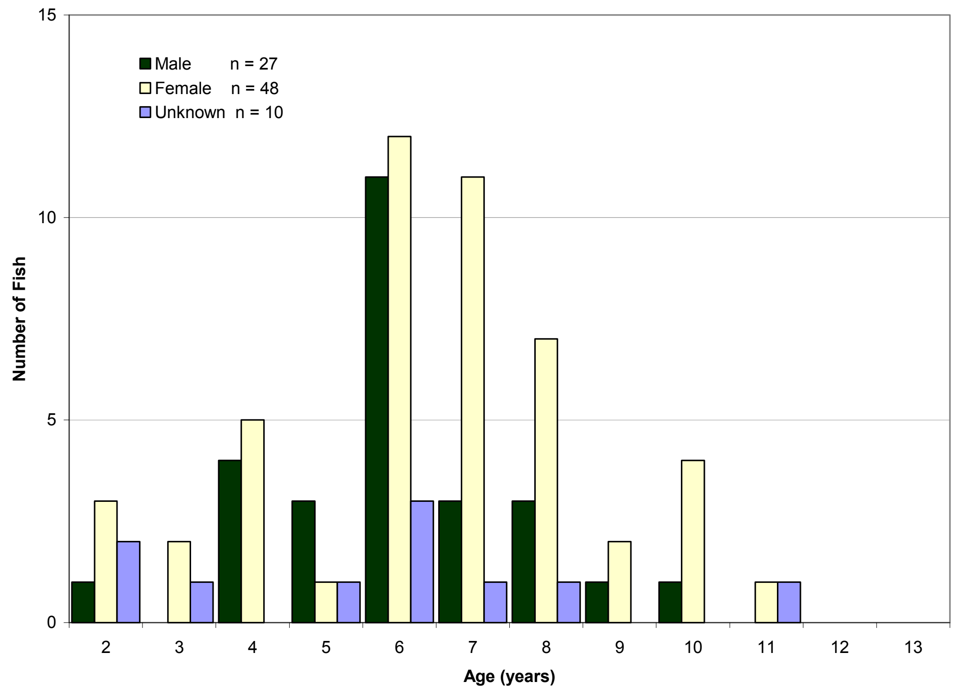


Figure 6.50 Length-age relationship by sex for northern pike sampled at the Muskeg River fish fence, May 2003 (Mean ± SE).

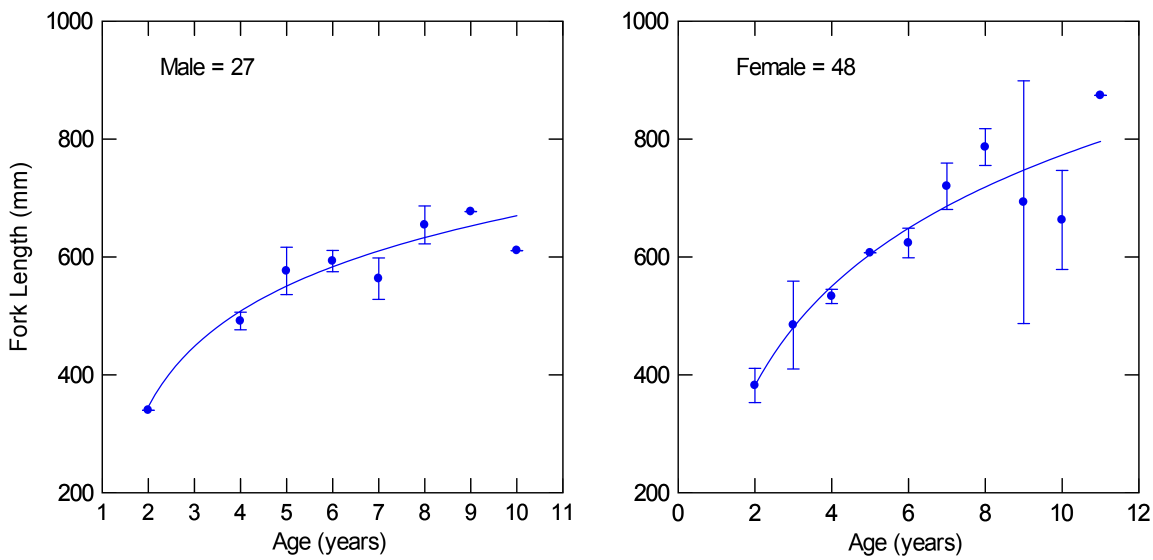
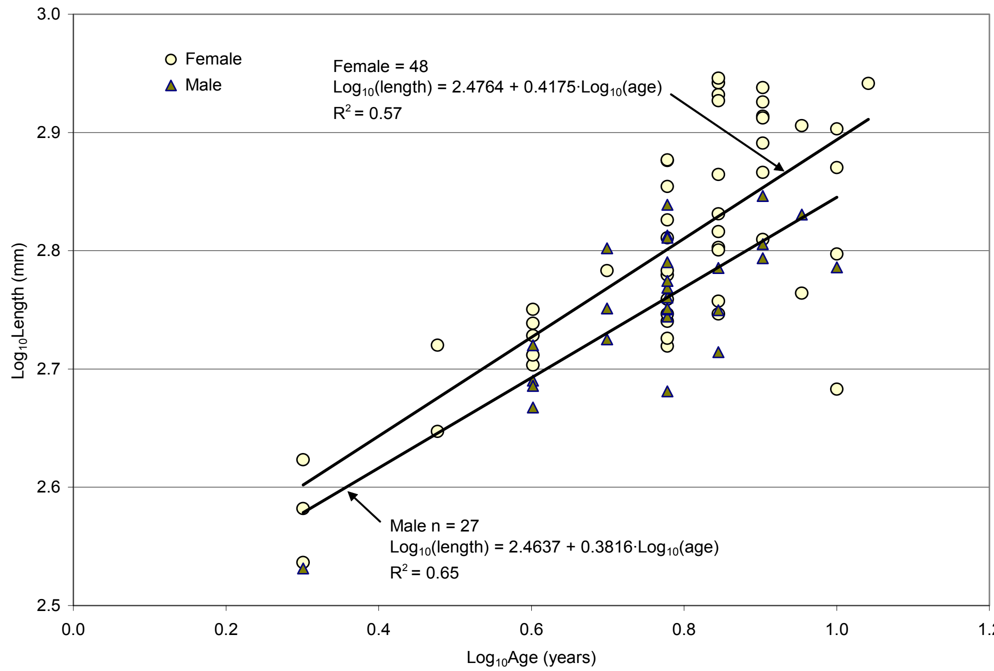


Figure 6.51 Size-at-age relationship by sex for northern pike sampled at the Muskeg River fish fence, May 2003.



Incidental Fish Species

Data of the incidental catch of individual Arctic grayling, mountain and lake whitefish and walleye are presented in Table 6.31.

Table 6.31 Data on incidental fish species caught at the Muskeg River fish fence, May 2003.

Species	Date	Fork Length (mm)	Weight (g)	Condition Factor	Sex	Maturity	Age	Migration Direction
ARGR	25-May	342	446	1.11	Unknown	Unknown	4	Down
ARGR	27-May	375	532	1.01	Unknown	Ripe	7	Up
LKWH	03-May	368	609	1.22	Female	Maturing	n/a	Down [a]
LKWH	03-May	330	601	1.67	Female	Immature	7	Down
MNWH	11-May	302	340	1.23	Unknown	Unknown	6	Up
MNWH	11-May	295	330	1.29	Unknown	Unknown	5	Up
MNWH	27-May	370	674	1.33	Unknown	Unknown	10	Up
MNWH	27-May	435	1,104	1.34	Unknown	Unknown	13	Up
WALL	17-May	467	968	0.95	Unknown	Spent	8	Down
WALL	17-May	447	980	1.10	Unknown	Unknown	8	Down

Species Legend: ARGR = Arctic grayling; LKWH = lake whitefish; MNWH = mountain whitefish; WALL = walleye

[a] Both lake whitefish caught in the downstream trap died from stress

Only two grayling were counted during the period of time the Muskeg River fence was in operation. On May 25, a ripe four year old was captured in the upstream trap. Two days later (last day of monitoring), a seven year-old grayling was captured in the downstream trap. Both fish were tagged and released.

Two female lake whitefish were found dead in the downstream trap on the second day of fence operation. This occurred when stream flow was still high and before adjustments were made to rate of water flow through the holding box.

Mountain whitefish were counted moving upstream on two separate occasions. The first two fish were recorded on May 11 and were 5 and 6 years old. Two other whitefish were counted on May 27 and were 10 and 13 years old.

Two adult walleye were caught in the downstream trap on May 17. Both fish were eight years old and were similar in size (447 mm and 467 mm). The larger fish was spent.

6.3.3.4 Results of Other Sampling Methods

Electrofishing

A limited electrofishing program was conducted in the vicinity of the fish fence to provide information on resident and non-resident fish, particularly small-bodied species. Attempts were made to sample different habitat types; however, in some cases channel depth or stream flow required either combining or partitioning of habitat types. Each habitat type sampled was a representative subset of the available habitat and was selected at random. A list of common and scientific names of species captured during the electrofishing program is presented in Table 6.32.

Table 6.32 Results of electrofishing in association with the fish fence program, Muskeg River, May 2003.

Common Name	Total Fish Caught
Minnow species	8
Sucker species	9
Trout-perch	1

Hoop Nets

On May 7, 2003, one hoop net was deployed in the Muskeg River approximately 200 m upstream of the fish fence. Initially, the plan was to monitor stream flows and other physical factors on the first net before deploying the second net. Due to a series of difficulties including high debris loads and unfavourable flow conditions, fish predation and net damage from resident otters, and a heavy workload at the fence, the hoop net program was abandoned after only a week of operation. No fish catch were obtained during the hoop net program. Further, it should be noted that the area in the vicinity of the fish fence presented limited suitable habitat (i.e., sections of slow-moving water, back channels, etc.), and was difficult to access. There may be some value in experimenting with the hoop nets at some future date on the Muskeg River if a suitable site can be identified and appropriate human resources are made available for installation, maintenance and monitoring.

Drift Nets

A series of trial drift netting efforts were conducted in the Muskeg River in association with the fish fence program. Due to high levels of suspended debris, nets were rapidly filled and rendered ineffective for capture of small-bodied fish species. Futher attempts to use drift nets to catch fish were abandoned.

6.4 DISCUSSION

6.4.1 Fish Inventory

6.4.1.1 Athabasca River

The total number of species recorded during surveys in 2003 was near the upper end of the range documented for previous inventories (highest: 22 species in 1997; lowest: 13 species in 1999) (Golder 2003b).

Percent composition of goldeye, longnose sucker and white sucker increased in 2003, relative to the declining trend in past years. Walleye increased in percent composition in 2003 relative to previous years, but did not exceed the historical maximum value observed in spring 1995. The percent composition of northern pike in the 2003 spring survey remained consistent with historical inventory results.

Of the 29 fish species known to inhabit the Athabasca River in the oil sands region, 22 species have previously been caught during RAMP fish inventory activities (Golder 2003a). In 2003, three species were captured that were known in the Athabasca River, but had not been previously captured under RAMP. These included cisco (electrofishing, spring and fall), pearl dace (spring seining, fall electrofishing), and longnose dace (spring seining).

Overall, it appears that, although the CPUE for all species increased in 2003, it was due to an increase in percent composition of species other than key fish indicators.

Examination of length-frequency distributions for key fish indicator species suggests that results have been generally consistent over time. Statistical differences in length-frequency distributions have been observed for some species over time; however, there were no consistent temporal trends that could be identified. Given the large sample sizes (i.e., all fish caught from 1997-2003), comparisons had a high level of statistical power and could detect small differences in length-frequency. However, these differences did not appear to be ecologically relevant. Though some variability exists regarding the number of small or large individuals captured between years, in general, the dominant length classes have remained consistent over time. Effort should continue to collect sufficient number of individuals to allow appropriate comparison of length-frequency distributions (~100 per species per year would be optimal). Trout-perch, northern pike and goldeye are frequently captured in low numbers (at times <20 adults per year). Where possible, inventory efforts should be habitat-specific (i.e., backwater areas for northern pike) and method specific (i.e., continue seining efforts for trout-perch), in order to improve sample sizes for some species.

There were no statistical differences in condition among years for any of the key indicator species studied. This suggests that the relationship between body weight and fork length has remained consistent over time. With the recent addition of trout-perch as a key fish indicator, it is recommended that weight information be collected to allow analysis of condition for this species as well.

From the results of the Athabasca River inventory, there is little evidence suggesting that characteristics of key indicator fish populations have changed during increasing development in the oil sands region.

6.4.1.2 Clearwater River

In 2003, inventory studies in the Clearwater River were undertaken for the first time under RAMP. Sampled populations of walleye and northern pike were of similar size to Athabasca River fish populations, while goldeye were slightly larger. Sucker populations in the Clearwater River appeared to be dominated by smaller (likely juvenile) individuals. The 2003 results suggest that fish populations in the two rivers are similar; the degree of mixing between individuals from these two rivers, and the likelihood of fish being from the same populations, is not known. The low numbers of lake whitefish captured in the Clearwater River in the fall strongly suggests that the river is not used by this species for migration to spawning areas (in contrast to the population in the Athabasca River at the same time of year). It is likely, therefore, that spawning habitat for this species is limited or not available in the Clearwater River in proximity to Fort McMurray.

Length-weight relationships for walleye and northern pike captured in the Clearwater River in 2003 were similar to Athabasca River fish populations. Longnose sucker had a lower mean condition factor compared to those in the Athabasca River, although this was likely influenced by the presence of immature individuals in the sample.

More detailed conclusions regarding fish populations in the Clearwater River will require additional data in future RAMP fish inventories.

6.4.1.3 Firebag River

Fish inventory results from the Firebag River in 2003 are considered preliminary due to the low level of effort expended and few fish which were captured. Data from future RAMP surveys will be used to develop a more comprehensive understanding of fish populations in this river.

6.4.2 Fish Tissue Analyses

6.4.2.1 General Comparisons

Generally, lake whitefish exhibited lower mercury levels compared to walleye and northern pike. This difference can be primarily attributed to differences in feeding behavior. Adult lake whitefish are benthic feeders that consume a wide variety of benthic invertebrates and small fish (Scott and Crossman 1973). In comparison, diets of northern pike and walleye include a much greater proportion of fish. Because of the tendency of mercury to bioaccumulate up the food chain, upper trophic level consumers, such as piscivorous fish, can accumulate much higher concentrations of mercury in their tissues (Eisler 1987b).

For walleye and lake whitefish, there was a strong positive relationship between age and mercury concentrations. The relationship between body size, particularly length, and mercury burden was more variable between species and waterbodies. Given the fish tissue program targeted larger fish, the relationship between mercury concentration and body size may be weaker compared to age because the growth rate in older fish continues to decrease with age. At this latter stage in the growth curve, age may be a more accurate predictor of compounds that bioaccumulate over time.

6.4.2.2 Screening for Potential Effects

Human Health – Athabasca River

Mercury

In Table 6.20 and Table 6.33, mercury concentrations in individual fish and composite samples are screened against a number of criteria to assess potential risks to human health. Concentrations of mercury in all individual and composite walleye samples were higher than the USEPA screening value for subsistence fishers by up to 15-fold. All walleye, with the exception of one male and two immature fish, also exceeded the less conservative Health Canada criterion for subsistence fishers by up to 3.6-fold. Mercury concentrations in all individual fish exceeded the Region III risk-based criterion by up to 5.1-fold. However, concentrations of mercury in composite walleye samples were below the Region III criterion and Health Canada criterion for subsistence fishers. Concentrations of mercury in nine males and two walleye females exceeded the screening value for recreational fishers (0.40) by up to 1.8 times. Concentrations of mercury in two females and five males exceeded the Health Canada criterion for general consumers (0.50) by up to 1.4 times.

Concentrations of mercury in all individual and composite lake whitefish samples were up to 5.3-fold higher than the USEPA screening values for subsistence fishers. Two females and three males exceeded the Region III risk-based criterion by up to 1.9-fold. One female lake whitefish had mercury concentrations slightly above the Health Canada criteria for subsistence fishers. No lake whitefish exceeded the screening values for recreational fishers or the Health Canada criterion for general consumers.

Based on the above information, there are potential health risks for humans consuming walleye and lake whitefish from the Athabasca River. Risks associated with whitefish consumption are, for the most part, for subsistence fishers and sensitive subpopulations (e.g., pregnant woman and children). Walleye pose a greater risk to human health than whitefish; a number of walleye exhibited mercury concentrations that exceeded the highest criterion. The risk to individuals, especially subsistence fishers, will vary with the consumption rates and dietary preferences of the community in question, community characteristics, extent of exposure to other contaminants, and exposure to contaminants through other routes (USEPA 2000).

Table 6.33 Screening of mercury concentrations in muscle of lake whitefish and walleye collected from the Athabasca River (September, 2003) against criteria for fish consumption for the protection of human health.

Species	Sex		Mercury Concentration (mg/kg)
Criteria			
Health Canada Criteria		*General Consumer*	0.50
		Subsistence Fishers	0.20
Region III USEPA Risk-based Criterion[1]			
National USEPA Screening Values[2]		*Recreational Fishers*	0.40
		Subsistence Fishers	0.049
Lake whitefish	Female		0.11
			0.09
			0.09
			<u>0.26</u>
			0.12
			0.07
			0.10
			0.14
			0.12
	Male		0.07
			0.04
			0.08
			0.05
			0.11
			0.07
			0.13
			0.16
			0.08
			0.07
			0.08
			0.16
			0.05
			0.12
			0.10
			0.18

Table 6.33 (cont'd).

Species	Sex	Mercury Concentration (mg/kg)
Walleye	Female	0.32
		0.32
		0.34
		0.27
		0.65
		0.67
	Male	0.28
		0.44
		0.35
		0.37
		0.47
		0.33
		0.16
		0.53
		0.42
		0.53
		0.72
		0.59
		0.60
		0.48
	Immature	0.20
		0.15
		0.18
		0.25
		0.21

All values exceed the USEPA screening values for subsistence fishers.
value = exceeds Health Canada criterion for subsistence fishers.
value = exceeds USEPA screening value for recreational fishers.
value = exceeds Health Canada criterion for the general consumer.
[1]Region III USEPA risk- based criteria for fish consumption are based on a 70 kg individual consuming 54 g of fish per day over a 30-year period (USEPA 2003). Criterion is for methylmercury.
[2]National USEPA screening values for recreational fishers are based on a 70 kg individual consuming 17.5 g of fish per day over a 70-year period; screening values for subsistence fishers are based on a 70 kg individual consuming 142.4 g of fish per day over a 70-year period; USEPA 2000). Criterion is for methylmercury.

Other Chemicals

In Table 6.20, metals and tainting compounds in fish are screened against several criteria to assess potential risks to human health. Only one exceedance was observed. Arsenic concentrations were below the analytical detection limit (0.2 mg/kg); however, this detection limit was higher than the USEPA screening values (0.00327 and 0.026 mg/kg) and Region III risk-based criteria (0.002 mg/kg). Overall, these results indicate that metals and tainting compounds do not pose a risk to human health; however, the next sampling program should incorporate lower detection limits for arsenic to better assess potential risks to human health.

Human Health – Regional Lakes

In Christina Lake, concentrations of mercury in all fish were higher than the USEPA screening values for subsistence fishers by up to 13-fold (Table 6.34). Mercury concentrations were higher than the Region III criterion and Health Canada criterion for one of the lake whitefish (up to 1.4-fold) and all of the walleye (up to 4.4-fold) and northern pike samples (up to 4.7-fold). Two walleye and one northern pike were slightly higher than the screening value for recreational fishers (by up to 1.7-fold) and the Health Canada criterion for general consumers (by up to 1.3-fold).

In Lake Claire, concentrations of mercury in all fish were higher than the USEPA screening values for subsistence fishers by up to 13-fold. All of the fish, with the exception of one lake whitefish, had mercury concentrations that were higher than the Region III criteria (by up to 4.5-fold). Four northern pike and one walleye had concentrations that were higher than the Health Canada criterion for subsistence fishers (by up to 3.2-fold). Three northern pike had concentrations that were slightly elevated above the screening values for recreational fishers (by up to 1.6-fold); two of those fish were also elevated above the Health Canada criterion for general fish consumers (by up to 1.3-fold).

These results indicate there are potential health risks for humans consuming lake whitefish, walleye, and northern pike from Christina Lake and Lake Claire. Given the small sample sizes of each sampling program, it is not feasible to define or delineate these risks in greater detail at this time.

Effects on Fish and Wildlife – Athabasca River

Mercury

In Table 6.34 and Table 6.35, mercury concentrations in individual and composite lake whitefish and walleye samples are screened against criteria and thresholds for effects in fish and wildlife. All mercury concentrations exceeded the CCME criteria for the protection of piscivorous wildlife (0.033 mg/kg) by up to 22-fold, indicating that there are potential risks to wildlife that consume fish. Mercury concentrations did not exceed any of the effects (or no effects) thresholds for fish.

Other Chemicals

In Table 6.36, concentrations of other contaminants in lake whitefish and walleye from the Athabasca River were screened against the lowest thresholds for effects (and absence of effects) in fish. Five metals exceeded the no effects thresholds for fish: aluminum, cadmium, selenium, silver, and vanadium. Four of these metals (excluding selenium) were below analytical detection limits; however, the detection limits were above the lowest no-effects threshold. Selenium concentrations in male lake whitefish and female walleye were slightly elevated above the lowest sublethal effects threshold. Because these metals were below, or only slightly above the lowest reported effects level, these results suggest that there is low potential for risk at these concentrations. Future tissue analyses should utilize lower detection limits for aluminum, cadmium, silver, and vanadium to better assess potential risks to fish.

Table 6.34 Screening of mercury concentrations in lake whitefish, walleye, and northern pike collected from the Christina Lake (September, 2003) and Lake Claire (December, 2002) against criteria for fish consumption for the protection of human health.

Species	Sex[1]	Mercury Concentration (mg/kg)
Criteria		
Health Canada Criteria	*General Consumer*	0.50
	Subsistence Fishers	0.20
Region III USEPA Risk-based Criterion[1]		0.14
National USEPA Screening Values[2]	*Recreational Fishers*	0.40
	Subsistence Fishers	0.049
Christina Lake		
Lake whitefish		
Individual samples		
	F	<u>0.20</u>
	M	0.06
	F	0.07
Composite samples		
(n=5)	M, F, and IF	0.09
	M, F, and U	0.09

Table 6.34 (cont'd).

Species	Sex[1]	Mercury Concentration (mg/kg)
Walleye		
Individual samples		
	F	***0.56***
	F	***0.61***
	F	0.31
Composite samples		
(n=5)	M, F, IF, and U	0.26
	M, F, and U	0.29
Northern Pike		
Individual samples		
	F	0.27
	F	0.37
	F	***0.66***
Composite samples		
(n=5)	F	0.38
	F	***0.44***
Lake Claire		
Lake Whitefish		
Individual samples		
	U	0.07
		0.15
Northern Pike		
Individual samples		
	U	0.14
	U	***0.63***
	U	***0.49***
Composite samples		
(n=5)	U	***0.55***
		0.30
Walleye		
Individual samples		
	U	0.18
		0.21

value = exceeds Health Canada criterion for subsistence fishers.

value **=** exceeds USEPA screening value for recreational fishers.

value **=** exceeds Health Canada criterion for the general consumer.

[1]F=adult female; M=adult male; IF=immature F; U=unknown

[1]Region III USEPA risk- based criteria for fish consumption are based on a 70 kg individual consuming 54 g of fish per day over a 30-year period (USEPA 2003). Criterion is for methylmercury.

[2]National USEPA screening values for recreational fishers are based on a 70 kg individual consuming 17.5 g of fish per day over a 70-year period; USEPA 2000).Criterion is for methylmercury.

Table 6.35 Screening of mercury concentrations in muscle of lake whitefish and walleye collected from the Athabasca River (September, 2003) for the protection of fish and wildlife.

Species	Sex		Mercury Concentration (mg/kg)
Criteria			
CCME criteria for the protection of wildlife1			0.033
Effects thresholds for fish2	No effects	*lethal*	1.91
		sublethal	2.28
	Effects	*lethal*	6.2
		sublethal	8.6
Lake whitefish	Female		0.11
			0.09
			0.09
			0.26
			0.12
			0.07
			0.10
			0.14
			0.12
	Male		0.07
			0.04
			0.08
			0.05
			0.11
			0.07
			0.13
			0.16
			0.08
			0.07
			0.08
			0.16
			0.05
			0.12
			0.10
			0.18

Table 6.35 (cont'd).

Species	Sex	Mercury Concentration (mg/kg)
Walleye	Female	0.32
		0.32
		0.34
		0.27
		0.65
		0.67
	Male	0.28
		0.44
		0.35
		0.37
		0.47
		0.33
		0.16
		0.53
		0.42
		0.53
		0.72
		0.59
		0.60
		0.48
	Immature	0.20
		0.15
		0.18
		0.25
		0.21

value = exceeds CCME criteria for piscivorous wildlife; potential risk to animals consuming fish.

value **=** exceeds lethal effects thresholds; potential risk to fish.

Thresholds and criteria are for methylated forms of mercury.

[1]Canadian Councils of Ministers of the Environment (CCME) criteria for the protection of wildlife that consume fish (CCME 2001b.

[2]Threshold values were derived from effects data presented in Jarvinen and Ankley (1999).

Effects on Fish and Wildlife – Regional Lakes

In Table 6.37, mercury concentrations in individual and composite lake whitefish, walleye, and northern pike samples are screened against criteria and thresholds for effects in fish and wildlife. All mercury concentrations exceeded the CCME criteria for the protection of piscivorous wildlife (0.033 mg/kg) by up to 20 times, indicating that there are potential risks to wildlife that consume fish. Mercury concentrations did not exceed the effects thresholds for fish.

Effects on Palatability of Fish – Athabasca River

The presence of elevated concentrations of tainting compounds can result in decreased palatability of fish due to presence of an undesirable odor or flavor. All tainting compounds were present at concentrations well below 1 mg/kg (<0.02 mg/kg) indicating that fish palatability is not likely to be an issue.

Table 6.36 Screening of metal and PAH concentrations in lake whitefish and walleye collected from the Athabasca River (September, 2003) for protection of fish.

	Thresholds for Protection of Fish[1]				Observed Concentrations (mg/kg)			
	Lowest no-effects thresholds		Lowest effects thresholds		Lake whitefish		Walleye	
	lethal	sublethal	lethal	sublethal				
Analyte	(mg/kg)	(mg/kg)	(mg/kg)	(mg/kg)	Female	Male	Female	Male
Metals								
Aluminum	1.0	nd	20	nd	<u><4</u>	<u><4</u>	<u><4</u>	<u><4</u>
Antimony	5	nd	9	nd	<0.04	<0.04	<0.04	<0.04
Arsenic	2.6	0.9	11.2	3.1	<0.2	<0.2	<0.2	<0.2
Barium	nd	nd	nd	nd	0.21	0.22	0.25	0.22
Beryllium	nd	nd	nd	nd	<0.2	<0.2	<0.2	<0.2
Boron	nd	nd	nd	nd	<2	<2	<2	<2
Cadmium	0.02	0.09	0.14	0.12	<u><0.08</u>	<u><0.08</u>	<u><0.08</u>	<u><0.08</u>
Chromium	nd	nd	nd	nd	<0.2	<0.2	<0.2	<0.2
Cobalt	nd	nd	nd	nd	<0.08	<0.08	<0.08	<0.08
Copper	0.5	3.4	0.5	nd	0.20	0.29	0.41	0.30
Iron	nd	nd	nd	nd	3	4	3	4
Lead	4.0	nd	nd	nd	<0.04	<0.04	<0.04	<0.04
Lithium	nd	nd	nd	nd	<0.5	<0.5	<0.5	<0.5
Manganese	nd	nd	nd	nd	0.11	0.14	0.05	0.06
Mercury[2]	1.91	2.28	6.2	8.6	0.09	0.05	0.07	0.10
Molybdenum	nd	nd	nd	nd	<0.04	<0.04	<0.04	<0.04
Nickel	0.82	nd	118.1	nd	<0.08	0.08	<0.08	<0.08
Selenium	0.28	0.08	0.92	0.32	<u>0.3</u>	***0.4***	***0.4***	<u>0.3</u>
Silver	0.003	0.003	nd	nd	<u><0.08</u>	<u><0.08</u>	<u><0.08</u>	<u><0.08</u>
Strontium	nd	nd	nd	nd	0.16	0.38	0.48	0.17
Thallium	nd	nd	nd	nd	<0.04	<0.04	<0.04	<0.04
Tin	nd	nd	nd	nd	<0.08	<0.08	<0.08	<0.08
Titanium	nd	nd	nd	nd	0.21	0.15	0.24	0.31
Vanadium	5.33	0.02	nd	0.41	<u><0.08</u>	<u><0.08</u>	<u><0.08</u>	<u><0.08</u>
Zinc	60	60	nd	nd	6.7	6.0	7.7	6.6
Tainting Compounds (PAHs)								
Thiophene	nd	nd	nd	nd	<0.02	<0.02	<0.02	<0.02
Toluene	nd	nd	nd	nd	<0.02	<0.02	<0.02	<0.02
M+P-Xylenes	nd	nd	nd	nd	<0.02	<0.02	<0.02	<0.02
o-Xylene	nd	nd	nd	nd	<0.02	<0.02	<0.02	<0.02
1,3,5-Trimethylbenzene	nd	nd	nd	nd	<0.02	<0.02	<0.02	<0.02
Naphtalene	nd	nd	nd	nd	<0.02	<0.02	<0.02	<0.02

<u>value</u> = exceeds lethal or sublethal no effects threshold; effects have not been observed at this concentration.
value = exceeds lethal or sublethal effects threshold; effects have been observed at this concentration.
n=5 fish/composite sample
nd = no data available
[1]Threshold values were derived from effects data presented in Jarvinen and Ankley (1999).
[2]Thresholds are for methylated forms of mercury.

6.4.2.3 Comparison to Historical Data

Mercury

Mean mercury concentrations for individual fish in 2002 are presented in Table 6.38 and for composite samples in 2001 and 2002 in Table 6.39. Only qualitative comparisons were made between years because 2001 data were comprised of composite samples (comprised of 5 fish per sex). Mercury concentrations in individual whitefish and walleye were similar among years; the age and size of the fish were also similar. Mean mercury concentrations in lake whitefish in 2003 were similar to those observed in 2002. Mean mercury concentrations in walleye in 2003 were also similar to those observed in 2002.

Concentrations of mercury in composite walleye samples in 2003 were lower than those observed in 2001 and 2002.

Comparisons of 2003 results to historical data collected within and outside of the oil sands region (as summarized in Golder 2003a) demonstrates that mercury concentrations are naturally elevated in this region. Historically, mercury concentrations in fish have ranged from 0.33 to 0.79 mg/kg from the Athabasca River upstream of the oil sands region and 0.15 to 0.79 mg/kg within or downstream of the oil sands region (Golder 2003a). Fish tissue data collected in 2003 fall within this range, indicating that mercury concentrations are not elevated above historical levels and do not appear to be linked to oil sands operations.

Other Chemicals

Concentrations of metals and tainting compounds in composite muscle samples of lake whitefish and walleye collected in 2001, 2002, and 2003 are presented in Table 6.39. Only qualitative comparisons were made between years because in previous years all chemical analyses were conducted on composite tissue samples, comprised of five fish per sex. Only a few analytes differed from those observed in 2002. Most of these changes were slight, with one exception. Toluene concentrations were substantially lower in 2003 (<0.02 mg/kg) relative to those observed in 2002 (36 to 270 mg/kg). The remaining analytes are described below.

Table 6.37 Screening of mercury concentrations in whitefish, walleye, and northern pike collected from the Christina Lake (September, 2003) and Lake Claire (December, 2002) for protection of fish and wildlife.

Species	Sex[1]	Mercury Concentration (mg/kg)
Criteria		
CCME criteria for the protection of wildlife[1]		0.033
Effects thresholds for fish[2]	No effects - *lethal*	1.91
	sublethal	2.28
	Effects - *lethal*	6.2
	sublethal	8.6
Christina Lake		
Lake whitefish		
Individual samples		
	F	0.20
	M	0.06
	F	0.07
Composite samples		
(n=5)	M, F, and IF	0.09
	M, F, and U	0.09
Walleye		
Individual samples		
	F	0.56
	F	0.61
	F	0.31
Composite samples		
(n=5)	M, F, IF, and U	0.26
	M, F, and U	0.29
Northern Pike		
Individual samples		
	F	0.27
	F	0.37
	F	0.66
Composite samples		
(n=5)	F	0.38
	F	0.44

Table 6.37 (cont'd).

Species	Sex[1]	Mercury Concentration (mg/kg)
Lake Claire		
Lake Whitefish		
Individual samples		
	U	0.07
		0.15
Northern Pike		
Individual samples		
	U	0.14
	U	0.63
	U	0.49
Composite samples		
(n=5)	U	0.55
		0.30
Walleye		
Individual samples		
	U	0.18
		0.21

value = exceeds CCME criteria for piscivorous wildlife; potential risk to animals consuming fish.

value **=** exceeds lethal effects thresholds; potential risk to fish.

Thresholds and criteria are for methylated forms of mercury.

[1]Canadian Councils of Ministers of the Environment (CCME) criteria for the protection of wildlife that consume fish (CCME 2001b).

[2]Threshold values were derived from effects data presented in Jarvinen and Ankley (1999).

Table 6.38 Mean mercury concentrations in individual muscle samples of lake whitefish and walleye from the Athabasca River, September 2002.

Species	Sex	n	Fork Length (mm)	Weight (g)	Age	Mercury Concentration (mg/kg)
Lake whitefish						
Female	Mean	9	433	1,335	8.3	0.12
	SD		26	269	2.2	0.07
Male	Mean	16	427	1,189	9.7	0.14
	SD		39	289	3.8	0.11
Walleye						
Female	Mean	8	494	1,356	8.8	0.40
	SD		79	641	3.2	0.19

Table 6.38 (cont'd).

Species	Sex	n	Fork Length (mm)	Weight (g)	Age	Mercury Concentration (mg/kg)
Male	Mean	11	405	765	7.1	0.38
	SD		74	355	3.4	0.23
Immature	Mean	6	266	248	2.0	0.27
	SD		58	143	1.5	0.24

The following chemicals increased in 2003 walleye and lake whitefish compared to previous years:

- Barium: concentrations were slightly higher in 2003 (0.21 to 0.25 mg/kg) relative to those observed in 2001 and 2002 (<0.08 to 0.15 mg/kg).

- Copper: concentrations were slightly higher in 2003 (0.20 to 0.41 mg/kg) relative to those observed in 2002 (0.16 to 0.21 mg/kg), and were similar to those observed in 2001 (0.32 to 0.45 mg/kg).

- Strontium: concentrations were slightly higher in 2003 (0.16 to 0.48 mg/kg) relative to those observed in 2001 and 2002 (0.05 to 0.13 mg/kg).

- Titanium: concentrations were slightly higher in 2003 (0.15 to 0.31 mg/kg) relative to those observed in male whitefish and walleye (<0.05 mg/L) in 2002 (concentrations in female lake whitefish were 0.67 mg/kg) and were lower than those observed in 2001 (0.11 to 0.83 mg/L).

Concentrations of the following chemicals decreased in 2003 compared to previous years:

- Manganese: concentrations were slightly lower (0.05 to 0.14 mg/kg) than those observed in 2001 and 2002 (0.11 to 0.24 mg/kg).

- Thiophene: concentrations were lower in 2003 (<0.02 mg/kg) than those observed in 2002 (<1 to 3 mg/kg).

Concentrations of several metals, including cadmium, chromium, iron, lead, nickel, and vanadium, were similar to those observed in 2002 (usually below detection limits), but were lower than the concentrations observed in 2001.

Overall, results indicate that tissue quality has stayed the same or improved since 2002. The most significant improvement was observed for toluene.

Table 6.39 Metal and PAH concentrations in composite muscle samples of lake whitefish and walleye collected from the Athabasca River in 2001, 2002, and 2003.

	2001 Concentration (mg/kg)				2002 Concentration (mg/kg)				2003 Concentration (mg/kg)			
	Lake whitefish		Walleye		Lake whitefish		Walleye		Lake whitefish		Walleye	
Analyte	Female	Male	Female	Male	Female	Male	Female	Male	Female	Male	Female	Male
Metals												
Aluminum	7	<4	<4	<4	<4	<4	<4	<4	<4	<4	<4	<4
Antimony	<0.04	<0.04	0.05	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04
Arsenic	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2
Barium	0.14	<0.08	0.15	0.09	0.10	0.10	0.11	0.11	0.21	0.22	0.25	0.22
Beryllium	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2
Boron	na	na	na	na	<2	<2	<2	<2	<2	<2	<2	<2
Cadmium	0.08	0.09	<0.08	0.11	<0.08	<0.08	<0.08	<0.08	<0.08	<0.08	<0.08	<0.08
Chromium	0.5	0.5	<0.2	0.5	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2
Cobalt	<0.08	<0.08	<0.08	<0.08	<0.08	<0.08	<0.08	<0.08	<0.08	<0.08	<0.08	<0.08
Copper	0.32	0.45	0.36	0.32	0.20	0.21	0.16	0.20	0.20	0.29	0.41	0.30
Iron	10	16	15	11	3	4	3	3	3	4	3	4
Lead	0.04	0.08	<0.04	0.15	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04
Lithium	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5
Manganese	0.21	0.22	0.12	0.24	0.16	0.17	0.11	0.14	0.11	0.14	0.05	0.06
Mercury[1]	0.11	0.11	0.46	0.36	0.12	0.14	0.43	0.43	0.09	0.05	0.07	0.10
Molybdenum	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04
Nickel	0.65	1.22	0.26	0.56	<0.08	<0.08	<0.08	<0.08	<0.08	0.08	<0.08	<0.08
Selenium	0.5	0.5	0.4	0.6	0.4	0.4	0.3	0.3	0.3	0.4	0.4	0.3
Silver	<0.08	<0.08	<0.08	<0.08	<0.08	<0.08	<0.08	<0.08	<0.08	<0.08	<0.08	<0.08
Strontium	0.12	0.12	0.10	0.11	0.13	0.12	0.06	0.05	0.16	0.38	0.48	0.17
Thallium	<0.04	<0.04	0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04
Tin	<0.08	<0.08	.12	<0.08	<0.08	<0.08	<0.08	<0.08	<0.08	<0.08	<0.08	<0.08
Titanium	0.83	0.48	0.11	0.49	0.67	<0.05	<0.05	<0.05	0.21	0.15	0.24	0.31
Vanadium	0.12	0.17	<0.08	0.14	<0.08	<0.08	<0.08	<0.08	<0.08	<0.08	<0.08	<0.08
Zinc	4.8	3.3	7.4	4.3	9.6	4.6	5.2	6.7	6.7	6.0	7.7	6.6
Tainting Compounds (PAHs)												
Thiophene	na	na	na	na	<1	3	<1	<1	<0.02	<0.02	<0.02	<0.02
Toluene	na	na	na	na	270	130	73	36	<0.02	<0.02	<0.02	<0.02
M+P-Xylenes	na	na	na	na	<1	5	<1	<1	<0.02	<0.02	<0.02	<0.02
o-Xylene	na	na	na	na	na	na	na	na	<0.02	<0.02	<0.02	<0.02
1,3,5-Trimethylbenzene	na	na	na	na	na	na	na	na	<0.02	<0.02	<0.02	<0.02
Naphtalene	<0.02	<0.02	<0.02	<0.02	<1	<1	<1	<1	<0.02	<0.02	<0.02	<0.02

[1]Results for 2002 represent the mean for individual adult fish for each sex and species combination.
na = not analyzed

6.4.2.4 Fish Health Asessment

The high frequency of abnormalities observed in whitefish and walleye do not appear to be directly linked to chemical exposure. The most prevalent abnormalities including scars on the surface of the skin, general liver discoloration, presence of parasites in the body cavity, and granular deposits on the surface of the heart appear to be linked to non-chemical sources or sampling artifacts. The presence of scars in both species indicates that fish were injured in the past by source(s) such as predators, fishers, physical features in the environment, and/or disease; these factors do not appear to be currently causing external injuries in fish, given the low frequency of open wounds that was observed. General liver discoloration, observed in males and females of both species, was most likely caused by the length of time that elapsed between death and sampling (Goede and Barton 1990). Parasites were observed at a higher frequency in lake whitefish than walleye, which is not surprising, given that lake whitefish are host to a wide range of parasites (Scott and Crossman 1973; Stewart and Bernier 1999). The granular appearance of hearts in lake whitefish most likely represents parasitic cysts of the trematode, *Icthyoctylurus* (Stewart and Bernier 1999).

Historically, the percentage of gross abnormalities observed in fish in the Athabasca River basin and delta has been low (less than 1% of fish in large scale collections; Mill 1997). However, occasionally, high frequencies of pathological abnormalities have been observed. In lake whitefish, the percentage of abnormalities in three studies conducted between 1993 and 1995 has ranged from 0.95% (n=105) to 77% (n=30). Results from historical studies indicate that both the types and frequencies of abnormalities are highly variable among and between different species. Given the inherent variability in occurrence of abnormalities, to adequately assess abnormalities in fish populations, future studies must employ larger samples sizes and collection of fish from reference areas.

6.4.2.5 Conclusions

Potential effects on human health were predicted from the fish tissue analyses. Results indicate that due to the presence of elevated concentrations of mercury, there is potential risk to humans consuming target fish species from the Athabasca River and regional lakes examined. In the Athabasca River, there are potential human health risks from consuming walleye for the subsistence and recreational fishers, sensitive subpopulations (i.e., children, pregnant women), and general fish consumers; for lake whitefish risks are largely limited to subsistence fishers and sensitive subpopulations. Other metals and tainting compounds do not appear to pose any human health risks; however, to effectively screen for human health risks, higher detection limits are needed for some analytes, and should be employed in future sampling programs. In the regional lakes, mercury concentrations in all fish evaluated pose potential risk to subsistence fishers and sensitive subpopulations. Northern pike and walleye also pose risks to recreational fishers and general consumers. More intensive sampling of these lakes is recommended to better evaluate potential risks.

Although mercury concentrations are elevated in fish tissues in the RAMP study area, comparison with historical data shows that mercury concentrations observed in the current study fall within the naturally elevated range of concentrations observed in this region. Given that mercury concentrations in fish have not increased above natural background levels during increasing oil sands development, there is little evidence suggesting that the ongoing development is influencing mercury concentrations in fish tissues. In addition, water and sediment concentrations of mercury presented in Chapter 2 and 3 further support the assertion that there is a baseline level of mercury in the oil sands region unrelated to increasing oil sands development.

Effects on fish health were not predicted from the screening against literature-based thresholds for effects. The fish health assessment also indicated that chemical-related effects were not evident in fish collected from the Athabasca River. However, based on comparisons with CCME criterion for wildlife, there are potential risks to wildlife that consume fish from the Athabasca River and regional lakes.

Effects on fish palatability were not predicted, given that concentrations of the tainting compounds measured were below detection limits and screening values. Concentrations of tainting compounds were significantly reduced from those observed in 2002.

6.4.3 Fish Fence

6.4.3.1 General Overview

The 2003 spring fish migration study on the Muskeg River satisfied the established objectives, specifically:

- the fish fence resulted in collection of accurate data on the biology and movement of large-bodied fish species in the Muskeg River drainage;
- data collected were suitable for assessment of potential regional environmental impacts/effects in the Muskeg River watershed; and
- the study documented the current use of the Muskeg River by spawning fish populations from the Athabasca River.

To facilitate comparison between studies, all future fish fence studies in the Muskeg River should be conducted immediately after ice-out (i.e., when the river becomes safe for field personnel to enter). Although fish were migrating prior to installation of the fence on May 2, 2003, water levels before this date were considered too high to allow installation of the fence (see hydrograph for the Muskeg River, Chapter 2, Figure 2.17). Additionally, the location of the fish fence at the mouth (as in this study) should be maintained in future years. Variability in both of these factors was cited as a limitation to comparison of data from previous fish fences studies in the Muskeg River (Golder 2003a). The most successful studies to date (in terms of overall data quality and applicability) were conducted in the spring and at either the river mouth (Bond and Machniak 1977, 1978), or at a point 16.5 km upstream of the mouth (Golder 1996). Incidental observations of suckers holding and spawning in the lower Muskeg reaches (including areas downstream of the 2003 fence) were reported during the current study and supports the need to operate the fence as close to the river mouth as possible.

6.4.3.2 Comparison with Historical Data

Fish count data from the four studies that are considered comparable (1976, 1997, 1995 and the present study), indicate that the abundance of migrant large-bodied fish in the Muskeg River appears to have declined substantially over time (Table 6.40). The most dramatic decline was observed between the fence studies conducted in 1976/1977 and the fence study in 1995, prior to oil sands development in the Muskeg River watershed.

Although the duration of fence monitoring varied among studies, the relative strength of the upstream spawning runs were comparable because: a) all studies deployed the fence in late April/early May and monitored the fence until at least the end of May to characterize the upstream spawning migration; and b) Bond and Machniak (1978, 1979) monitored fish movements from late April to July and found that a vast majority of the upstream migration occurred in May (e.g., 90% of longnose sucker, 79 to 88% of northern pike in 1976 and 1977, respectively). Conversely, the 2003 (and 1995) fence operations were not deployed long enough to fully characterize downstream movements of fish following spawning.

Study results suggest that the number of migrating Arctic grayling has declined over time in the Muskeg River. A total of two Arctic grayling individuals were observed near the end of the 2003 counting fence program (Table 6.40). This represents a substantial decline relative to 1995 results, which, in turn, were well below results from studies in 1976 and 1977. As discussed above, before the reduced numbers can be considered definitive, the likelihood for under ice movement should be documented. Regardless, the apparent decline in numbers of Arctic grayling (a "species of special concern" in Alberta [ASRD 2003]) migrating into the Muskeg River in 1995 and 2003, requires additional investigation.

Table 6.40 Summary of spring migration fish counts for large-bodied fish species from counting fences (full width), Mainstem Muskeg River (1976 – 2003).

Species	1976 [(a)]		1977 [(b)]		1995 [(c)]		2003	
	Up	Down	Up	Down	Up	Down	Up	Down
Arctic grayling	305	78	161	11	14	49	1	1
Bull trout	0	0	3	0	0	0	0	0
Burbot	1	2	1	0	0	0	0	0
Cisco	0	0	1	0	0	0	0	0
Lake whitefish	3	14	7	6	0	0	0	2
Longnose sucker	2,837	2,191	1,641	1,004	308	36	162	47
Mountain whitefish	33	101	50	17	0	0	4	0
Northern pike	131	155	433	59	126	3	79	27
Walleye	4	3	8	5	1	0	0	2
White sucker	2,839	1,669	2,970	1,385	299	1	647	234
Total	6,153	4,213	5,275	2,487	748	89	893	313
Overall Total (# days)	10,366 (94)		7,762 (49)		837 (26)		1,152 (25)	

[a] Fish fence operated near the river mouth from April 28 to July 30, 1976 (Bond and Machniak 1977).
[b] Fish fence operated near the river mouth from April 28 to June 15, 1977 (Bond and Machniak 1978).
[c] Fish fence operated 16.5 km upstream of the river mouth from May 6 to 31, 1995 (Golder 1996).

White sucker is one of the most abundant large-bodied fish species in the Muskeg River (Golder 2003a); it was also the most abundant species observed at the counting fence in 2003. The number of migrating spawners captured in 2003 was approximately 10% of that reported in the late-1970s (Bond and Machniak 1977, 1978); however, the number in 2003 was more than 50% higher than reported in 1995 (Golder 1996). Length-frequency distribution and fish condition distribution of fish in 2003 was generally consistent with previous years (Bond and Machniak 1977, 1978, Golder 2003a). Similar to results by Bond and Machniak (1977, 1978), the majority of white suckers captured at the fence in 2003 were between 8 and 12 years old; however, a higher number of younger fish were found in 1995 (Golder 2003a). Growth rates based on size-at-age data exhibit high variability between years (Golder 2003a) and results obtained in 2003 are consistent with this trend. The ratio of males to females was about 1:2.5 in 2003, which is in contrast to the 1:1 ratio documented by Bond and Machniak (1977, 1978). It is unclear why this skewed sex ratio was observed in 2003. General references (e.g., Scott and Crossman 1973, Nelson and Paetz 1992) do not suggest that variable timing of migration has been observed for white sucker.

Longnose suckers were the second most abundant species in 2003. As with white sucker, the number of migrating individuals of this species appears to be decreasing over time (Bond and Machniak 1977, 1978, Golder 2003a) (Table 6.40).

The number of migrants declined sharply between 1976/1977 and 1995. The number of longnose suckers observed in 2003 was approximately 50% lower than the number observed in 1995 (Table 6.40). For fish observed in 2003, the majority were of the same length class (351-450 mm) as reported in 1976 and 1977 (Bond and Machniak 1977, 1978); further, females were significantly longer (and were longer at any given age) relative to captured males. As would be expected, females had a higher condition relative to males in 2003, which was consistent with findings in 1977, but divergent from results in 1976 when the length-weight relationship was similar between sexes. In 2003, migrating longnose sucker ranged in age from 7 to 19 years, with the majority of fish (71% of females, 81% of males) between 9 and 13 years old. In contrast, Bond and Machniak (1977, 1978) found generally younger fish, with a maximum age of 13 years. As with white sucker, the ratio of male to female longnose sucker was about 1:2.5, which contrasts with results from Bond and Machniak (1977, 1978).

As in previous fish fence studies, northern pike was the most abundant sport fish species observed at the counting fence in 2003. Further, the number of northern pike observed in 2003 was similar to the number seen in 1995. Previous studies have shown that suitable habitat for northern pike occurs in the upper mainstem river (Golder 2003a). Although some decline is evident in the number of pike observed since the 1976 and1977 studies, the magnitude of difference is much less dramatic than for both sucker species over the same time period. The length-frequency distribution was variable between years; Bond and Machniak (1977, 1978) reported generally smaller size ranges (401 to 550 mm in length, 1977 spring program) than more recent results. As observed for longnose sucker, female northern pike were significantly longer (and had a higher length-at-age), on average, than males in 2003. In 2003, older fish made up a greater proportion of all fish observed relative to 1976 and 1977 results (Bond and Machniak 1977, 1978). It has been reported (Golder 2003a) that spawning adult northern pike have been more abundant in the Muskeg River watershed in recent years.

The cause of the declining trend observed in the number of spring migrants is uncertain. The most dramatic decline in numbers occurred between fish fence studies conducted in 1976/1977 and 1995. Results in 2003 are similar to those reported in 1995. It is noted, however, that the decline in abundance was observed prior to initiation of oil sands development in the Muskeg River watershed (i.e., year of first disturbance: Aurora North, 1996; Muskeg River Mine, 2000). It appears, therefore, that the number of fish that enter the Muskeg River from the Athabasca River is highly variable among years. It is possible that recent low water levels (previous five years), common throughout the lower Athabasca basin, have affected the accessibility of the river to spawning fish. An increase in the number of beaver dams, as a result of the lower water levels, may have also reduced access to spawning areas. In response, fish normally spawning in the Muskeg River may have been unable to, or chose alternate habitat (e.g., other Athabasca tributaries) for spawning. The Muskeg River fish fence study continues to be effective in documenting fish use of the river for migration and spawning; however, given the level of variability in numbers observed to date, many years of data would be required to establish representative baseline conditions sufficient to detect a development-related change.

6.4.3.3 Fence Operation

With the exception of one day when the fence collapsed due to high flows, few operational problems were encountered while the fence was in place in 2003. The overall success of the 2003 study was, in part, related to changes in the fence design recommended by North/South Consultants Inc. Although successful, several areas for improvement for future fences require discussion.

Historical hydrological data indicates that much higher average spring flows commonly occur in the Muskeg River, in comparison to flows observed during the period of fence operation in 2003. In higher flow years, the success experienced in this study may not be as easily replicated. Improvements to the fence design used in 2003 should be considered in future, including a better system to anchor the fence in position (e.g., cables to shore). Such modifications would increase the fence's inherent stability and potentially reduce the frequency of collapse (and associated data loss).

It appears that the success of fish fence studies conducted to date (the present one included) is strongly linked to the timing for installation of the fish fence in the river, and the total length of time the fence is in operation. Uncertainty exists regarding the possibility that some species (e.g., Arctic grayling, but also potentially sucker and northern pike) may enter the Muskeg River prior to complete ice-out (Scott and Crossman 1973). The extent to which this occurs is presently unknown; however, in the event that it does, the number of migrating fish in the Muskeg River would be consistently underestimated.

Although valuable to maximize number of fish counted, design and operational considerations exist regarding early fence installation. Fence deployment immediately after ice-out would be subject to impingement by large quantities of floating ice, which would most likely make it impossible to keep a counting fence of standard design in place. Other fence designs exist (e.g., a "floating fence") that may be more suitable for these circumstances; however, these designs can be much more costly to build than a standard fence. Alternatively, a partial fence with an upstream deflector could be deployed using existing fence material; however, there would still be uncertainty regarding the accuracy of count data if a full spanning fence is not used.

Prior to implementation of an alternate fence design, preliminary studies (i.e., presence/absence) could be conducted to determine if early migrants (e.g., Arctic grayling) do, in fact, enter the Muskeg River prior to ice-out. For instance, in spring 2003, it was found that fish migration had already begun prior to the time the fence was installed (i.e., prior to May 2). It was reported by local people that a large amount of water was flowing on top of the ice during that period. Under these conditions, fish may be able to enter the mouth of the Muskeg River, however, installation of a fish fence would not be feasible. Overall, the use of alternate fence designs to allow earlier installation should be weighed against the importance of catching early spring migrant fish.

While in the field, it was difficult to definitively determine the end of the spawning migration period in the Muskeg River. The fence study was terminated when upstream fish counts for all three dominant species were in decline (May 27); however, it is likely that fish may have continued to leave (i.e., move downstream) the Muskeg River after this date. First-time captures of white sucker, for instance, were highest during the last week of May. It was surmised that this species had entered the river before the fence was deployed, however, the majority of the spawners had not yet returned downstream to the fence when it was removed. Similar observations have been observed for the timing of northern pike in the Muskeg River (Golder 2003a), where most individuals remained in upper reaches of the river for the summer. Based on past studies (Bond and Machniak 1977, 1978), it is probable that a large proportion of white sucker continued their downstream movement out of the Muskeg River throughout June. Extension of the fence monitoring period may have resulted in observation of a higher proportion of this species.

Overall, the 2003 spring fish fence program on the Muskeg River was successful. Compared to past fence studies, there have been marked declines in the abundance of dominant species, including sucker species and Arctic grayling. The observed natural variability in spring spawning runs may limit the use of a fish fence for long-term monitoring until several years of baseline data are available; however, the fence program has proven to be effective at documenting the current use of tributaries of the Athabasca River by mainstem fish populations.

7.0 AQUATIC VEGETATION

7.1 OVERVIEW OF 2003 PROGRAM

The objective of the RAMP aquatic vegetation program is to detect and measure the temporal and spatial change in health and distribution of aquatic vegetation communities within the oil sands area. The 2003 program was designed to build upon the cumulative data acquired from previous annual results under this component of RAMP. The 2003 program focused on monitoring of vegetation communities through field investigations and air photo analysis. Waterbodies sampled included Isadore's Lake, Shipyard Lake and Kearl Lake.

A screening exercise carried out to assist in the selection of reference lakes indicated that few reference lakes were available (many candidate lakes were located in areas to be potentially affected by development). Therefore, the RAMP Technical Committee did not recommend selection of reference lakes; a comprehensive reference lake selection study was not conducted in 2003.

Field surveys focused on sampling of both submergent and emergent aquatic macrophyte vegetation species for occurrence, percent cover and vigour. The historical air photo component assessed the change in distribution of identifiable aquatic vegetation communities and the spatial extent of open water.

7.2 METHODS

7.2.1 Study Background and Sampling Areas

The field sampling program for the 2003 aquatic vegetation component focused on wetland areas within Shipyard Lake, Isadore's Lake and Kearl Lake. The location of each lake is shown in Figure 7.1.

The RAMP Aquatic Vegetation sub-group decided prior to the 2003 field program, to restrict the sampling to the aquatic vegetation zones within the three study lakes. This differs from past sampling years where the transitional zone from the aquatic to terrestrial ecosystem was also sampled. Coinciding with this decision, field sampling was logistically restricted to the submergent/emergent vegetation zone interface.

Shipyard Lake

Shipyard Lake is located within the Athabasca River floodplain and is adjacent to Suncor's Steepbank/Project Millennium Mine. The lake is fed by an unnamed creek entering the wetland from the northeast and several small channels to the southeast. The wetland discharges to the Athabasca River through Shipyard Creek at the north end.

Analysis of peat deposits suggests that Shipyard Lake has been isolated from the Athabasca River for several hundred years (Golder 1996)..

The Alberta Wetland Inventory (AWI) classes reported for Shipyard Lake are as follows: 53 ha of open, shrubby swamp (SONS); 65 ha of gramminoid marsh (MONG); 1 ha of shallow open water (WONN); and 1 ha of wooded swamp (STNN). The AWI classification system is presented in Appendix A7.

Isadore's Lake

Isadore's Lake is a riparian wetland located on the Athabasca River floodplain adjacent to Albian Sands Muskeg River Mine Project. It is an open water fen complex dominated by cattails and sedges, with low shrub and treed fens along the outer perimeter. A channel situated north of the lake provides an outlet to the Athabasca River.

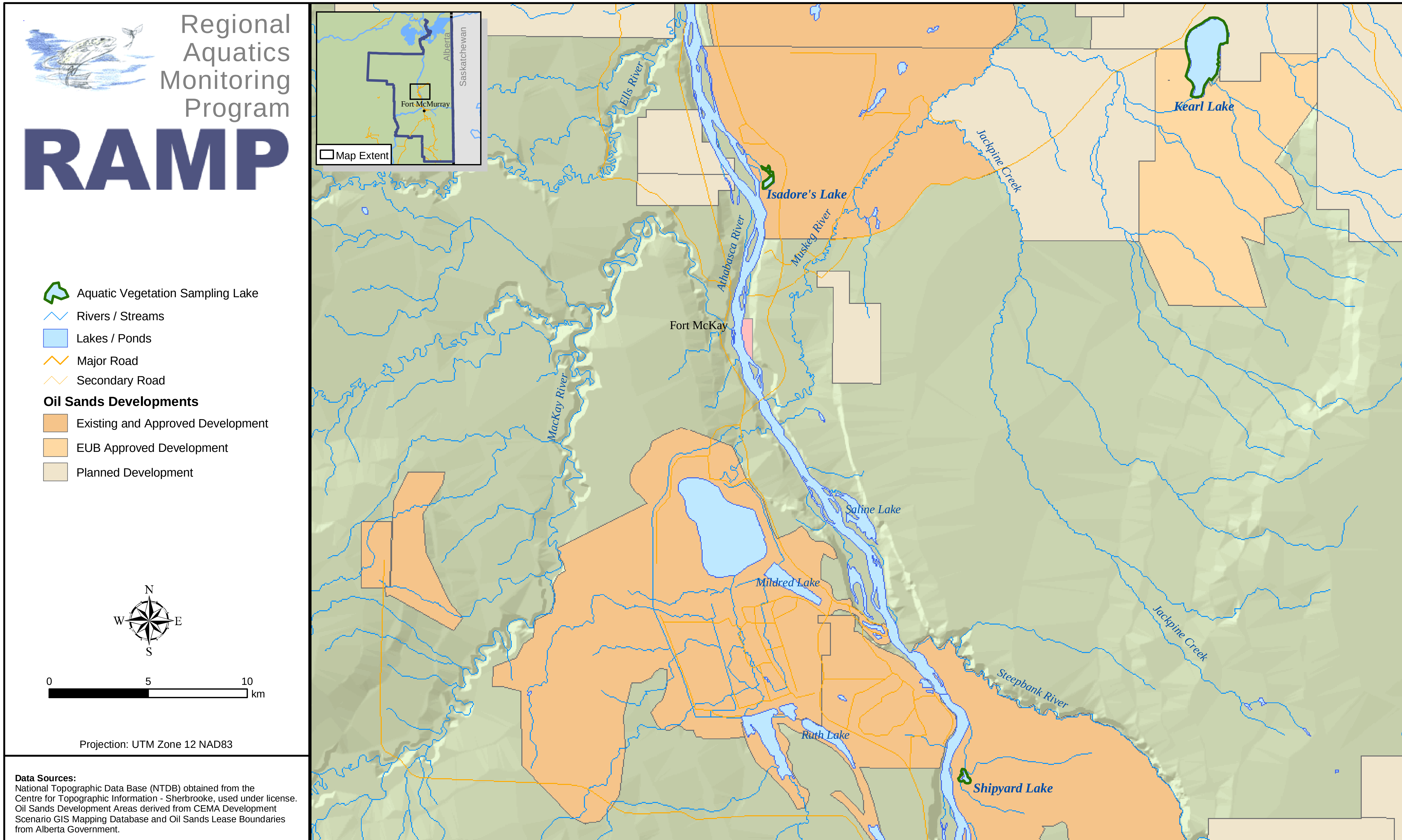
The AWI classes reported for Isadore's Lake (Golder 2003b) are as follows: 27 ha of fen consisting of open, non-patterned, shrubby fen (FONS); 36 ha of open, non-patterned, gramminoid fen (FONG); 4 ha of wooded fen with no internal lawns (FTNN); and 16 ha of open, shrubby swamp (SONS).

Kearl Lake

Kearl Lake is a large lake-wetland complex located approximately 12 km east of the Athabasca River in the Muskeg River watershed. The lake and adjacent wetland complex is approximately 955 ha, while the lake basin is approximately 547 ha (Golder 1999b). Kearl Lake is not considered to be a riparian wetland but rather a large upland lake with a wetland perimeter.

The AWI classes reported for Kearl Lake (Golder 2003b) are as follows: 172 ha of open, non-patterned, gramminoid fen (FONG); 133 ha of wooded fen with no internal lawns (FTNN); and 52 ha of open, shrubby fen (FONS).

Figure 7.1 Location of Aquatic Vegetation Sampling Lakes, 2003.



Data Sources:
National Topographic Data Base (NTDB) obtained from the Centre for Topographic Information - Sherbrooke, used under license. Oil Sands Development Areas derived from CEMA Development Scenario GIS Mapping Database and Oil Sands Lease Boundaries from Alberta Government.

Mxd: G:\DATA\PROJECTS\RAMP1069\GIS\Fig7-1_AquaticVeg2003.mxd
Last Modified: 2/11/2004 11:29:08 AM

7.2.2 Vegetation Field Survey

To ensure consistency of data collection and analysis, the methodologies used for the 2001 field investigations were used for the 2003 program. Boundaries for the wetland community types used for the 2001 program were also used for the 2003 program.

In 2001, Alberta Wetland Inventory (AWI) boundaries of the wetland community types were assessed and verified for accuracy in the field. The classification system and the wetland community type for each lake are documented in Appendix A7.

Wetland vegetation was examined during field surveys on August 13, 14 and 15, 2003 and were documented by:

- observing mapped wetlands classes on aerial photographs and comparing to field conditions;
- conducting a vegetation survey along fixed transects and compiling a list of species and relative percent cover within permanent sampling plots;
- recording vegetation vigour and health characteristics; and
- photographing representative vegetation community types.

The transect and plot coordinates for the 2001 field survey were loaded into a Garmin eTrex Global Positioning System (GPS) receiver to help locate the previous transect and plot locations. Once the initial site had been located, wetland vegetation transects were conducted from open water towards the shore. In areas where no previous field markers were observed, the GPS was used along with professional judgment to determine the likely transect start point.

All sampling was conducted using a boat with a two-person field crew. Attempts were made to visit all benchmark plots that were established as part of the 1997 and 2002 field programs. All vegetation communities were measured at representative plots along transects within each distinct community type observed. A representative transect was positioned to traverse perpendicularly from the open water towards the shoreline.

Sampling points were established along the transect, with a point chosen for each distinct community type encountered. At each plot, a 1 m x 1 m floating quadrant was used to obtain an estimate of cover for each plant species from the bottom of the lake to the surface. When plants were too deep to see, but still within the 2 m depth range, specimens were collected with a rake outside the plot boundary. Cover was estimated visually.

Species encountered during the sampling program were collected in plastic bags and labeled with transect, plot, location and date. When possible, stems, leaves and fruiting bodies or flowers were collected for unknown species. Species were identified while still fresh using field guides and botanical keys. Species that could not be identified in the field were pressed and dried for later comparisons with herbarium samples and standard botanical keys and field guides (i.e., Hudson 1977; Moss 1983; Burland 1994; Johnson *et al*. 1995).

Plant vigour was estimated for each cover class according to AEP (1994). Plant vigour represents a visual index of health and can be a qualitative measure of change over time. Four vigour classes were used: '4' indicates excellent, '3' good, '2' fair (average) and '1' poor, respectively. A '0' was used to show dead vegetation. A dash indicates that there was no vegetation in the cover class.

7.2.2.1 Data Analysis

A template spreadsheet was developed for field data entry and a portion of required analyses. The spreadsheet included tables with information on location and site characteristics of transects, site characteristics of the plots including species composition, species cover classes and percent cover. All statistical analyses were conducted using SYSTAT 10.2 (SPSS 2002).

A series of indices were used to describe the characteristics of the plant community at each lake. Indices are derived by calculating the ratio of one field measured variable (e.g., species richness) to another. Although caution is advised when using derived variables, given ratios assume some relationship between variables which may not exist, they are included here as one component of the discussion of the aquatic vegetation results.

Species Richness

Measures of species richness are commonly used to describe biodiversity. Species richness is defined as the total number of species present in a given area (e.g., plot) (Barbour *et al*. 1987). Total richness of all species was calculated for each plot surveyed.

Shannon-Wiener Index

Species diversity calculations were based on the Shannon–Wiener Index. There are two community attributes that determine diversity: species richness and evenness. Species richness is independent of species percent cover. Species evenness is the distribution of individuals among the species, or species equitability. The value of evenness is largest when all the species present have the same cover value. Species diversity is an index calculated from species richness and weighted by evenness. Minimal values occur when one or a few species have a disproportionate dominance, whereas maximum values occur when many species share equally in the dominance of the community. Many formulae have been developed, which provide an index of diversity (Washington 1984). The Shannon–Wiener diversity index was used herein (Barbour *et al*. 1987). The Shannon-Wiener formula is as follows (Equation 1):

$$H' = -\sum_{i=1}^{s}(p_i)(\ln p_i) \qquad (1)$$

where:

H' = the diversity index number;

s = the total number of species in the plot or vegetation layer; and

p_i = the proportion that each species contributes to the overall percent cover.

Similarity Indices

Species composition between lakes was compared to assess similarities and differences. In addition, comparisons within lakes were made to monitor changes over time. The comparison between lakes was done using similarity indices. Similarity indices are measurements of the degree to which two plant communities resemble each other and are based upon the species composition of each community. Washington (1984) recommended the use of both Jaccard's Index and Bray-Curtis Index to compare species overlap.

Jaccard's Index

Jaccard's index is an index of similarity that is calculated as follows (Equation 2):

$$JI = \left(\frac{n_c}{n_t + n_c}\right) \qquad (2)$$

where:

n_c = the number of species common within two communities; and

n_t = the total number of species in each community.

As a measure of community structure, Jaccard's Index only takes into account species number and not abundance (e.g., percent cover) (Washington 1984). Jaccard's Index was therefore used to assess the similarity in relative species composition (i.e., species presence/absence) between plots within lakes and between lakes.

Bray-Curtis Index

The Bray-Curtis dissimilarity (or distance) index is a measure of species overlap that also considers species abundance (i.e., percent cover). The Bray-Curtis dissimilarity index was used to assess the dissimilarity in species composition that includes abundance between plots within a lake. The formula for the Bray-Curtis Index is as follows (Equation 3):

$$\text{Bray} - \text{Curtis} = \frac{\sum_k \left| x_{ik} - x_{jk} \right|}{\sum_k x_{ik} + x_{jk}} \qquad (3)$$

where:

x_{ik} = percent cover of species k in plot i; and

x_{jk} = percent cover of species k in plot j.

The Bray-Curtis Index (BCI) of dissimilarity was converted to a similarity index by subtracting the calculated value from 1. This modified BCI is used in the study to facilitate a comparison with Jaccard's Index of similarity. As with Jaccard's Index, a value of 1 indicates perfect similarity, while a value of 0 would indicate completely dissimilar plots.

7.2.3 Historical Air Photograph Review

Data Acquisition

Spatial data was acquired to completely cover the three areas of interest, Isadore's Lake, Kearl Lake and Shipyard Lake. Large-scale mapping (1:20,000) was purchased for each area from the Government of Alberta's official data vendor, AltaLIS. These data served as base maps for the study areas and offered ground control to geo-reference the aerial photography.

Aerial photography was acquired from Alberta Environment's Air Photo Services Division. Air photos were selected based on set criteria of year and scale. Years obtained included:

- Shipyard Lake – 1949, 1953, 1967, 1972, 1974, 19841 1986, 1987, 1994, 1999;
- Isadore's Lake – 1949, 1951, 1967, 1971, 1972, 1977, 1979, 1980, 1990, 1999, 2001; and
- Kearl Lake – 1949, 1951, 1967, 1971, 1972, 1977, 1979, 1980, 1990, 1999, 2001.

Precipitation data from Environment Canada for the Fort McMurray station was collected and plotted for 56 consecutive years between 1945 and 2002 (excluding 1946; data not available). As air photos were taken during the summer months, the precipitation data for each year was adjusted to reflect the precipitation for the 12 months prior to summer. A year of precipitation data thus covered the time period from the previous September through to August of the year of interest. The interpretation of these data allowed for the selected air photos to be representative of the hydrological variation within the area.

Data Assembly

Large-scale mapping information was assembled, cleaned and reprojected to the Universal Transverse Mercator projection using North American Datum 1983 and Zone 12. The air photos purchased through Air Photo Services were delivered in MrSID image format. These MrSID images were cropped to the study area and imported into ArcGIS. The photos were then geo-referenced using a 'rubber-sheet' method to scale and align them with the base map information.

Data Analysis

The dates (i.e., time of year) that the air photos were flown may not be consistent with each other. However, all air photographs were taken in non-winter months and most likely during the summer. The relationship between open water area and precipitation is weak, therefore, the relatively minor variability in the time of year of the air photographs was assumed to not significantly impact the result of the regression.

It was assumed that the precipitation data measured at Fort McMurray is similar to that for each of the three areas of interest. The precipitation data for each of the lakes investigated was obtained from the Fort McMurray Meteorological station (Environment Canada 2003). Precipitation values were adjusted to capture the precipitation from September to August. The precipitation for these months would have a stronger relationship on the size of the open water for each lake during the time of image capture (assumed to be August for all photos).

Once the photos were geo-referenced, accurate delineations of the water levels for each of the lakes could be performed. Polygons were digitized for each year investigated. Area calculations for each polygon were derived. The boundaries of the polygons were overlaid to determine the change in water levels over time.

7.3 RESULTS

7.3.1 Field Survey Results

Shipyard Lake

The vegetation surrounding the shallow open water portion of Shipyard Lake is comprised primarily of floating mats of cattail (*Typha latifolia*). The dominant submergent plant in the shallow open water is hornwort (*Ceratophyllum demersum*). The 2003 field sampling program focused on these two habitats. A total of 12 plots were sampled during the field surveys. Plot locations are illustrated in Figure 7.2. A complete species list and percent cover for the Shipyard Lake survey is presented in Appendix A7.

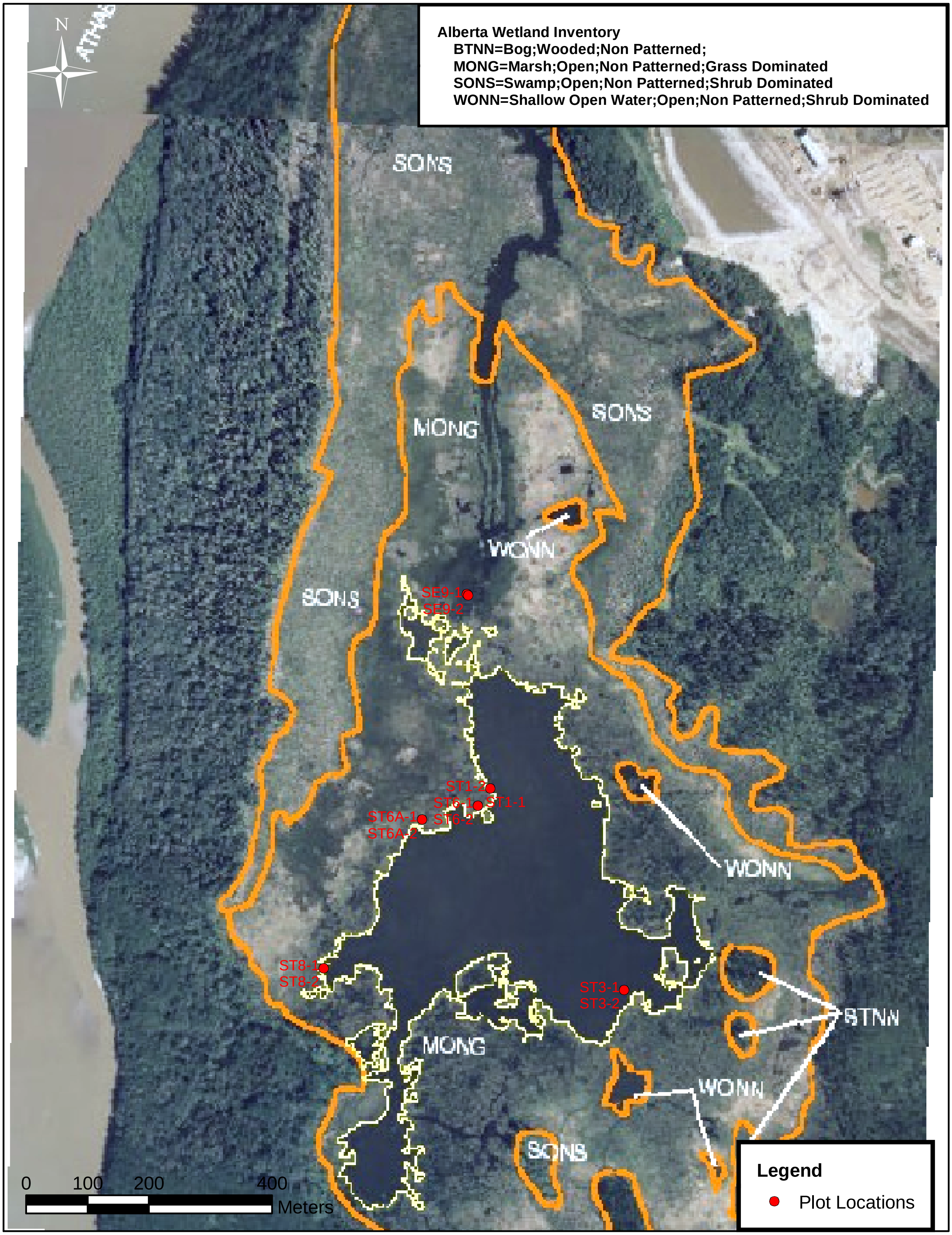
Isadore's Lake

The vegetation surrounding the shallow open water of Isadore's Lake is dominated by floating mats of cattail and giant bur-reed (*Sparganium eurycarpum*), both emergent species. The dominant submergent plant in the shallow open water varied between hornwort and chara (*Chara sp.*). The 2003 field sampling program focused on these two habitat types. A total of 21 plots were sampled during the field surveys. Plot locations are illustrated in Figure 7.3. A complete species list and percent cover for the Isadore's Lake survey is presented in Appendix A7. Plot locations for the 2003 sampling program are illustrated in Figure 7.3.

Kearl Lake

The sampled area was more variable than the other two sampled lakes with respect to vegetation types. The emergent zone was not typically dominated by one species. The vegetation cover in the submergent zone was less than that found in the other two lakes. Typical species included flat-leaved bladderwort (*Utricularia vulgaris*) and common bladderwort (*U. intermedia*). A total of 15 plots were sampled during the field surveys. Plot locations are illustrated in Figure 7.4. A complete species list and percent cover for the Kearl Lake survey is presented in Appendix A7.

Due to the changes made to the 2003 sampling program (i.e., terrestrial/aquatic interface areas not included), vegetation communities sampled were nearly devoid of the drier site plant species, in particular the shrub species, found in previous years.

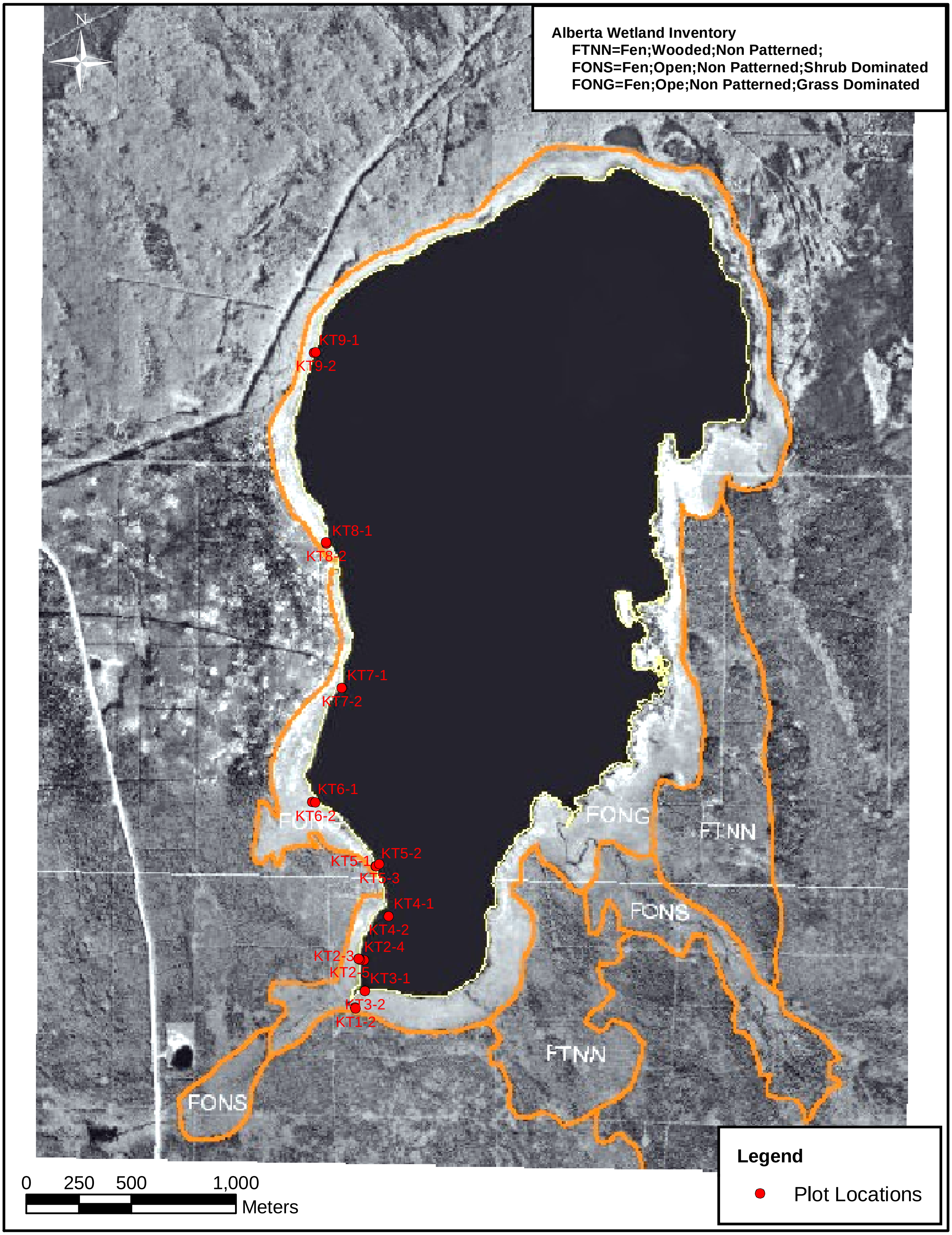


RAMP	Scale: 1: 8 500 Date: 27/01/04 Drawn By: SAR/SB Approved By:	**Shipyard Lake** Aquatic Vegetation	Original aerial photo date: 2001 Source: Golder 2003b	Figure No.: 7.2

\\50000\50000\50401\GIS\Wetlands\Shipyard Lake 2001img.mxd 27/01/04

RAMP	Scale: 1: 7 000 Date: 27/01/04 Drawn By: SAR/SB Approved By:	**Isadore's Lake** Aquatic Vegetation	Original aerial photo date: 2002 Source: Golder 2003b	Figure No.: 7.3

\\50000\\50000\\50401\\GIS\\Wetlands\\Isadores\\Isadores Lake 2002img.mxd 27/01/04



RAMP	Scale: 1: 20 000 Date: 27/01/04 Drawn By: SAR/SB Approved By:	**Kearl Lake** Aquatic Vegetation	Original aerial photo date: 2001. Source: Golder 2003b	Figure No.: 7.4

\50000\50000\50401\GIS\Wetlands\Kearl Lake 2001img.mxd 27/01/04

A combined total of 52 plant species were observed in the three study lakes during the 2003 field survey. This compares with a total of 81 species observed during the 2001 survey, 30 of which were also observed in 2003. Twenty-two new species were observed during the 2003 survey. A list of species observed in 2003 is presented in Appendix A7.

A comparison of vegetation types for each cover class at the three study sites is presented in Table 7.1.

Table 7.1 Number of vegetation species collected per cover type, 2001 and 2003

Vegetation Type	Shipyard Lake		Isadore's Lake		Kearl Lake	
	2001	2003	2001	2003	2001	2003
Shrub	0	0	13	1	2	1
Forb	18	14	23	16	24	21
Gramminoid	3	1	7	3	9	10
Moss	1	3	6	1	5	6
Lichen	0	0	5	0	0	0
Total	22	18	54	21	40	38

7.3.1.1 Species Diversity

Rare Plants

Of the 22 new species identified in the 2003 program, three were listed as rare. Cyperus-like sedge (*Carex pseudocyperus)* was found in Isadore's Lake and Kearl Lake while lakeshore sedge *(Carex lacustris*) was found only in Kearl Lake; Canada water-lily (*Elodea canadensis*) was found in both Shipyard Lake and Isadore's Lake. Both sedge species are listed as S2 provincially and G5 globally (Vujnovic and Gould 2002). Canada water-lily, listed as SRF provincially (SRF indicates a previous false reporting) and G5 globally, has never been recorded as occurring in Alberta although its occurrence was expected due to observations in Saskatchewan and British Columbia (Kershaw 2001).

Three other rare plants identified during the 2001 survey were observed again in 2003. White water-lily (*Nymphaea tetragona),* listed as S1 provincially and G5 globally, and beaked sedge (*Carex rostrata)* and floating-leaf pondweed (*Potamogeton natans*) (both listed as S2, G5) were observed in Kearl Lake. White water-lily was observed in Shipyard Lake in 2001 but was not observed in 2003.

Shannon-Wiener Index

Results for Shannon-Weiner Index (describing species diversity), average total percent cover and species richness (species count) are presented for each lake in Table 7.2.

Relative to 2001, the 2003 Shannon-Weiner Index increased for Shipyard Lake, but decreased for both Isadore's Lake and Kearl Lake (Table 7.2). Average percent cover values increased for Shipyard Lake and Isadore's Lake but decreased for Kearl Lake. The average number of species observed per plot in Shipyard Lake and Kearl Lake remained relatively similar between the 2001 and 2003 surveys. The average number of species observed per plot in Isadore's Lake dropped from 7.48 in 2001 to 4.26 in 2003 (Table 7.2). The maximum number of species observed in a plot also decreased in Isadore's Lake from 19 in 2001 to 7 in 2003.

Table 7.2 Summary of species diversity measures for Shipyard, Isadore's and Kearl lakes, 2001 and 2003.

Lake		Shipyard		Isadore's		Kearl	
Year		2001	2003	2001	2003	2001	2003
Number of Plots		11	12	21	19	15	22
Shannon – Weiner	Mean	0.352	0.604	1.145	0.580	1.151	1.012
	+/- SD	0.339	0.364	0.634	0.461	0.763	0.609
	Min/Max	0.018/	0.047/	0.000/	0.0/	1.600/	0/
		0.950	1.314	2.098	1.416	70.50*	1.936
Percent Cover	Mean	36.15	84.34	32.82	67.04	25.47	16.37
	+/- SD	13.36	29.83	20.92	33.19	24.63	15.73
	Min/Max	17.6/ 62.8	21.2 / 133.0	3.0/ 70.1	11.5/116. 0	1.6/70. 5	1.1/57. 6
Richness	Mean	4.73	5.17	7.48	4.26	7.67	6.79
	+/- SD	3.23	1.89	6.35	1.59	5.23	3.60
	Min/Max	2 / 11	4 / 10	1/19	1/7	1/16	1/15

* as reported in Golder 2002.

7.3.1.2 Indices of Similarity

Jaccard's Index within Lakes

As in the 2001 RAMP study, Jaccard's Index was used to assess the similarity of vegetation plots within each of the lakes. Using the 0.500 cut-off as a measure of moderate similarity (an index of 1 indicates similar plots), 15 paired plots were similar in Shipyard Lake, 26 in Isadore's Lake and 6 in Kearl Lake. Table 7.3 presents the summary of the Jaccard's Indices for the 2001 and 2003 field surveys.

The plots within each lake for which the calculated Jaccard's Index was 0.500 or larger are listed in Appendix A7. Shipyard Lake was found to be the most homogenous lake for both the 2001 and 2003 study years, with a mean index of 0.299 for the 2003 survey. The 2003 mean index for Kearl Lake (0.146) dropped one-tenth from the 2001 results while Isadore's Lake mean index increased by one tenth over the same period. This increase in the index values for Shipyard and Isadore's lakes is at least partially the result of restricting the sampling to the emergent/submergent portion of the lakes for the 2003 survey.

Table 7.3 Summary statistics of Jaccard's Index, 2001 and 2003 field surveys.

Lake	Shipyard		Isadore's		Kearl	
Year Sampled	2001	2003	2001	2003	2001	2003
Mean	0.235	0.299	0.134	0.231	0.157	0.146
Standard Deviation	0.240	0.214	0.191	0.237	0.192	0.158
Number of pairs with Index ≥0.500	19	15	15	26	2	6

Bray-Curtis Index

The mean BCI value for Shipyard Lake decreased between 2001 to 2003 while the Isadore's Lake mean remained relatively the same (Table 7.4). The RAMP 2002 program (Golder 2003b) reported that the mean BCI for Kearl Lake was 0.104. However, a re-calculated BCI for the 2001 Kearl Lake survey resulted in a mean value of 0.084, which is comparable to the 2003 survey mean of 0.070 (Table 7.4). The modified BCI results for all paired plots with a value of 0.500 and greater for the 2003 survey are presented in Appendix A7.

Table 7.4 Summary statistics of Bray-Curtis Index for Shipyard, Isadore's and Kearl lakes , 2001 and 2003 field surveys.

Lake	Shipyard		Isadore's		Kearl	
Year Sampled	2001	2003	2001	2003	2001	2003
Mean	0.339	0.275	0.100	0.105	0.084*	0.070
Standard Deviation	0.316	0.304	0.171	0.205	0.165	0.119
Number of pairs with Index ≥0.500	16	18	11	12	4	3

*Re-calculated using 2001 data.

Proportionally, Kearl Lake had the lowest number of similar plots relative to the other two sampled lakes. This indicates that, overall, the aquatic vegetation community in Kearl Lake is the least homogenous (i.e., the most diverse) of the three lakes. A qualitative assessment of field observations yielded the same result.

7.3.1.3 Vigour

The vigour assessment for each species observed in each plot is presented in Appendix A7. In general, vigour values ranged from 2 to 3 meaning that most species were in good to fair (average) health. Only in isolated and rare instances were species found to be in poor health (with a rating of 1). Although plant vigour is a subjective assessment, the monitoring the health of individual species over time is useful for monitoring overall wetland health.

7.3.1.4 Water Depth

In contrast to the 2001 aquatic vegetation results (Golder 2002b), plots furthest from the shoreline did not always have the deepest water. The first plot of many transects was placed on peninsulas of floating vegetation mats with the second and third plots being placed in open water closer to the shoreline. The lack of access to most areas closer to the shoreline and the decision to keep the plots in the wetter aquatic vegetation zones resulted a reduced gradient in water depth compared to the 2001 program.

In Shipyard Lake, the water depth of submergent vegetation plots ranged from 108 to 147 cm, while the water depth for emergent vegetation plots ranged from 0 to 16 cm. Water depths for emergent vegetation plots for Kearl Lake ranged from 0 to 40 cm with the submergent vegetation plots ranging in depths from 80 to 150 cm. Isadore's Lake had water depths ranging from 0 to 145 cm with no distinct separation of vegetation types (emergent versus submergent). For example, plot IT74 (depth=145 cm) contained minor amounts of both emergent and submergent species (e.g., cattail and common bladderwort respectively). Table 7.5 summarizes the measured water depths at each plot for all three lakes.

Table 7.5 Summary of water depths at aquatic vegetation plots for lakes sampled, 2003.

Lake	Shipyard	Isadore's	Kearl
Mean (cm)	69	47	44
Standard Deviation	65.8	33.7	59.0
Minimum (cm)	0	0	0
Maximum (cm)	147	145	150

The measured water depth for each plot is presented in Figures 7.5 to 7.7.

Figure 7.5 Water depth in Shipyard Lake observed during the aquatic vegetation program, 2003.

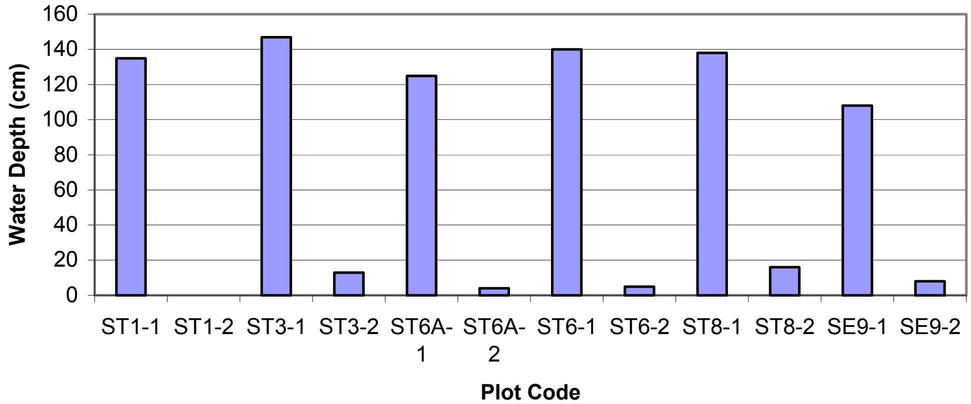


Figure 7.6 Water depth in Isadore's Lake observed during the aquatic vegetation program, 2003.

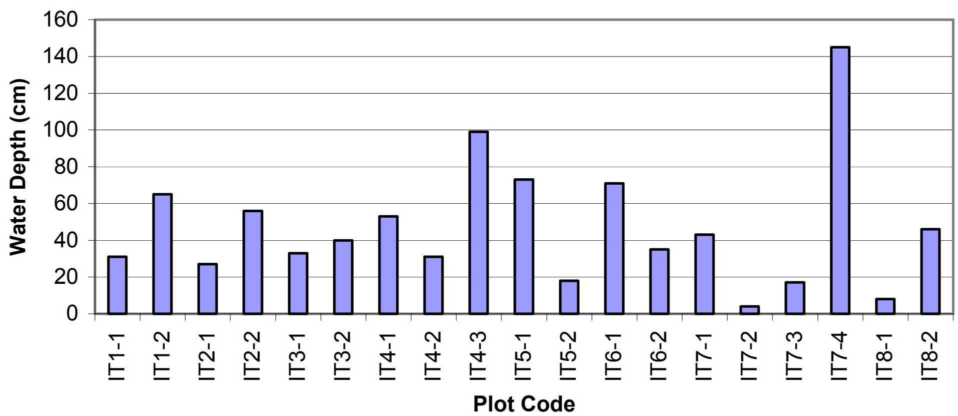
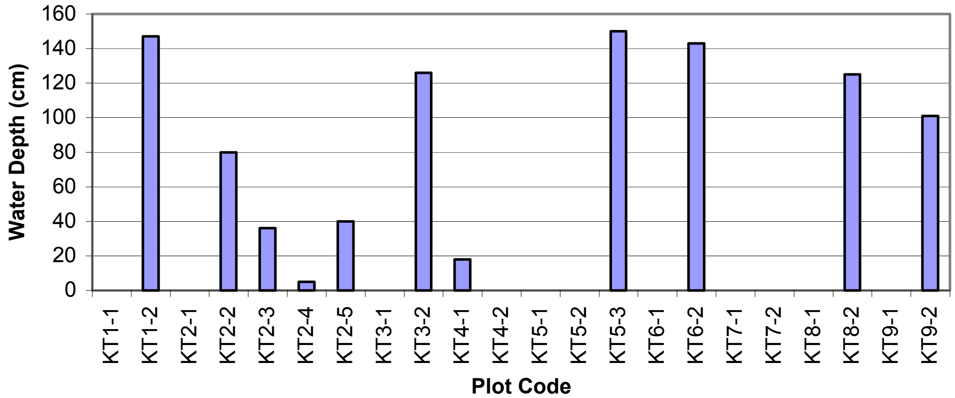


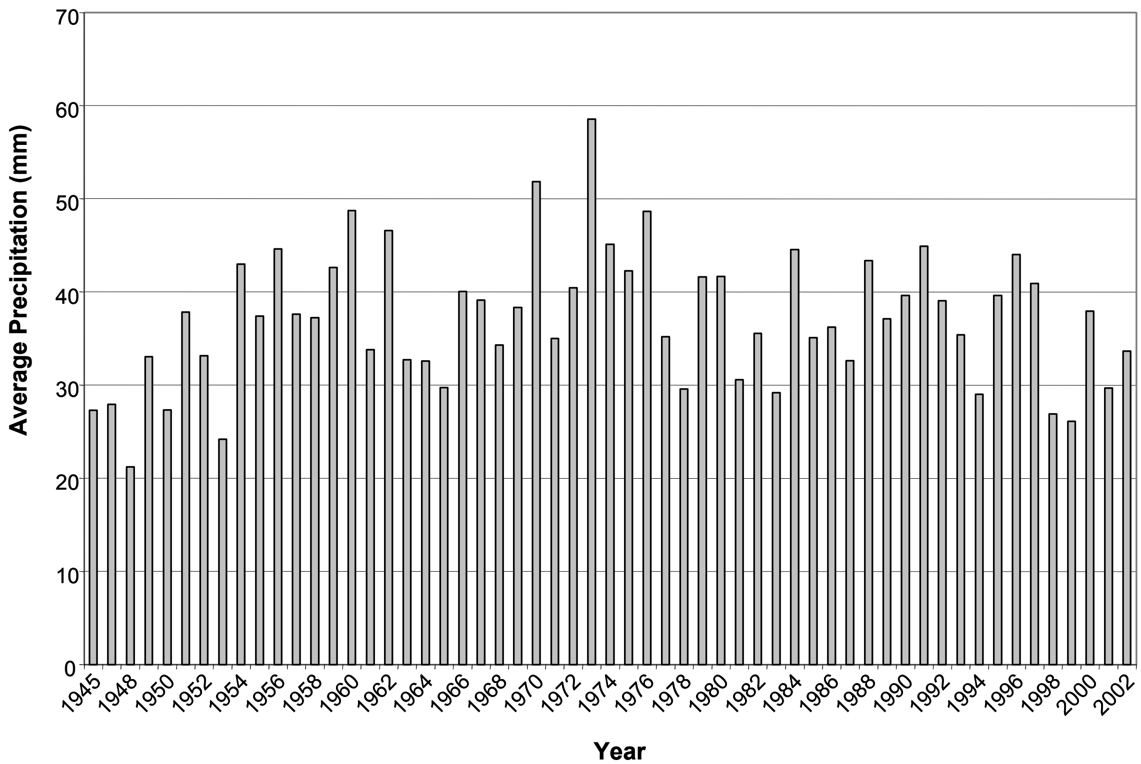
Figure 7.7 Water depth in Kearl Lake observed during aquatic vegetation program, 2003.



7.3.2 Historical Lake Review

The historical review of the lakes involved the collection of precipitation data for the area and the examination of a time series of aerial photographs in order to identify the area of open water. Regression analyses were performed on the data to determine if there was a relationship between precipitation and the size of the open water. The distribution of open water for each of the sample years for the three lakes is presented in Appendix A7. Figure 7.8 presents the adjusted annual monthly precipitation from 1945 to 2002.

Figure 7.8 Adjusted annual monthly precipitation – Fort McMurray 1945, 1947 to 2002.



7.3.2.1 Shipyard Lake

Aerial photographs of Shipyard Lake were available for 11 years between 1949 and 2001. With the exception of 1979 and 1990, the open water area of Shipyard Lake has consistently grown from each of the previous sampled years. In 2001, the open water area of Shipyard Lake was 236 percent larger than in the 1949 benchmark year. The largest increase in size occurred between 1951 and 1967 where the open water area increased by 119 percent. This time period was also the largest between sampled years and, given the trend of increasing size, the large increase is not unusual from other years.

Figure 7.9 and Figure 7.10 present a graphical representation of the open water area and precipitation values for Shipyard Lake for each year investigated.

Figure 7.9 Open water area for Shipyard Lake in sampled years.

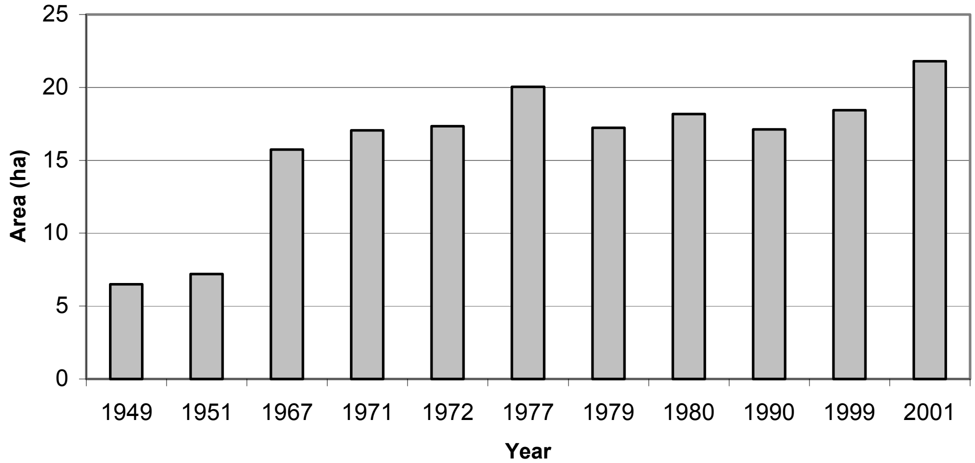
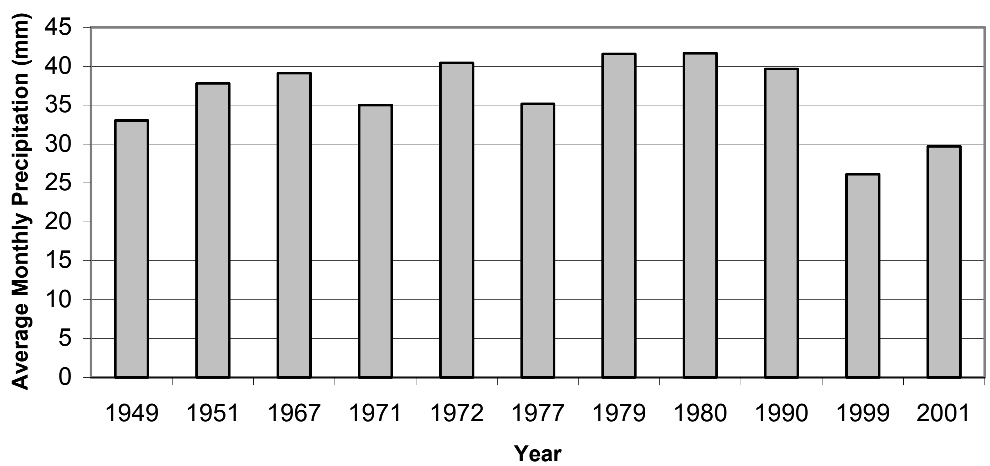


Figure 7.10 Annual average monthly precipitation values for Shipyard Lake in sampled years.



The results of the calculations and precipitation values for each year investigated are displayed in Table 7.6.

Table 7.6 Summary of changes in open water area and precipitation for Shipyard Lake, 1949 to 2002.

Year	Area (ha)	Percent Change Between Years	Percent Change from 1949	Average Precipitation (mm)
1949	6.49			33.05
1951	7.20	11%	11%	37.81
1967	15.75	119%	143%	39.11
1971	17.05	8%	163%	35.00
1972	17.35	2%	167%	40.45
1977	20.04	16%	209%	35.17
1979	17.23	-14%	165%	41.60
1980	18.18	6%	180%	41.65
1990	17.13	-6%	164%	39.63
1999	18.44	8%	184%	26.11
2001	21.78	18%	236%	29.68

Regression analysis was performed to measure the strength of the relationship, if any, between precipitation and the size of the open water areas for Shipyard Lake. Both the R square and adjusted R square are extremely low (0.010 and -0.100 consecutively) which indicates a very weak to no relationship between the tested variables. Accordingly, the extent of open water cannot be explained by the amount of precipitation alone and so other factors are contributing to the amount of water present in Shipyard Lake in any given year. The relationship between open water area and precipitation was not significant ($p=0.77$, $r^2=0.010$).

7.3.2.2 Isadore's Lake

Aerial photographs of Isadore's Lake were available for 12 years between 1949 and 1999. Isadore's Lake has in general, increased in size from the benchmark year of 1949. The extent of open water area has varied considerably between 1949 and 2002. The year 1974 is of note due to the substantial increase in size from the previously sampled year and from the 1949 benchmark. In 1974, the area of open water was 151% greater than in 1949, and 126% larger than in 1972. The years 1984, 1986 and 1987 are also of significance. The open water area decreased by 83 percent in 1986 relative to 1984 but then in 1987 increased in size by 631 percent from 1986.

Figure 7.11 and Figure 7.12 offer a graphical representation of the open water area and precipitation values for Isadore's Lake for each year investigated.

Figure 7.11 Open water area for Isadore's Lake for sampled years.

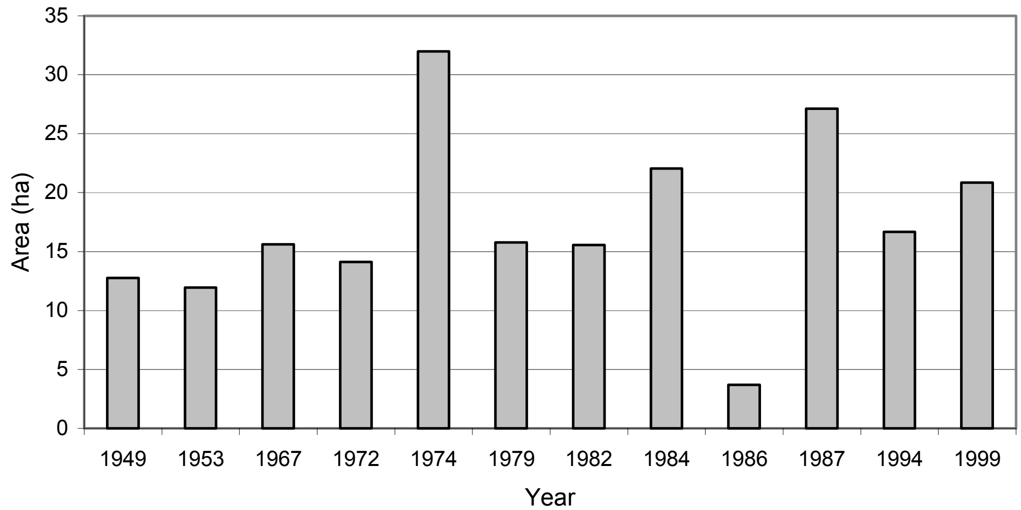


Figure 7.12 Annual average monthly precipitation values for Isadore's Lake for sampled years.

The results of area calculations and precipitation values for each year investigated are presented in Table 7.7.

Table 7.7 Summary of changes open water area and precipitation for Isadore's Lake, 1949 to 2002.

Year	Area (ha)	Percent Change Between Years	Percent Increase from 1949	Average Monthly Precipitation (mm)
1949	12.75	-	-	33.05
1953	11.96	-6%	-6%	24.19
1967	15.62	31%	23%	39.11
1972	14.13	-10%	11%	40.45
1974	32.00	126%	151%	45.13
1979	15.78	-51%	24%	41.60
1982	15.57	-1%	22%	35.55
1984	22.04	42%	73%	44.54
1986	3.71	-83%	-71%	36.23
1987	27.13	631%	113%	32.62
1994	16.68	-39%	31%	29.00
1999	20.84	25%	63%	26.11

As with Shipyard Lake, the relationship between open water area and precipitation was not significant ($p=0.38$, $r^2=0.079$).

7.3.2.3 Kearl Lake

Aerial photographs of Kearl Lake were available for seven years between 1949 and 2002. The open water area of Kearl Lake shows very little variation between the years covered in this study with only a 3% maximum change in size from 1949 benchmark levels.

Figure 7.13 and Figure 7.14 offer a graphical representation of the area and precipitation values for Kearl Lake for each year investigated.

Figure 7.13 Open water area for sampled years for Kearl Lake.

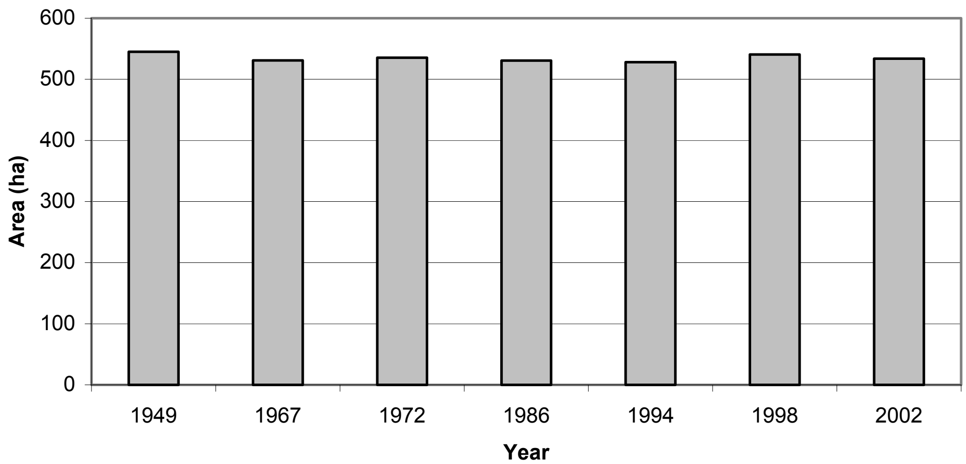
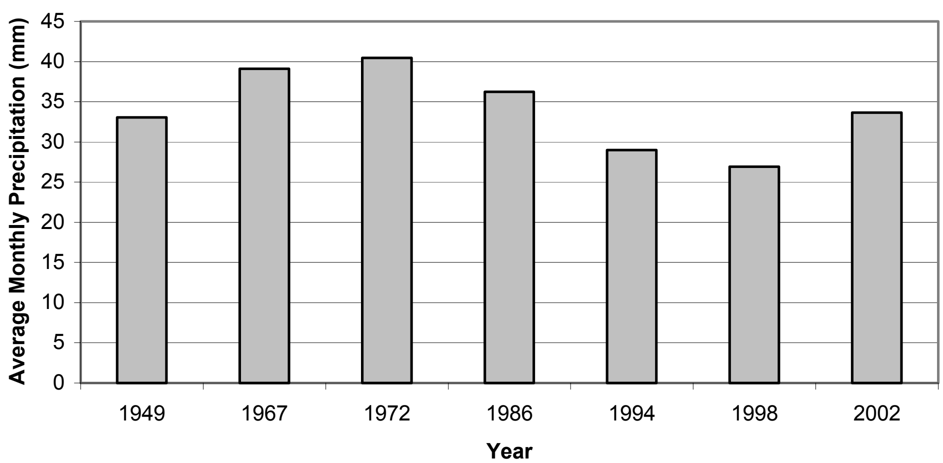


Figure 7.14 Annual average monthly precipitation for Kearl Lake sample years.



The results of the area calculations and adjusted annual average precipitation values for each year investigated are displayed in Table 7.8.

Table 7.8 Summary of changes in open water area and precipitation for Kearl Lake, 1949 to 2002.

Year	Area (ha)	Percent Change Between Years	Percent Change from 1949	Average Monthly Precipitation (mm)
1949	545.20	-	-	33.05
1967	530.95	-3%	-3%	39.11
1972	535.29	1%	-2%	40.45
1986	530.78	-1%	-3%	36.23
1994	528.15	0%	-3%	29.00
1998	540.55	2%	-1%	26.91
2002	533.87	-1%	-2%	33.64

As with Shipyard and Isadore's lakes, the relationship between open water area and precipitation was not significant ($p=0.61$, $r^2=0.056$). It was determined that the extent of open water cannot be directly explained by the amount of precipitation alone. Therefore, other factors may contribute to the amount of water present in Kearl Lake.

7.4 DISCUSSION

Species diversity and similarity measurements indicated a change in wetland composition from 2001 to 2003. It is likely that the change in sampling strategy to focus only on the aquatic wetlands within the lakes accounts for at least a portion of the measured change. This resulted in exclusion of plant species associated with more diverse drier sites in 2003. Further, the emergent zone of all three lakes was composed of tall floating vegetation mats, which prevented placement of a sampling transect from a boat and was unsafe to walk on. It is likely that this also influenced the degree of difference observed in vegetation communities between sampling years. Given the results of the historical air photo analysis, the wetlands have undergone substantial natural change over time. This is particularly true for Shipyard Lake and Isadore's Lake. Any potential change resulting from industrial activity may not yet be detectable given the amount of variability currently in the baseline data.

The historical air photo review indicates that water levels in Isadore's and Shipyard lakes, in particular, vary significantly from year to year. The review also indicates that precipitation has only a minor role in determining the extent of open water. It is likely that other factors such as hydrogeology play a larger role in determination of the extent of open water.

Consistent and careful monitoring of vegetation changes over time and space will be necessary to separate natural change from potential changes related to industrial activity. Likely indicators of change include species diversity, diversity within the lakes and plant health as measured in the 2003 study. Focusing the sampling program to the aquatic zone will facilitate monitoring and reduce variability.

To ensure a consistent data set necessary for monitoring change over time, data collection techniques may need to be strengthened for future programs. Permanent plot markers should be established that can withstand winter ice conditions. As an alternative to permanent markers, plot locations could be established with GPS units capable of sub-metre accuracy. Consideration should be given to data collection outside of the existing plot locations. A thorough plant species list obtained from a larger sample size (number of plots) for each lake would allow for a more sensitive indicator of change in species diversity. Given that vegetation deep within the floating vegetation mats could not be sampled from a normal boat, or by foot, for the 2003 program, other access approaches should be investigated. The observed variation in open water area (and, thus, water levels) from year to year could have an effect on the consistency of field sampling. Future field sampling programs should be designed to accommodate that level of variability.

8.0 ACID SENSITIVE LAKES

8.1 OVERVIEW OF THE 2003 PROGRAM

The 2003 acid sensitive lakes (ASL) program consisted of sampling 50 lakes and ponds in the oil sands region during late August and early September and analyses of the water quality data. The analyses of the water quality data were more detailed in 2003 than in previous years and included:

1. Comparisons of the chemical characteristics of the RAMP lakes to the general characteristics of lakes within the oil sands region;
2. Calculations of organic anion concentrations and charge densities of dissolved organic materials in each lake;
3. The analysis of the contribution of strong acid anions to the acid-base status in each lake;
4. Analysis of the degree of buffering attributable to weak organic anions in each lake;
5. Calculations of critical loads of acidity for each lake and comparison with modeled potential acidic input (PAI);
6. Calculations and evaluation of ion ratios that are frequently used to indicate acidification in lakes, and
7. Analysis of potential trends in water quality parameters.

8.2 METHODS

8.2.1 Station Locations

The date of lake sampling, the latitude and longitude of each lake and the tertiary watershed in which each lake was found are presented in Table 8.1. The unique ID number ascribed to each lake was derived from the Lake Sensitivity Mapping Program conducted by NOx-SOx Management Working Group (NSMWG) (WRS 2004). The locations of each lake relative to the major oil sands developments are indicated in Figure 8.1.

Table 8.1 Name, location and date of sampling of lakes in 2003 for the acid sensitive lake program.

Lake Identification			Latitude	Longitude	Sampling Date
Unique ID[1]	Name	Tertiary Wshd.	dec. deg.	dec. deg.	m/d 00:00
Stony Mountains Sub-Region					
168	A21	7CE	56.2667	111.2583	08/25 18:30
169	A24	7CE	56.2167	111.2500	08/25 18:16
170	A26	7CE	56.2153	111.1869	08/25 17:32
167	A29	7CE	56.1667	111.5417	08/25 13:48
166	A86	7CE	55.6833	111.8250	08/25 12:05
287	25		56.2083	111.2000	08/25 16:45
289	27		56.2000	111.3667	08/25 11:31
290	28		56.1750	111.2083	08/25 13:48
342	82		55.7917	111.8250	08/25 11:25
354	94		55.7583	110.7500	08/25 10:20
Birch Mountains Sub-Region					
436	L18/Namur		57.4444	112.6211	08/26 9:55
442	L23/Otasan		57.7072	112.3875	08/26 13:45
444	L25/Legend		57.4122	112.9336	08/26 11:13
447	L28		57.8556	112.9717	08/26 16:45
448	L29/Clayton	7KE/7KF	58.0572	112.2761	08/26 17:30
454	L46/Bayard		57.7725	112.3964	08/26 15:00
455	L47		57.6894	112.7361	08/26 12:10
457	L49		57.7600	112.5967	08/26 12:45
464	L60		57.6533	112.6142	08/26 15:50
175	P13	7DA	57.3140	112.3950	09/01 14:05
199	P49	7DA	57.6940	111.9060	09/01 13:40
North East of Fort McMurray Sub-Region					
452	L4 (A-170)		57.1519	110.8514	08/31 14:15
470	L7		57.0903	110.7519	08/31 15:15
471	L8		57.0458	110.5975	08/30 16:58
400	L39/E9/A-150		57.9600	110.3969	08/30 14:34
268	E15		56.8917	110.9000	08/31 16:00
182	P23	7DA	57.2630	110.8510	09/01 10:45
185	P27	7DA	57.1470	110.8630	09/01 10:00
209	P7	7DC	57.2320	110.7450	09/01 11:45
270	4		56.7667	110.9000	08/31 17:18
271	6		56.6417	110.2000	08/27 15:38
418[2]	Kearle[2]		57.291667	111.23333	08/31 14:40

Table 8.1 (cont'd).

Lake Identification			Latitude	Longitude	Sampling Date
Unique ID[1]	Name	Tertiary Wshd.	dec. deg.	dec. deg.	m/d 00:00
West of Fort McMurray Sub-Region					
165	A42	7CC	56.3500	113.1833	08/27 12:40
171	A47	7CC	56.2440	113.1410	08/27 13:30
172	A59	7PA	55.9083	112.8667	08/27 11:45
223	P94	7BD	57.1460	111.9820	09/01 14:45
225	P96	7BD	56.8000	111.9170	09/01 15:20
226	P97	7DA	56.8100	111.7210	09/01 16:00
227	P98	7CC	56.7830	111.7890	09/01 16:15
267	1		56.7583	111.9500	08/27 10:00
Caribou Mountains Sub-Region					
146	E52/ Fleming	7JF	58.7708	115.4342	08/28 11:05
91	O-1/E55	7PC	59.2378	114.5200	08/28 14:40
97	O-2/E67	7PA	59.3108	115.3589	08/28 13:40
152	E59/Rocky Island	7JF	59.1350	115.1336	08/28 12:20
89	E68 Whitesand	7PA	59.1905	115.4490	08/28 13:00
Canadian Shield Sub-Region					
473	A301		59.1760	110.5600	08/29 14:45
118	L107/Weekes	7MD	59.7219	110.0158	08/29 9:45
84	L109/Fletcher	7NA	59.1206	110.8197	08/29 15:50
88	O-10	7NA	59.1436	110.6847	08/29 16:35
90	R1	7NA	59.1985	110.6868	08/29 13:46
473	A301		59.1760	110.5600	08/29 14:45

[1] Unique identification number derived from the Lake Sensitivity Mapping Program conducted by NSMWG (WRS 2003).

[2] First time sampling in ASL program

8.2.2 Field Methods

Alberta Environment (AENV) provided the sampling equipment and logistical support. A float plane was used to access the majority of study lakes while a helicopter with floats was used to access the smaller lakes.

Water samples were collected from the euphotic zone at a single deep-water site in each major basin of each lake using weighted Tygon tubing and were then combined to form a single composite sample for chemical analysis. When the euphotic zone extended to the lake bottom, sampling was restricted to depths greater than 1 m above the lake bottom. In shallow lakes (< 3 m deep), composite samples were created from five to ten - one litre grab samples collected at 0.5 m depth along a transect dictated by wind direction (upwind to downwind shore).

The euphotic zone was defined as twice the Secchi disk depth. In previous years, 1% light penetration was determined with a LiCor quantum sensor and found to correlate reasonably well with twice the Secchi depth. Vertical profiles of dissolved oxygen, temperature, conductivity and pH were measured at the deepest location using a field-calibrated water quality meter. Secchi depth was also recorded. Samples for chemical analysis were stored on ice and were shipped to the Limnology Laboratory, University of Alberta, Edmonton, within 48 hours of collection.

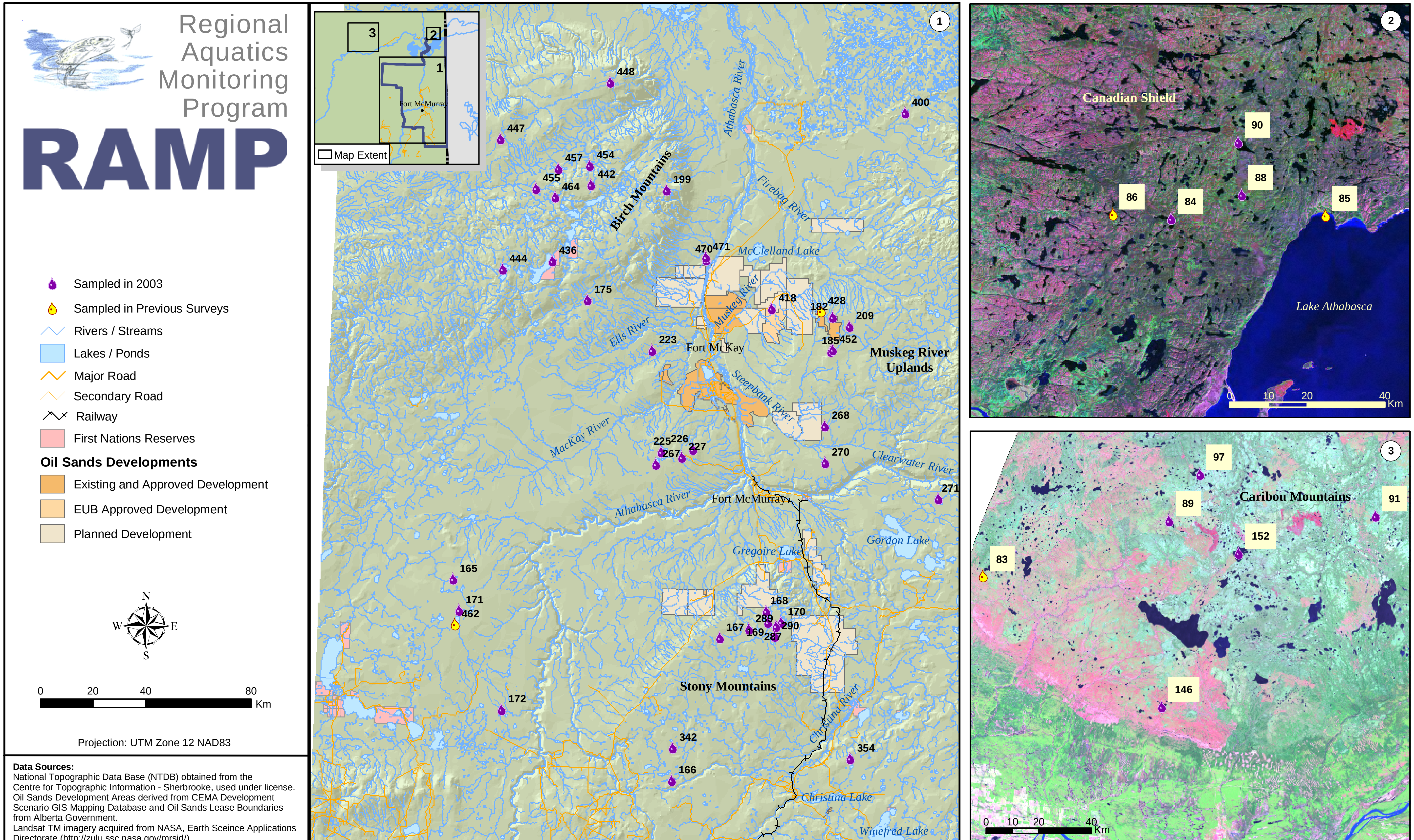
Subsamples of 150 mL volume were taken from the euphotic zone composite samples for phytoplankton taxonomy. These samples were preserved using Lugol's solution. One or two replicate zooplankton samples were also collected in each lake as vertical hauls through the euphotic zone, using a #20 mesh (63 µm), conical plankton net. Zooplankton samples were preserved in approximately 5% formalin after anaesthetizing in club soda. Plankton samples are being stored at AENV.

Water quality samples were analyzed for the following parameters:

- pH
- turbidity
- colour
- total suspended solids (TSS)
- total dissolved solids (TDS)
- dissolved organic carbon (DOC)
- dissolved inorganic carbon (DIC)
- conductivity
- iron
- total alkalinity (fixed point titration to pH 4.5)
- Gran alkalinity
- bicarbonate
- Gran bicarbonate
- chloride
- sulphate
- calcium
- potassium
- sodium
- magnesium
- silicon
- total dissolved nitrogen (TDN)
- ammonia
- nitrite + nitrate
- total Kjeldahl nitrogen (TKN)
- total nitrogen (TN)
- total phosphorus (TP)
- total dissolved phosphorus (TDP)
- chlorophyll a

All samples were also analyzed for a suite of 29 metals and trace elements at Alberta Research Council (ARC) Vegreville. This analysis was requested and funded by AENV. As part of the QA/QC program, one blind field blank was collected using deionized water from the Limnology Laboratory, University of Alberta. Split samples were additionally assessed by the University of Alberta lab. Quality control samples were analyzed for all parameters listed above.

Figure 8.1 Locations of Lakes Sampled under the RAMP Acid-Sensitive Lake Component, 2003.



Mxd: G:\DATA\PROJECTS\RAMP1069\GIS\Fig8-1_AcidSensitive2003.mxd
Last Modified: 2/11/2004 11:33:52 AM

8.2.3 Details of Data Analyses

This year's analyses of the RAMP ASL monitoring data had a different emphasis than the analyses in previous years. The addition of Gran alkalinity and dissolved inorganic carbon (DIC) as monitoring parameters in 2002 and 2003 permitted the determination of the effects of organic acids on the acid-base status of these lakes. The RAMP lakes are generally highly coloured with high contents of dissolved organic carbon (DOC). It has always been known that organic acids play a significant role in the acid-base dynamics of these lakes but this role was poorly defined. Using techniques and calculations derived from the international literature on humic materials in lakes, it was possible to answer a number of questions concerning the role of these organic acids in these lakes. These questions included:

1. The concentrations of free dissociated organic acids in each lake;
2. The amount of buffering or acid neutralizing capacity (ANC) attributable to weak organic acids, and
3. The role of strong organic acids in lowering the acid neutralizing capacity of these lakes.

Publication of the lake sensitivity mapping report on 460 regional lakes to the NOx-SOx Management Working Group (NSMWG) allowed the comparison of the water chemistry of the RAMP lakes to the general chemistry of lakes in the oil sands region. The chemical characteristics of the RAMP lakes could therefore be discussed within a regional context.

Critical loads of acidity were calculated for each lake to be compared with levels of modeled Potential Acidic Input (PAI). The critical load, in units of keq H+/ha/y, is defined as the highest load of acid deposition that will not cause long-term changes in lake chemistry and biology. The PAI is defined as the sum of the wet and dry deposition of sulphur and nitrogen oxides minus the wet and dry deposition of base cations. Exceedances of the critical load by the PAI in a lake imply a potential for acidification. The assumptions inherent in the use of critical loads were discussed.

Two ratios were calculated that have been used in the literature (and in previous RAMP reports) to indicate the *current* degree of acidification of freshwater lakes. These included the ratio of alkalinity to [calcium + magnesium] and the ratio of sulphate to base cations. The relevance of these ratios to the RAMP lakes was investigated in light of the role of organic acids in these lakes and their distinct chemistry.

Trends in chemical parameters including alkalinity, sum of the base cations, sulphate and nutrients were examined over the five monitoring years of the program and longer periods for lakes having more extensive data.

8.2.3.1 Comparison of the Chemistry of the RAMP Lakes to Regional Lake Chemistry

The water quality data from the 2003 field program were tabulated for each lake. The chemical characteristics of the lakes were compared to those of 460 regional lakes as reported in the NSMWG lake sensitivity mapping study (WRS 2004). The NSMWG report included historical data for each lake from the following field surveys:

- Erikson's survey of Alberta Lakes conducted in 1983-1987 (Erikson 1987);
- Saffran and Trew's survey of 109 lakes in 1995 (Saffran and Trew 1996);
- Preston McEachern's study of the Caribou Lakes in 1997 (WRS 2003);
- Water quality surveys conducted by Alberta-Pacific Forest Industries in 1998 and 1999 (WRS 2003);
- A pond water survey conducted for the NSMWG (WRS 2003); and,
- Previous RAMP surveys.

The chemistry of the RAMP lakes was thereby put into a regional context.

8.2.3.2 Determination of Organic Acid Concentrations

Method of Anion Deficit

Weak organic acid concentrations were calculated by two methods: anion deficit and a calibration of the organic acid dissociation equations of Oliver *et al.* (1983). The anion deficit method is based on the principle of electroneutrality in which the charges on cations and anions in any solution must be balanced. In coloured waters, a fraction of the inorganic cations are balanced by organic anions, the products of dissociated organic acids. By subtracting the inorganic anions from the cations the anionic deficit can be used as an estimate of the concentration of dissociated organic anion A^-:

$$[A^-] = 2[Ca^{2+}] + 2\,[Mg^{2+}] + [Na^+] + [K^+] + [K^+] + [NH^{4+}] + 3[Al^{3+}] + [H^+]$$
$$- 2[SO_4^{2-}] - [Cl^-] - [NO_3^-] - [F^-] - [HCO_3^-] - 2\,[CO_3\text{-}]$$

where all ions are expressed in μeq/L. The charge density is expressed as the organic anion concentration divided by the DOC in units of μeq A^- /mg C and represents the number of dissociated carboxyl groups per mg of DOC at the pH of the sample.

The determination of A^- by anionic deficit requires an estimate of bicarbonate concentrations. These are not the bicarbonate concentrations generally reported by the laboratories but must be calculated by equilibrium relationships and DIC measurements. The bicarbonate normally quoted by the laboratory is really the titration bicarbonate and is in error in humic lakes because weak organic anions (and aluminum) are titrated at the same time as the bicarbonate. The titration bicarbonate, then overestimates the real bicarbonate concentration.

Bicarbonate was determined from ionization fractions (α) representing the fractions of the bicarbonate, carbonate and carbonic acid species in solution:

$$\alpha\ HCO_3 = ([H^+]/K_1 + 1 + K_2/[H^+])^{-1}$$

$$\alpha\ CO_3 = ([H^+]^2/K_1K_2 + [H^+]/K_2 + 1)^{-1}$$

$$\alpha\ H_2CO_3 = (1 + K_1\,[H^+] + K_1K_2\,/[H^+]^2)^{-1}$$

K_1 and K_2 are constants ($pK_1 = 6.464$ and $pK_2 = 10.49$). The constants were taken from Stumm and Morgan (1981) for a water at temperature of 10°C and low ionic strength.

Method of Oliver et al. (1983)

The model of Oliver *et al.* (1983) is based on the single mass action coefficient model of organic acid dissociation proposed by Perdue *et al.* (1980). In the Oliver *et al.* (1983) model, concentrations of dissociated organic ions at a given pH are estimated from the equilibrium equation:

$$[A^-] = \underline{K}\,[C_T] \,/\, (\,\underline{K} + H^+\,)$$

where $\underline{K}$ is a mass action quotient and C_T is the total concentration of acidic functional groups (total acidity) determined from base titrations of purified humic and fulvic acids to pH 7-8. C_T is a function of DOC expressed as:

$$C_T = m\,[DOC]$$

where m is the number of equivalents of carboxyl units per mg of DOC or the carboxyl content.

The dissociation behaviour of purified humic and fulvic acids was studied by titrating the two isolates with NaOH to pH 7.0 with CO_2 excluded. The measured pH and known equivalents of base titrant were then used to develop a formula relating p$\underline{K}$ to pH:

$$p\underline{K} = a + b\,(pH) + c\,(pH)^2$$

where a, b, and c are constants.

Once the dissociation behaviour of the humic materials is known, the organic ion concentration can be calculated from at the DOC content and pH of the sample.

The method of Oliver *et al.* (1983) has been widely applied by calibrating the parameters of the model to particular sets of lakes and conditions (Lazerte and Dillon 1984; Driscoll *et al.* 1989; Wilkinson *et al.* 1992; Kortelainen 1992). In all cases, the A^- estimated from the ion deficit and field measurements of DOC and pH were used in the calibration process to generate the constants a, b and c.

For this study, a calibration process was followed based on the Oliver *et al.* (1983) equations. Examination of these equations indicated that $[A^-]$ is proportional to the DOC content and a non-linear, in particular, an exponential function of pH. This knowledge was used to fit A^-, as calculated from the anion deficit, to an appropriate function of DOC and pH. Using non-linear regression (SYSTAT 10.2), the data were fitted to an equation of the form:

$$A^- = a\ DOC\ \exp(b*pH).$$

The charge density was calculated for each RAMP lake and compared to literature values.

8.2.3.3 Calculation of Strong Organic Acid Concentrations

Strong acid anions (A^-_{SA}) in the RAMP lakes were analyzed by the method suggested by Cantrell *et al.* (1990), Munson and Guerini (1993) and Kortelainen (1993). Gran alkalinity typically underestimates the charge balance alkalinity where the discrepancy is proportional to the DOC content. The calculation of the charge balance alkalinity (ANC_{CB}) is based on electroneutrality principles where ANC_{CB} is equivalent to the sum of strong bases minus the sum of strong acid anions (Stumm and Morgan 1981):

$$ANC_{CB} = 2[Ca^{2+}] + 2\,[Mg^{2+}] + [Na^+] + [K^+] + [NH_{4+}] + 3[Al^{3+}] + [H^+]$$
$$- 2[SO4^{2-}] - [Cl^-] - [NO_{3-}] - [F^-]$$

The concentration of strong organic acids is then calculated from:

$$A^-_{SA} = ANC_{CB} - ANC_{gran}.$$

8.2.3.4 Calculation of the Buffering Attributable to Weak Organic Acids

The ANC or buffering attributable to the weak organic acids (ANC_{org}) was calculated by the method of Roila *et al.* (1994):

$$ANC_{org} = ANC_{gran} – [HCO_3] + [H^+]_{sample} – [H^+]_{endpoint}$$

Where ANC_{gran} is the measured Gran Alkalinity, $[HCO_3]$ is the bicarbonate concentration calculated using DIC and the pH, $[H^+]_{sample}$ is the initial hydrogen concentration of the sample and $[H^+]_{end}$ is the hydrogen concentration at the end point (equivalence point) of the titration.

8.2.3.5 Calculation of Critical Loads of Acidity to the RAMP Lakes

Critical loads of acidity were calculated for each lake using the Henriksen's steady state water chemistry model (Henriksen and Posch 2001; Henriksen *et al.* 1992; Forsius *et al.* 1992; Rhim 1994). In the Henriksen model the critical load for a lake is calculated as:

$$CL = ([BC]^*_0 - [ANC_{lim}]) .Q$$

where CL in the critical loading level of acidity.

$[BC]^*_0$ is the pre-industrial (original) non-marine base cation concentration in the lake,

ANC_{lim} is the critical value for the acid neutralizing capacity in the water for a given indicator organism, and Q is the mean annual catchment runoff calculated from regional analysis of flow data collected from over 40 hydrometric stations monitored by the Water Survey of Canada.

The equation states that the critical load is equivalent to the acid neutralizing capacity (ANC) or alkalinity generated within the lake catchment (acid consuming processes) minus a critical chemical threshold of ANC (ANC_{lim}) required to protect a selected biological indicator. The alkalinity generating processes are represented by the original or historical export of base cations from the catchment (weathering). By including Q, the runoff, in the equation, both ANC generation and the critical chemical threshold are expressed in terms of a flux (mass/time). In application of this model for these RAMP lakes, it was assumed that the pre-industrial base cation concentration $[BC]^*_0$ was equivalent to the current base cation concentrations and that ANC_{lim} was 75 μeq/L. These and other assumptions are discussed in the NSMWG report (WRS 2004).

The critical loads of acidity in 2003 were compared to critical loads calculated in previous years for the RAMP program and in previous lake surveys. Changes in critical loads between years were noted.

The critical loads were also compared with levels of PAI for each lake basin. The PAI used for the comparison was that generated, under a cumulative effects scenario, for the most recent impact assessment conducted in the oil sands region. Exceedances of the critical load in a lake imply a potential for acidification.

8.2.4 Changes from 2002 Study

There are no changes from the 2002 field program with the exception of the inclusion of Kearl Lake (ID 418) in the 2003 sampling program. The analyses of the data will be more extensive than in previous years as described above.

8.3 RESULTS

8.3.1 Chemical Characteristics of the RAMP Lakes

The chemical characteristics of the RAMP lakes were compared to characteristics of lakes in the oil sands region to determine how these lakes fit into the regional context. Table 8.2 summarizes the chemical characteristics of the 50 RAMP Lakes in 2002 and 2003. The detailed chemical data for all years can be found in Appendix A8. Included in Table 8.2 are the regional range and medians values for each parameter as tabulated in a lake sensitivity report produced by the NOx-SOx Management Working Group (NSMWG). The regional values were based on a sample of 366 study lakes in the oil sands region (WRS 2004).

The RAMP lakes fit well within the ranges of each parameter in the regional lakes. The regional lakes are described in the NSMWG report as:

- Exhibiting a large range in pH (4.4 to 9.59; median: 7.71);
- Exhibiting a large range of ANC (non-detectable to 4,797 μeq/L), although most lakes are highly buffered. The major source of ANC are bicarbonates of calcium and magnesium;
- Exhibiting a wide range of conductivity 11 μS/cm to 481 μS/cm (median: 117 μS/cm);
- High in colour and dissolved organic carbon (median: 17.9 mg/L); and,
- Unusually high in nutrient content especially in total phosphorus (range: non-detectable – 495 μg/L). Nitrates were often low (median: 2μg/L) except for several individual lakes where concentrations as high as 1860 μg/L were observed.

The 50 RAMP lakes cover a similar pH range (4.17 to 9.46) although having a lower median value (6.87 vs. 7.71). Titration alkalinity ranged from non-detectable to 1687 µeq/L with a median of 223 µeq/L, again much lower than the regional median (974 µeq/L). Conductivity was relatively low in the RAMP lakes and ranged from13.5 µS/cm to 172 µS/cm (median: 38.4 µS/cm). The regional median for conductivity was 117 µS/cm. As in the regional lakes, Total P was exceptionally high in individual lakes attaining values as high as 341 µg/L. The median concentration of Total P was similar in both lake populations (median 41 µg/L; vs. 47 µg/L). As in the regional lakes, nitrate concentrations were generally low (median: 2.32 µg/L in 2003), although several lakes had exceptionally high values (e.g., 733 µ/L).

DOC was somewhat higher in the RAMP lakes and ranged from 8.35 mg/L to 55.5 mg/L (median 22.8 mg/L).

Table 8.2 Comparison of major chemical parameters in the RAMP lakes to a population of 366 regional lakes (Source WRS 2004).

	Units	RAMP Lakes				Regional Lakes	
		Year	Min	Max	Median	Range	Median
Lake Area	**km^2**	-	0.031	431	1.38	0.074 - 431	1.93
Net Catchment Area	**km^2**	-	0.62	2137	10	0.269 - 2137	21.9
Drainage Ratio		-	0.223	88.628	10.1	0.219 - 332	10
Lab pH		2002	4.17	8.03	6.82	4.4 - 9.59	7.71
		2003	4.33	9.46	6.87		
Total Alkalinity	µeq/L	2002	ND	1,691	228	ND - 4797	974
		2003	ND	1,577	223		
Gran Alkalinity	µeq/L	2002	ND	1,687	212		
		2003	0.2	1,560	201		
Specific Conductivity	µS/cm	2002	13.5	172.3	34.1	11.0 - 481	117
		2003	13.7	163.8	38.4		
Total Dissolved Solids	mg/L	2002	14	151.5	48.5	13.0 - 261	60.5
		2003	27.3	179	75.7		
Turbidity	NTU	2002	0.48	20	1.7	0.34 - 58.0	
		2003	0.53	29	2.3		
Suspended Solids	mg/L	2002	0.3	122.5	4		
		2003	0.4	85	3.4		
Colour	TCU	2002	10.7	422	124		
		2003	11.9	486	143		

Table 8.2 (cont'd).

	Units	RAMP Lakes				Regional Lakes	
		Year	Min	Max	Median	Range	Median
Dissolved Inorganic Carbon	mg/L	2002	0.242	18.7	2.04		
		2003	0.262	15.7	2.07		
Dissolved Organic Carbon	mg/L	2002	8.35	55.5	21.6	0.20 - 59.5	17.9
		2003	8.02	51.5	22.8		
Sodium	mg/L	2002	0.34	8.75	1.29	0.28 - 49.1	2
		2003	0.45	8.55	1.13		
Potassium	mg/L	2002	0.06	1.67	0.51	0.05 - 11.9	0.63
		2003	0.03	1.95	0.51		
Calcium	mg/L	2002	0.5	24.1	4.76	0.5 - 54.0	13.9
		2003	0.56	21.2	4.86		
Magnesium	mg/L	2002	0.16	8.09	1.49	0.30 - 22.4	4
		2003	0.15	7.33	1.44		
Sum of Base Cations	µeq/L	2002	54.9	1,963	403	90.4 – 5,769	1,111
		2003	79.4	1,770	426		
Titration Bicarbonate	Mg/L	2002	0	103	13.9	0.92 - 262	65.0
		2003	0	96.1	13.6		
Chloride	Mg/L	2002	0.10	2.36	0.22	0.01 - 18.0	0.50
		2003	0.06	2.50	0.13		
Sulphate	mg/L	2002	0.25	16.71	1.05	0.025 - 99.0	2.41
		2003	0.18	13.87	0.88		
Ammonia	(µg/L)	2002	1.09	1,509	15.5	ND - 650	10
		2003	2.36	390.7	13.8		
Nitrate + Nitrite	(µg/L)	2002	0.44	733	5.26	ND – 1,860	2
		2003	0.12	131.1	2.32		
Total Kjeldahl N	(µg/L)	2002	336	5,663	876	27 – 5,900	930
		2003	301	5,040	993		

Table 8.2 (cont'd).

	Units	Year	RAMP Lakes Min	Max	Median	Regional Lakes Range	Median
Total Dissolved N	(µg/L)	2002	324	2,689	722		
		2003	271	2,458	655		
Total Nitrogen	(µg/L)	2002	341	5,664	910		
		2003	301	5,040	1,024		
Total Phosphate	(µg/L)	2002	6.6	209.6	34.1	ND - 495	47
		2003	5.7	340.8	41.0		
Dissolved Phosphate	(µg/L)	2002	2.7	96.7	12.2		
		2003	1.8	155.8	10.9		
Chlorophyll *a*	(µg/L)	2002	1.34	144.0	7.4		
		2003	1.53	128.0	8.5		
Iron	mg/L	2002	0.02	2.2	0.24		
		2003	0.05	3.88	0.4		

The chemical differences between the RAMP lakes and the population of regional lakes reflect a bias in the selection process for the RAMP program. Most of the RAMP lakes were selected for study because they were thought to represent lakes that are potentially sensitive to acid deposition. In practice, this meant selecting lakes that were the most poorly buffered and had the lowest values of pH. Low ANC, low base cation concentrations, and low conductivity are associated with these characteristics. These types of lakes are also often the smallest lakes and are often located in the upland regions. Only the median DOC concentration was greater in the RAMP lakes. The higher values of DOC in the RAMP lakes may reflect the extensive networks of fens in the catchment basins of lakes in the upland regions. The fens are known to export the humic acids that are responsible for the DOC and colour of these lakes (Gorham *et al.* 1984; Kortelainen and Mannio 1990; Kortelainen 1993).

Several lakes stand out as exceptional in their chemistry. These are summarized in Table 8.3. Included in Table 8.3 is whether or not the lakes exhibit exceedances of their critical loads of acidity (See Section 8.3.4).

Table 8.3 RAMP study lakes having exceptional chemical characteristics.

Lake	Region	pH	ANC µeq/L	DOC	Critical Load Exceedance
168 (A21)	Stony Mountains	4.93	31.8	21.5	Yes
169 (A24)	Stony Mountains	4.67	15.6	18.65	Yes
287 (25)	Stony Mountains	5.17	37.0	17.10	Yes
448 (L29) Clayton L.	Birch Mountains	4.23	Non-detect	16.95	Yes
447 (L28)	Birch Mountains	5.17	51.5	27.79	No
444 (L25) Legend	Birch Mountains	6.75	188	8.45	No

In general, these lakes have the lowest ANC, lowest pH of all the RAMP lakes. Lake 444 (Legend Lake), while not having as low a pH and ANC as the other lakes, had a usually low DOC concentration (8.45 mg/L), atypical of the majority of Birch Mountain lakes. As Legend Lake is unusually deep (10 m), the clearer water in this lake may reflect a greater water retention time than in the majority of Birch Mountain lakes. DOC is known to decrease with water retention time in a number of studies (Engstrom 1987; Rasmussen *et al.* 1989). All these lakes are located in the upland regions.

8.3.2 Organization of RAMP Lakes into Sub-regions

In previous reports, the RAMP lakes have been divided into sub-regions that include:

1. North-East of Fort McMurray;
2. Stony Mountains;
3. West of Fort McMurray;
4. The Birch Mountains;
5. The Caribou Mountains, and
6. The Canadian Shield.

The latter two sub-regions were chosen as reference regions for comparison to the lakes in the other sub-regions that are potentially affected by oil sands development. The division of the lakes into sub-regions is indicated in Table 8.2 and Figure 8.1 of the Methods Section.

The sub-region designations are retained in this report for continuity and convenience, although the sub-regions really are quite variable in both lake type and chemistry. The first sub-region (North-East of Fort McMurray), for example, contains both Lakes 452 (L4) and 418 (Kearl Lake). The former is a small, low ANC-low pH lake with a mean pH of 5.86 and mean alkalinity of 103 μeq/L. Kearl Lake is a much larger lake of high pH (7.94) and high alkalinity (1576 μeq/L).

More important than the sub-regional classification are the characteristics of the individual catchment basin of each lake. Lake L4, for example is located in the Muskeg River Upland region, a flat lowland area with an extensive network of fens and bogs. Lakes in the upland regions are typically low in conductivity, alkalinity, pH and base cations (Erikson 1987; WRS 2004). Upland regions include the Birch Mountains, the Caribou Mountains, the Stony Mountains and the Muskeg River Uplands. Differences in chemistry noted between sub-regions reflect more the type of lakes selected for monitoring within each sub-region. For example, previous RAMP reports found that both the pH and the alkalinity of lakes in the Stony Mountain sub-region were less than those of the other regions (Golder 2003b). Most of the lakes in this sub-region are found in a small area of the Stony Mountains, an upland region.

8.3.3 Potential Trends in Lake Chemistry

In general, there are too few years of data to analyze statistically for trends in chemical parameters that would indicate effects of acidic emissions on the RAMP lakes. It is still valuable to note any apparent trends in pH and total alkalinity. To detect trends in pH and alkalinity the average concentration over the last two years was compared to the average concentration over the first three years of the program, if available for each lake. Using this crude comparison, pH increased in 26 lakes and decreased in 6 lakes. The lakes showing pH decreases include A26, A59, L7, Legend Lake, A301 and Whitesand Lake. Some of these increases were very small (<0.1 pH units) and well within analytical error or natural variability. The highest decreases in pH were observed in A26 (0.22 pH), L7 (0.3 pH) and Whitesand Lake (0.14 pH). Total alkalinity increased in 21 lakes and decreased in 8 lakes. Lakes showing alkalinity decreases included A26, L7, L39, Legend Lake, Bayard Lake, L47, L109, and Whitesand lakes. As with pH, most of these decreases in alkalinity are less than 20 μeq/L which could easily be the result of analytical error or natural variability (20 μeq/L is equivalent to 1 mg/L $CaCO_3$). The largest decreases in total alkalinity were observed for A26 (39.2 μeq/L), L7 (30.2 μeq/L), Bayard Lake (108 μeq/L) and Whitesand Lake (39.6 μeq/L). It is notable that many of the lakes showing pH declines also show ANC declines. Of particular note are A26 in the Stony Mountains, L7 (N-E of Fort McMurray) and Whitesand Lake (Caribou Mountains). Bayard Lake in the Birch Mountains showed the highest decline in ANC, although a change in pH was not observed.

8.3.4 Calculations of Critical Loads of Acidity for RAMP Lakes

The critical load of acidity is defined as the highest level of acidic deposition that will not cause chemical changes leading to long-term harmful effects to the lake. The critical load is a property solely of the lake and its drainage basin. The critical load gives an indication of lake sensitivity and can be used to compare to acidic deposition expressed as PAI. The greater the critical load the less sensitive the lake to potential acidic deposition.

Critical loads of acidity were calculated for each lake using the Henriksen's steady state water chemistry model as described in Section 8.2.3.

Table 8.4 presents the critical loads calculated by year (1999-2003) and includes the critical loads from the NSMWG study. Critical loads ranged from 0.004 keq H^+/ha/y (Lake 448; Clayton L) to 1.353 keq H^+/ha/y (Lake 270). The median critical load over all the lakes and years was 0.272 keq H^+/ha/y.

Of the six sub-regions, the Stony mountain lakes were the most sensitive to acidic deposition with a mean critical load of only 0.101 (Table 8.5). The Caribou Mountains, the Birch Mountains and the Canadian Shield follow the Stony Mountains in sensitivity. As indicated in Section 8.3.2, the designation by sub-region is not exact since a number of the regions contain two or more catchment types. In general, lakes located in the upland regions (the Birch Mountains, The Muskeg River Uplands, the Caribou Mountains and the Stony Mountains) or in the Canadian Shield are the most sensitive by the critical load criterion. These areas are generally "lowlands" (despite their relatively high elevation) with extensive networks of fens and bogs. The Canadian Shield lakes are soft water lakes located on granitic bedrock. For example, Lake 170 (A26), having the lowest mean CL over the five years of the RAMP program (0.010 keq H^+ /ha/y), is located in the Stony Mountains. Clayton Lake (448) with a mean CL of 0.0015 keq H^+/ha/y is located in the Birch Mountains. Lake 91 (O-1) with a mean CL of 0.016 keq H^+/ha/y is located in the Caribou Mountains. In general, the ponds, designated with a P in Table 8.4, had relatively high CLs and were not particularly sensitive to acidification by this criterion.

8.3.4.1 Variability of the Critical Load Among Years

The calculation of the critical load for each year permits an estimate of its variability among years. The mean and coefficient of variation across the five years has been calculated in Table 8.4. The coefficient of variation ranged from 7.5 % to 92 5 % with a mean of 21.4 %. As a common value of runoff was used in application of the Henriksen model, this variability is attributable solely to differences in the base cation concentrations between years.

8.3.4.2 Comparisons of the Critical Loads of Acidity to Potential Acid Input

The lake-specific critical loads of acidity were compared to the modeled PAI at each lake location attributable to both natural and anthropogenic causes. The PAI corresponds to the nitrates and sulphates in dry and wet deposition minus the neutralizing effects of base cations. Values of the PAI at each lake (Table 8.4) were those modeled for the OPTI Environmental Impact Assessment in 2002 under a cumulative effects scenario and are identical to values used in the NSMWG mapping report (WRS 2004). Exceedances of the lake critical load by the PAI at each lake indicate a potential for acidification of this lake under the modelling scenario. A discussion of some of the assumptions in this approach can be found in the NSMWG report and those most relevant to the RAMP lakes are reproduced in the Discussion below (Section 8.4).

Exceedances of the critical loads are indicated by shading in Table 8.4. Two lakes previously sampled as part of RAMP (428 and 83), the first in the Muskeg River Uplands and the second in the Caribou Mountains were also exceeded. A total of 13 of the 50 (26%) currently monitored water bodies have critical load exceedances at least once during the five years of the program. The exceeded lakes are summarized in Table 8.6 along with some of their key chemical characteristics. As expected, these lakes are of low pH, low conductivity, low ANC and low base cation concentrations. The carbonate buffering capacity in these lakes is severely reduced. The DOC is also high in most of these lakes. Clayton Lake in the Birch Mountains stands out as having no bicarbonate alkalinity at all and the lowest base cation concentration of all the lakes. Most of the lakes are small (1-2 km^2 in area) with Lake 171 (A47) as the exception at 431 km^2.

Table 8.4 Calculation of critical loads of acidity to RAMP lakes.

NO_x-SO_x GIS No.	Original RAMP Designation	Sum Base Cations (µeq/L)					Gross Catchment Area (km^2)	Runoff (m^3/s)	Critical Load (keq H^+/ha/y)								
		1999	2000	2001	2002	2003			1999	2000	2001	2002	2003	WRS 2004	Mean	CV	PAI
Stony Mountains (Upper Christina River																	
168	A21	181.9	166.8	177.6	142.9	139.5	10.40	0.0404	0.131	0.112	0.126	0.083	0.079	0.131	0.106	22.6	0.131
169	A24	109.0	103.3	108.2	125.6	139.7	7.80	0.0264	0.036	0.030	0.035	0.054	0.069	0.036	0.045	35.9	0.122
170	A26	346.8	126.5	125.0	143.3	146.0	3.40	0.001	0.025	0.005	0.005	0.006	0.007	0.025	0.010	92.8	0.196
167	A29	137.2	158.7	173.2	149.2	151.4	4.50	0.0131	0.057	0.077	0.090	0.068	0.070	0.057	0.072	16.8	0.095
166	A86	237.7	240.7		264.6	280.9	197.00	0.2639	0.069	0.070		0.080	0.087	0.069	0.076	11.3	0.073
287	25 (287)				118.3	136.4	9.76	0.0223				0.039	0.056	0.031	0.042	21.4	0.152
289	27 (289)				164.4	178.0	7.77	0.0216				0.086	0.100	0.122	0.103	23.3	0.112
290	28 (290)				196.2	264.8	3.24	0.0124				0.146	0.229	0.130	0.168	31.5	0.141
342	82 (342)				387.8	362.2	6.10	0.0139				0.225	0.206	0.164	0.198	15.7	0.075
354	94 (354)				684.7	525.2	8.53	0.0162				0.365	0.270	0.319	0.318	15.0	0.113
West of Fort McMurray																	
165	A42	700.5	526.4	478.5	641.3	595.3	588.00	1.1136	0.374	0.270	0.241	0.338	0.311	0.374	0.307	17.2	0.075
171	A47	149.9	311.2	258.5	403.4	347.8	1,254.00	1.8707	0.035	0.111	0.086	0.154	0.128	0.035	0.103	44.0	0.075
172	A59	322.0	274.0	242.3	285.9	276.7	2,245.00	8.5666	0.297	0.240	0.201	0.254	0.243	0.297	0.247	13.9	0.075
223	P94 (223)				1477.7	1370.7	0.70	0.0019				1.196	1.104	1.030	1.110	7.5	0.331
225	P96 (225)				1010.3	834.7	1.26	0.0034				0.799	0.649	0.582	0.677	16.4	0.126
226	P97 (226)				514.3	557.6	1.80	0.0057				0.438	0.481	0.365	0.428	13.7	0.209
227	P98 (227)				996.8	967.3	1.92	0.007				1.058	1.024	0.942	1.008	5.9	0.166
267	1 (267)				1077.8	1005.0	34.50	0.1182				1.084	1.005	0.726	0.938	20.0	0.109

Table 8.4 (cont'd).

NO_x-SO_x GIS No.	Original RAMP Designation	Sum Base Cations (µeq/L)					Gross Catchment Area (km^2)	Runoff (m^3/s)	Critical Load (keq H^+/ha/y)								
		1999	2000	2001	2002	2003			1999	2000	2001	2002	2003	WRS 2004	Mean	CV	PAI
North-East of Fort McMurray (includes the Muskeg River Uplands																	
452	L4	308.1	301.4	273.6	277.2	269.0	20.61	0.092	0.328	0.319	0.280	0.285	0.273	0.239	0.287	11.3	0.236
470	L7	375.9	422.9	409.9	354.9	365.3	21.53	0.101	0.445	0.515	0.495	0.414	0.429	0.400	0.450	10.2	0.579
471	L8	635.4	598.9	627.3	549.9	605.6	10.56	0.045	0.753	0.704	0.742	0.638	0.713	0.609	0.693	8.3	0.538
400	L39	524.3	369.6	349.2	337.3	332.3	19.23	0.0501	0.369	0.242	0.225	0.215	0.211	0.271	0.256	23.3	0.069
268	E15 (268)		787.2	793.6	706.9	608.6	25.04	0.0809		0.726	0.732	0.644	0.544	0.656	0.660	11.6	0.319
182	P23 (182)				384.2	972.3	7.33	0.0296				0.394	1.142	0.462	0.666	62.1	0.132
185	P27 (185)				291.5	273.7	4.04	0.0172				0.291	0.267	0.307	0.288	7.0	0.188
209	P7 (209)				323.2	359.1	1.93	0.0072				0.293	0.335	0.387	0.338	13.9	0.236
270	4 (270)				1963.0	1758.0	18.08	0.0411				1.353	1.207	1.129	1.230	9.3	0.269
271	6 (271)				1933.6	1578.6	22.04	0.0485				1.290	1.043	0.887	1.073	18.9	0.193
418	Kearl L.					1770.1	71.14	0.169					1.270	1.416	1.343	7.7	0.816
Birch Mountains																	
436	L18 Namur	610.7	615.2	627.6	630.0	636.5	223.99	0.325	0.245	0.247	0.253	0.254	0.257	0.233	0.248	3.5	0.054
442	L23 Otasan	289.3	280.5	278.3	288.7	266.6	23.44	0.043	0.124	0.119	0.118	0.124	0.111	0.050	0.107	26.6	0.069
444	L25 Legend	298.4	309.9	322.0	274.3	283.9	93.10	0.1765	0.134	0.140	0.148	0.119	0.125	0.112	0.130	10.4	0.054
447	L28	239.2	214.7	229.4	225.6	213.7	19.00	0.0448	0.122	0.104	0.115	0.112	0.103	0.096	0.109	8.7	0.040
448	L29 Clayton	81.4		110.4	54.9	79.4	13.05	0.033	0.005		0.028		0.004	0.015	0.013	87.6	0.086
454	L46 Bayard	878.3	696.1	606.0	594.4	584.8	57.20	0.169	0.748	0.579	0.495	0.484	0.475	0.329	0.518	26.7	0.067
455	L47	748.5	628.8	604.7	597.5	537.4	49.21	0.1016	0.439	0.361	0.345	0.340	0.301	0.261	0.341	17.5	0.040
457	L49	637.1	653.5	579.4	619.4	568.6	31.11	0.0666	0.380	0.391	0.341	0.368	0.333	0.361	0.362	6.1	0.040
464	L60	556.9	644.7	643.9	635.2	628.3	60.21	0.163	0.411	0.486	0.486	0.478	0.472	0.422	0.459	7.3	0.040
175	P13 (175)				1482.0	1367.0	4.27	0.012				1.248	1.146	0.860	1.085	18.5	0.132
199	P49 (199)				294.3	288.4	0.84	0.0044				0.362	0.352	0.329	0.348	4.8	0.153

Table 8.4 (cont'd).

NO_x-SO_x GIS No.	Original RAMP Designation	Sum Base Cations (µeq/L)					Gross Catchment Area (km^2)	Runoff (m^3/s)	Critical Load (keq H^+/ha/y)								
		1999	2000	2001	2002	2003			1999	2000	2001	2002	2003	WRS 2004	Mean	CV	PAI
Canadian Shield																	
473	A301			595.4	590.1	558.0	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
118	L107 Weekes		622.2	650.4	616.0	602.7	12.20	0.0092		0.130	0.137	0.129	0.125	0.099	0.124	11.8	0.007
84	L109 Fletcher	583.8	609.9	602.7	572.8	558.4	115.80	0.3537	0.490	0.515	0.508	0.479	0.466	0.471	0.488	4.1	0.014
88	O-10	554.8	471.0	426.2	418.0	411.3	5.10	0.0118	0.350	0.289	0.256	0.250	0.245	0.352	0.290	17.0	0.014
90	R1	436.5	452.0	461.9	447.7	440.7	24.30	0.0788	0.370	0.386	0.396	0.381	0.374	0.370	0.381	2.7	0.014
Caribou Mountains																	
146	E52 Fleming	580.4	595.3	620.8	630.3	610.1	17.60	0.0439	0.398	0.409	0.429	0.437	0.421	0.302	0.399	12.4	0.027
152	E59 Rocky Is.	331.4	298.1	323.7	317.7	327.7	30.10	0.0124	0.033	0.029	0.032	0.032	0.033	0.047	0.034	18.6	0.027
89	E68 Whitesand		549.8	536.5	443.6	458.6	54.10	0.1576		0.436	0.424	0.339	0.352		0.388	12.7	0.027
91	O-1	245.3	234.7	226.7	230.7	245.6	3.30	0.001		0.015	0.014	0.015	0.016	0.016	0.015	5.1	0.027
97	O-2	409.8	424.4	416.6	394.4	376.3	9.30	0.0029		0.034	0.034	0.031	0.030	0.033	0.032	6.7	0.027
Previous RAMP Lakes																	
428	L1	283.7					4.30	0.016	0.245					0.200	0.222	14.3	0.312
83	O3/E64	711.0					7.60	0.001	0.026					0.026	0.026	-	0.034
85	R2	433.2					2.0	0.0060	0.348					0.348	0.348	-	0.014
86	R3	1146.3					8.00	0.0215	0.908					0.910	0.908	-	0.014
474	A300			497.0			NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA

Table 8.5 Summary of critical loads in the six RAMP sub-regions.

Region	Minimum	Maximum	Mean
Stony Mountains	0.005	0.365	0.101
West of Fort McMurray	0.035	1.196	0.526
North-East of Fort McMurray	0.211	1.416	0.595
Birch Mountains	0.004	1.248	0.310
Canadian Shield	0.099	0.515	0.329
Caribou Mountains	0.014	0.437	0.169

Table 8.6 Key chemical parameters in the 13 lakes having critical load exceedances.

Lake	Original Name	pH	ANC µeq/L	Base Cations µeq/L	Conductivity µS/cm	DOC mg/L	Lake Area km^2
168	A21	4.93	31.3	162	15.62	21.49	1.38
169	A24	4.67	15.6	117	14.94	18.65	1.45
170	A26	5.56	72.2	178	13.80	14.83	2.78
167	A29	5.77	60.6	151	13.02	15.13	1.05
166	A86	6.51	139	256	25.08	15.10	75
287	25	5.17	37	127	14.05	17.10	2.18
289	27	6.47	102	171	15.75	12.57	1.83
290	28	5.84	86	231	19.95	24.40	0.544
171	A47	6.16	134	294	30.54	19.88	431
470	L7	6.40	173	386	30.24	29.49	0.330
442	L23 Otasan	6.71	175	281	24.90	13.09	3.44
448	L29 Clayton	4.23	0.0	82	18.87	16.95	0.650
91	O-1	6.06	94.00	237	21.24	19.50	0.800

8.3.5 Calculations of Standard Indices of Acidification

Two indices have been proposed to indicate the degree of acidification that has occurred to date. The first is the ratio of alkalinity to base cations (SBC). The second is the ratio of sulphate to base cations. Both ratios were calculated for the RAMP lakes.

8.3.5.1 Ratio of Alkalinity to SBC

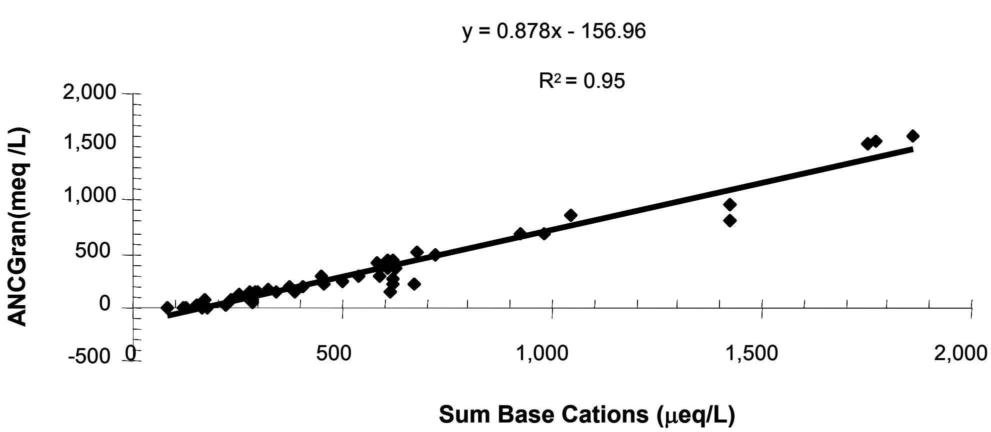
In a pristine system, unaffected by acidification, the ratio of Alkalinity: SBC has a theoretical value of one. A ratio of one implies an intact bicarbonate buffering system. Acidification by sulphate, for example, would replace bicarbonate with sulphate in the lakes and increase weathering of cations from the catchment, both factors tending to reduce the ratio. This ratio has been frequently used as an indication of lake acidification (Henriksen 1980: Scuton and Taylor 1980; Erickson 1987; Jeffries 1991). A very similar ratio [bicarbonate: (Mg+ Calcium)], based on the same idea was used in previous RAMP reports (Golder 2003b).

In calculating the ratios in 2003, the Gran alkalinity was used rather than the titration (total) alkalinity. The Gran alkalinity gives a more accurate determination of the equivalent points of the titration curve and includes the weak organic anions responsible for a proportion of the buffering in coloured, low pH-low ANC lakes.

The use of this index was found to be problematic in the highly coloured RAMP lakes and may have limited applicability. A plot of Gran alkalinity vs. SBC yields a line with a slope of 0.88 and an intercept of -157μeq/L (Figure 8.2). In theory, assuming a bicarbonate buffering system, the theoretical slope should be 1 and the intercept zero. The calculated values of the ratio are considerably less than one. Similarly low values of the ratio were found in previous RAMP studies (e.g., Golder 2003b).

While it is possible that some of these lakes have been affected by acidification and have a low ratio of alkalinity to base cations, it is highly unlikely that all of them have been so affected especially in the reference areas. The poor performance of this ratio can be attributed to the presence of organic acids acting in two ways: as strong acids and weak organic buffers. The effects of these two factors on this ratio are treated in the Discussion (Section 8.4).

Figure 8.2 Gran alkalinity vs. sum of base cations.

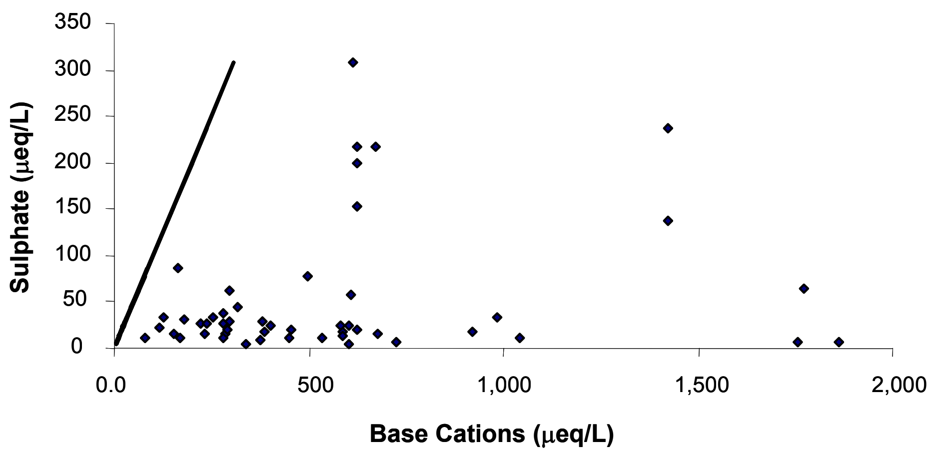


8.3.5.2 Ratio of Sulphate to Base Cations

This ratio is based on assumptions similar to those of the first ratio. During acidification strong acids, in this case, sulphate, will increase relative to base cations representing bicarbonate buffering. Harm to aquatic occurs when the ratio is greater than one regardless of the organic acid anion concentration (Sullivan 2000). The ratio for the RAMP lakes, ranging from 0.003 to 0.529, was always less than one (Figure 8.3). The median ratio is 0.072. Therefore according to this ratio, acidification attributable to sulphate is not indicated.

This ratio, like that of alkalinity to base cations, may have limited applications in the RAMP lakes. The problems associated with this ratio are also presented in Section 8.4.

Figure 8.3 Sulphate vs. base cations in the RAMP lakes. Line represents the 1:1 ratio.



8.3.6 Role of Humic Materials in the Acid-Base Status of the RAMP Lakes

The RAMP lakes, having a median DOC concentration of 21.6 mg/L, can by conventional definition be considered as humic (Forsius 1992; Driscoll *et al.* Kahl *et al.* 1989; Kortelainen *et al.* 1989). It has always been suspected that organic acids play a significant role in the acid-base status of these lakes, although this role was poorly defined. The role of organic acids on the acid-base status of these lakes was studied in detail to determine:

- The weak organic acid concentrations in the lakes;

- The strong acid component of the organic acids in the lakes, and
- The ANC or buffering attributable to organic acids in these lakes.

8.3.6.1 Use of Gran Alkalinity vs. Total Alkalinity

In these calculations of organic acidity, the Gran alkalinity was used as an estimate of ANC rather than the Total alkalinity normally reported by the laboratory. The Gran alkalinity gives a more accurate estimate of ANC because it actually determines the equivalence point of the titration. The Gran alkalinity is equivalent to the ANC attributable to the combination of bicarbonate alkalinity and weak organic anions. The total alkalinity is titrated to pH 4.5 regardless of the equivalence point and may overestimate or underestimate the true ANC.

8.3.6.2 Determination of Weak Organic Acid Concentrations and Charge Densities in the RAMP Lakes

As described in the Methods (Section 8.2), weak organic acid concentrations were calculated by two methods: anion deficit and calibration of the model of Oliver *et al.* (1983) to regional conditions. The concentrations of free organic anions at the sample pH of each lake [A^-] are expressed in μeq/L. The charge density is expressed as the organic anion concentration divided by the DOC in units of μeq A^- /mg C and represents the number of dissociated carboxyl groups per mg of DOC at the pH of the sample.

Organic Anions by Anion Deficit

In the method of anion deficit, the inorganic anions in the lake water are subtracted from the cations with the difference, the anionic deficit, used as an estimate of the concentration of dissociated organic anions A^-. It is essential to estimate the bicarbonate concentrations for this calculation from values of pH and dissolved organic carbon rather than from the titration bicarbonate reported in the laboratory (See Methods, Section 8.2).

Table 8.7 presents the results of the calculations of [A^-] by anion deficit. The concentrations of free organic anions ranged from 98 to 655 μeq/L with a median value of 256 μeq/L. The charge density, ranged from 4 to 18.9 μeq/mg C with a mean of 12.1 μeq/mg C. This mean value fits well within the range of values reported in the literature (see Discussion). Table 8.7 also shows that the bicarbonate reported by the laboratory greatly overestimates the true bicarbonate concentration. The median titration bicarbonate concentration was 227 μeq/L compared to the median calculated concentration of 112 μeq/L. The greatest discrepancies occurred at the lower values of pH.

Table 8.7 Calculations of organic acid concentrations and the charge density of organic carbon in the RAMP lakes.

GIS No.	Original Name	pH	DOC (mg/L)	Gran Alkalinity (µeq/L)	Titration HCO_3 (LAB) (µeq/L)	Calculated $[HCO_3]$ (µeq/L)	Calculated $[CO_3]$ (µeq/L)	Organic Anions (µeq/L)	Charge Density (µeq/mg C)
168	A21	4.93	21.49	5.4	31.2	0.7	4.08E-06	98.1	4.6
169	A24	4.67	18.65	-2.9	19.4	0.3	1.02E-06	121.6	6.5
170	A26	5.56	14.83	-1.8	72.1	3.2	7.45E-05	146.5	9.9
167	A29	5.77	15.13	13.9	60.5	7.9	3.05E-04	127.5	8.4
166	A86	6.51	15.10	114.9	139.3	57.2	1.21E-02	157.6	10.4
287	25 (287)	5.17	17.10	2.0	36.9	1.4	1.32E-05	105.3	6.2
289	27 (289)	6.47	12.57	72.0	102.0	39.5	7.45E-03	112.0	8.9
290	28 (290)	5.84	24.40	50.6	86.1	6.9	3.08E-04	214.3	8.8
342	82 (342)	6.80	25.55	196.4	221.0	103.1	4.20E-02	249.6	9.8
354	94 (354)	7.20	24.52	433.9	449.4	303.8	3.09E-01	286.3	11.7
165	A42	6.82	45.99	285.0	271.5	142.3	6.14E-02	417.4	9.1
171	A47	6.16	19.88	124.7	133.4	31.1	2.94E-03	222.2	11.2
172	A59	5.54	32.95	62.3	79.6	4.9	1.10E-04	234.8	7.1
223	P94 (223)	7.41	50.49	821.7	814.5	514.2	8.57E-01	655.5	13.0
225	P96 (225)	7.42	33.01	678.7	686.6	472.0	8.06E-01	423.6	12.8
226	P97 (226)	6.84	31.96	285.1	305.7	135.3	6.09E-02	383.7	12.0
227	P98 (227)	7.39	33.90	692.6	700.6	476.8	7.57E-01	464.9	13.7
267	1 (267)	7.81	22.62	865.6	884.3	757.5	3.13E+00	256.4	11.3
452	L4	5.86	25.61	76.9	103.0	6.6	3.08E-04	256.1	10.0
470	L7	6.40	29.49	155.9	172.6	32.1	5.24E-03	343.5	11.6
471	L8	7.04	22.33	400.7	420.5	254.0	1.79E-01	317.4	14.2
400	L39	6.76	13.30	178.3	221.0	141.8	5.24E-02	198.7	14.9
268	E15 (268)	7.15	42.99	478.7	466.8	282.8	2.60E-01	450.0	10.5

Table 8.7 (cont'd).

GIS No.	Original Name	pH	DOC (mg/L)	Gran Alkalinity (μeq/L)	Titration HCO_3 (LAB) (μeq/L)	Calculated $[HCO_3]$ (μeq/L)	Calculated $[CO_3]$ (μeq/L)	Organic Anions (μeq/L)	Charge Density (μeq/mg C)
182	P23 (182)	7.11	16.92	527.0	547.8	387.4	3.19E-01	265.9	15.7
185	P27 (185)	5.28	31.39	50.7	73.4	1.4	1.74E-05	272.9	8.7
209	P7 (209)	6.39	28.21	136.9	156.5	33.9	5.34E-03	298.5	10.6
270	4 (270)	8.26	28.27	1591.7	1560.1	1317.7	1.56E+01	509.2	18.0
271	6 (271)	8.67	25.20	1525.6	1328.8	1339.5	4.01E+01	363.0	14.4
418	Kearl L.	7.94	23.53	1560.0	1575.7	1260.1	7.02E+00	438.3	18.6
436	L18	7.11	7.95	378.2	414.7	315.0	2.61E-01	150.3	18.9
442	L23	6.71	13.09	142.3	174.6	85.7	2.87E-02	160.9	12.3
444	L25	6.75	8.45	150.2	188.3	105.7	3.88E-02	122.6	14.5
447	L28	5.17	27.79	23.3	51.5	1.2	1.17E-05	222.5	8.0
448	L29	4.23	16.95	-12.7	0.0	0.2	1.69E-07	131.2	7.7
454	L46	6.86	23.23	225.7	296.7	102.3	4.84E-02	388.7	16.7
455	L47	6.80	20.51	220.2	260.2	118.1	4.77E-02	333.2	16.2
457	L49	6.55	21.01	145.7	165.1	58.9	1.34E-02	255.0	12.1
464	L60	6.89	18.84	273.8	277.6	160.9	8.16E-02	255.5	13.6
175	P13 (175)	7.80	46.88	948.8	945.4	697.6	2.87E+00	576.5	12.3
199	P49 (199)	6.70	15.91	147.0	178.9	91.3	2.98E-02	172.3	10.8
473	A301	7.22	13.84	415.7	450.5	331.7	3.55E-01	187.5	13.5
118	L107	7.19	8.70	431.8	473.9	369.2	3.69E-01	159.2	18.3
84	L109	7.02	17.98	376.2	396.3	261.8	1.76E-01	259.0	14.4
88	O-10	6.81	21.32	214.3	233.3	134.5	5.62E-02	277.3	13.0
90	R1	6.98	16.88	280.5	301.7	190.6	1.19E-01	208.1	12.3
146	E52	7.03	22.62	359.1	361.8	224.0	1.54E-01	314.8	13.9

Table 8.7 (cont'd).

GIS No.	Original Name	pH	DOC (mg/L)	Gran Alkalinity (μeq/L)	Titration HCO_3 (LAB) (μeq/L)	Calculated $[HCO_3]$ (μeq/L)	Calculated $[CO_3]$ (μeq/L)	Organic Anions (μeq/L)	Charge Density (μeq/mg C)
152	E59	6.77	12.27	162.6	197.6	103.0	3.97E-02	165.2	13.5
89	E68	6.91	22.06	239.7	260.6	139.9	7.34E-02	259.8	11.8
91	O-1/E55	6.06	19.50	62.1	93.9	12.5	9.32E-04	195.7	10.0
97	O-2 E67	6.73	22.99	191.0	210.9	84.2	2.92E-02	292.2	12.7
Mean		6.63	22.92	335.2	353.1	234.1	1.49E+00	269.6	12.0
Min		4.23	7.95	-12.7	0.0	0.2	1.69E-07	98.1	4.6
Max		8.67	50.49	1591.7	1575.7	1339.5	4.01E+01	655.5	18.9
Median		6.80	21.78	205.3	227.1	111.9	4.80E-02	255.8	12.1

Model of Oliver et al. (1983)

Examination of the dissociation equations in the Oliver *et al.* (1983) model indicated that $[A^-]$ is proportional to the DOC content and a non-linear, in particular, an exponential function of pH. This knowledge was used to fit the A^- to an appropriate function of DOC and pH. The data were fitted to an equation of the form:

$$A^- = a \text{ DOC} \exp(b*pH).$$

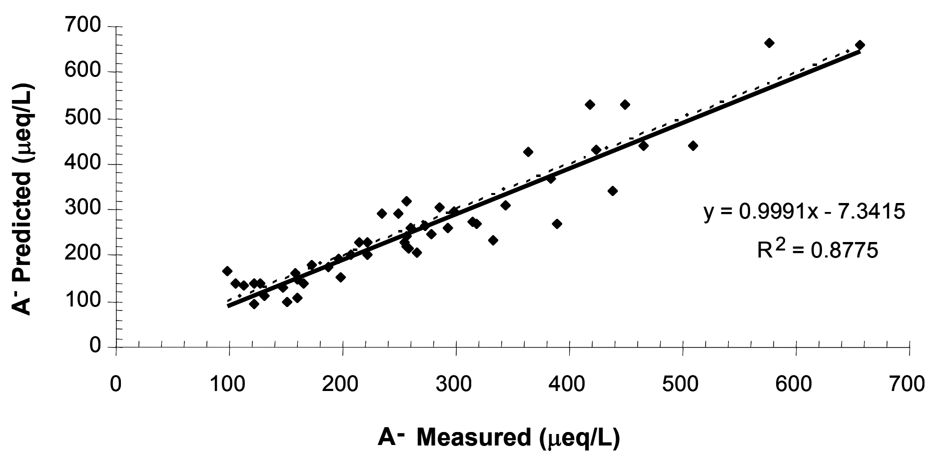
A non-linear regression using SYSTAT 10.2 produced the following equation:

$$A^- = 2.788*\text{DOC} \exp(0.208* pH)$$

$$r^2=0.975 \text{ (raw)}, 0.877 \text{ (corrected)}$$

The equation can be used to calculate the organic acid anion concentrations for regional lakes from field measurements of DOC and pH. A plot of the predicted vs. measured values of organic anions is reproduced in Figure 8.4.

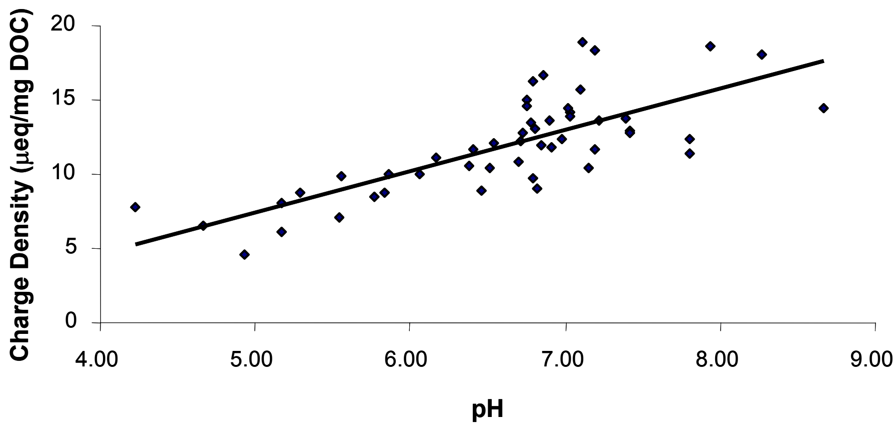
Figure 8.4 Plot of organic anion concentrations predicted from derived equation versus the calculated values.



The 1:1 line (broken line) is essentially co-linear with the first line and the slope of the line fitted to the data has a value of 0.999 compared to a theoretical value of 1.0. Most of the scatter occurs at the higher values of A^- which correspond to lakes having higher values of pH. At higher values of pH, organic groups other than carboxyl (in particular phenolic groups) may play a role in the acid-base dynamics of the lake (Kramer *et al.* 1990).

The derived exponential equation also indicates the strong positive relationship between the charge density (A^-/DOC) and pH which is represented in Figure 8.5.

Figure 8.5 Charge density vs. pH of RAMP lakes.



8.3.6.3 Calculation of Strong Acid Anions

Early studies on humic lakes assumed that organic acids were all weak acids. Later studies showed that DOC is actually a complex mixture of organic acids dissociating over a wide pH range. A certain fraction of these acids acts as strong acids of low pKa. These strong acids remain dissociated at low pH and reduce the overall ANC of the lake.

Strong acid anions (A^-_{SA}) in the RAMP lakes were analyzed by the method suggested by Cantrell *et al.* (1990), Munson and Guerini (1993) and Kortelainen (1993) from the difference between charge balance alkalinity and the Gran alkalinity (see Methods, Section 8.2).

The concentration of strong organic acids (A^-_{SA}) ranged from 78.3 µeq/L (Lake 444, L25) to 349 µeq/L (223, P94) with a median value of 158 µeq/L (Table 8.8). Figure 8.6 presents the difference between the charge balance alkalinity and the Gran Alkalinity as a function of DOC. As in previous studies, the relationship is linear with a slope of 5.82 µeq/mg C. The following relationship applies to the RAMP lakes:

$$A^-_{SA} = 5.82\ [DOC]$$

where the concentration of strong organic acids, A^-_{SA}, is expressed in µeq/L and DOC in mg/L.

Figure 8.6 Plot of charge balance alkalinity minus gran alkalinity versus DOC.

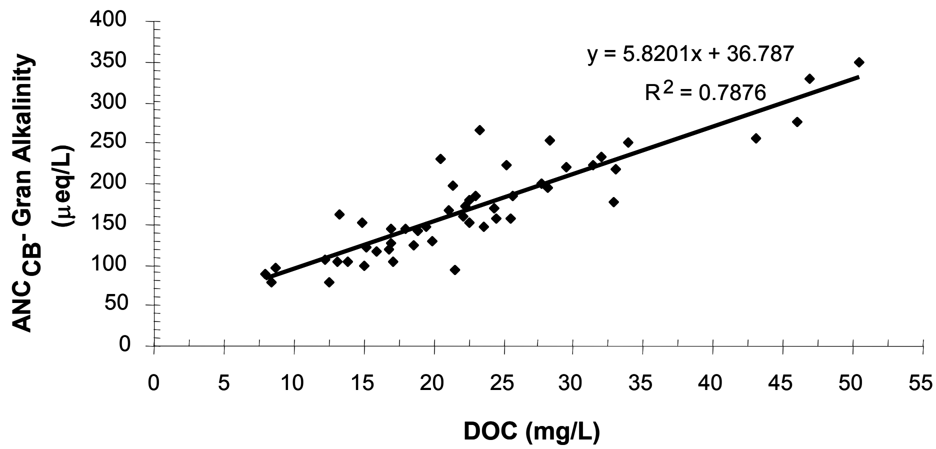


Table 8.8 Calculations of strong organic acids, ANC attributable to weak organic acids (ANC_{org}) and the proportion of ANC attributable to weak organic acids.

GIS No.	Original Name	pH	Charge Balance ANC (µeq/L)	Gran Alkalinity (µeq/L)	Strong Organic Acids (µeq/L)	ANC_{org} (µeq/L)	Percent ANC_{org} of Gran ANC	ANC_{org}/ DOC (µeq/L /mg C)
168	A21	4.93	98.9	5.40	93.5	4.50	83.3	0.21
169	A24	4.67	121.9	0.00	121.9			
170	A26	5.56	149.7	0.00	149.7			
167	A29	5.77	135.4	13.90	121.5	1.05	7.5	0.07
166	A86	6.51	214.8	114.87	100.0	48.00	41.8	3.18
287	25 (287)	5.17	106.7	2.00	104.7			
289	27 (289)	6.47	151.5	72.00	79.5	24.40	33.9	1.94
290	28 (290)	5.84	221.1	50.60	170.5	34.21	67.6	1.40
342	82 (342)	6.80	352.8	196.40	156.4	79.03	40.2	3.09
354	94 (354)	7.20	590.6	433.90	156.7	111.79	25.8	4.56
165	A42	6.82	559.8	284.95	274.8	125.53	44.1	2.73
171	A47	6.16	253.3	124.70	128.6	83.93	67.3	4.22
172	A59	5.54	239.7	62.30	177.4	49.96	80.2	1.52
223	P94 (223)	7.41	1170.8	821.70	349.1	280.85	34.2	5.56
225	P96 (225)	7.42	896.7	678.70	218.0	184.89	27.2	5.60
226	P97 (226)	6.84	519.1	285.10	234.0	130.90	45.9	4.10
227	P98 (227)	7.39	942.7	692.60	250.1	193.15	27.9	5.70
267	1 (267)	7.81	1017.7	865.60	152.1	87.37	10.1	3.86
452	L4	5.86	262.6	76.95	185.7	65.29	84.9	2.55
470	L7	6.40	375.6	155.90	219.7	108.02	69.3	3.66

Table 8.8 (cont'd).

GIS No.	Original Name	pH	Charge Balance ANC (µeq/L)	Gran Alkalinity (µeq/L)	Strong Organic Acids (µeq/L)	ANC_{org} (µeq/L)	Percent ANC_{org} of Gran ANC	ANC_{org}/ DOC (µeq/L /mg C)
471	L8	7.04	571.7	400.65	171.0	130.14	32.5	5.83
400	L39	6.76	340.6	178.35	162.2	28.23	15.8	2.12
268	E15 (268)	7.15	733.1	478.70	254.4	177.88	37.2	4.14
182	P23 (182)	7.11	653.7	527.00	126.7	118.23	22.4	6.99
185	P27 (185)	5.28	274.3	50.70	223.6	40.79	80.4	1.30
209	P7 (209)	6.39	332.5	136.90	195.6	87.67	64.0	3.11
270	4 (270)	8.26	1844.4	1,591.70	252.7	248.79	15.6	8.80
271	6 (271)	8.67	1747.3	1,525.60	221.7	163.13	10.7	6.47
418	Kearl L.	7.94	1706.3	1,560.00	146.3	272.48	17.5	11.58
436	L18	7.11	465.7	378.25	87.4	49.07	13.0	6.17
442	L23	6.71	246.7	142.30	104.4	45.26	31.8	3.46
444	L25	6.75	228.4	150.15	78.3	34.65	23.1	4.10
447	L28	5.17	223.7	23.35	200.3	16.92	72.5	0.61
448	L29	4.23	131.4	0.00	131.4			
454	L46	6.86	491.0	225.65	265.4	109.34	48.5	4.71
455	L47	6.80	451.4	220.20	231.2	86.08	39.1	4.20
457	L49	6.55	313.9	145.70	168.2	75.94	52.1	3.61
464	L60	6.89	416.6	273.80	142.8	95.33	34.8	5.06
175	P13 (175)	7.80	1277.7	948.80	328.9	223.88	23.6	4.78
199	P49 (199)	6.70	263.7	147.00	116.7	43.48	29.6	2.73
473	A301	7.22	519.7	415.67	104.0	67.89	16.3	4.90
118	L107	7.19	528.9	431.85	97.1	49.47	11.5	5.69
84	L109	7.02	521.2	376.20	145.0	99.11	26.3	5.51
88	O-10	6.81	411.9	214.30	197.6	65.24	30.4	3.06
90	R1	6.98	399.0	280.55	118.4	74.61	26.6	4.42
146	E52	7.03	539.0	359.10	179.9	116.19	32.4	5.14
152	E59	6.77	268.3	162.65	105.6	47.11	29.0	3.84
89	E68	6.91	399.9	239.73	160.1	86.22	36.0	3.91
91	O-1/E55	6.06	208.3	62.15	146.2	43.10	69.3	2.21
97	O-2 E67	6.73	376.5	191.00	185.5	92.95	48.7	4.04
Mean		6.63	505.4	335.5	169.9	95.70	38.7	4.05
Min		4.23	98.9	0.0	78.3	1.05	7.5	0.07
Max		8.67	1844.4	1591.7	349.1	280.85	84.9	11.58
Median		6.80	387.8	205.3	158.4	85.00	33.2	4.07

8.3.6.4 Calculation of the ANC (Buffering) Attributable to Weak Organic Anions

The ANC or buffering attributable to the weak organic acids (ANCorg) was calculated for each lake by the method of Roila *et al.* (1994):

$$ANC_{org} = ANC_{gran} – [HCO_3] + [H^+]_{sample} – [H^+]_{endpoint}$$

The results of these analyses are presented in Table 8.8. ANC_{org} ranged from 1.05 µeq/L to 281µeq/L for the RAMP lakes with a median of 85 µeq/L. The ANC_{org} is a strong function of both DOC and pH. The last column in Table 8.8 presents the organic ANC expressed per unit of DOC (ANC_{org}/DOC). This quantity, in effect an "organic buffering density", is frequently calculated in the humic acid literature. For the RAMP lakes, this value ranged from 0.07 µeq/mg C to 11.58 µeq/mg C with a median of 4.07 µeq/mg C. This quantity was plotted against pH in Figure 8.7 to show the strong increase of this quantity with pH. A more comprehensive model to fit the data was determined from the non-linear regression of ANC_{org} on both pH and DOC as:

$$ANC_{org} = 0.149*DOC\ exp(0.475*\ pH)$$

$$r^2 = 0.931\ ,\ r^2\ corrected = 0.790$$

This model shows that ANC_{org} increases proportionately with DOC and exponentially with pH.

Table 8.8 also presents the proportion of the total ANC or total buffering (expressed as Gran alkalinity) attributable to weak organic acids. This proportion ranged from 7.5 % to 84.9 % with a median of 38.7 %. The relation between the percent ANC_{org} and pH is a logistic dose- response curve (Figure 8.8) that accounts for about 83% of the variability of the data. At low values of pH, the percent of the buffering attributable to ANC_{org} is high, in excess of 80 %, but the absolute value of ANC_{org} is low (less than 20 µeq/L). At high values of pH, the percent of the total buffering attributable to ANC_{org} is small although the absolute value of the ANC_{org} is high (greater than 200 µeq/L).

Figure 8.7 Organic buffering density vs. pH in RAMP lakes.

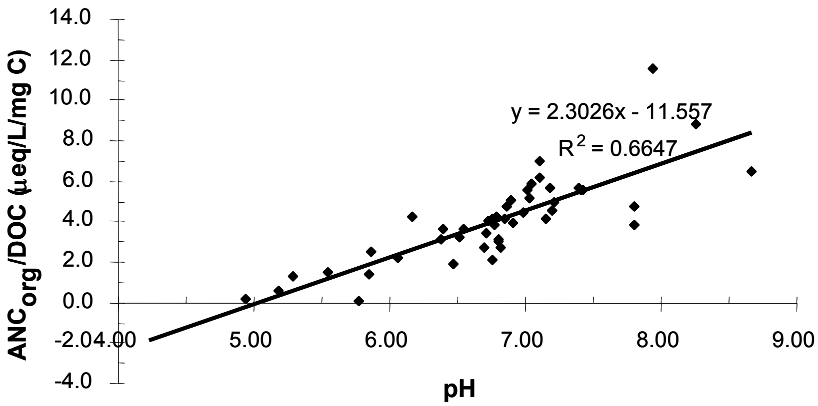
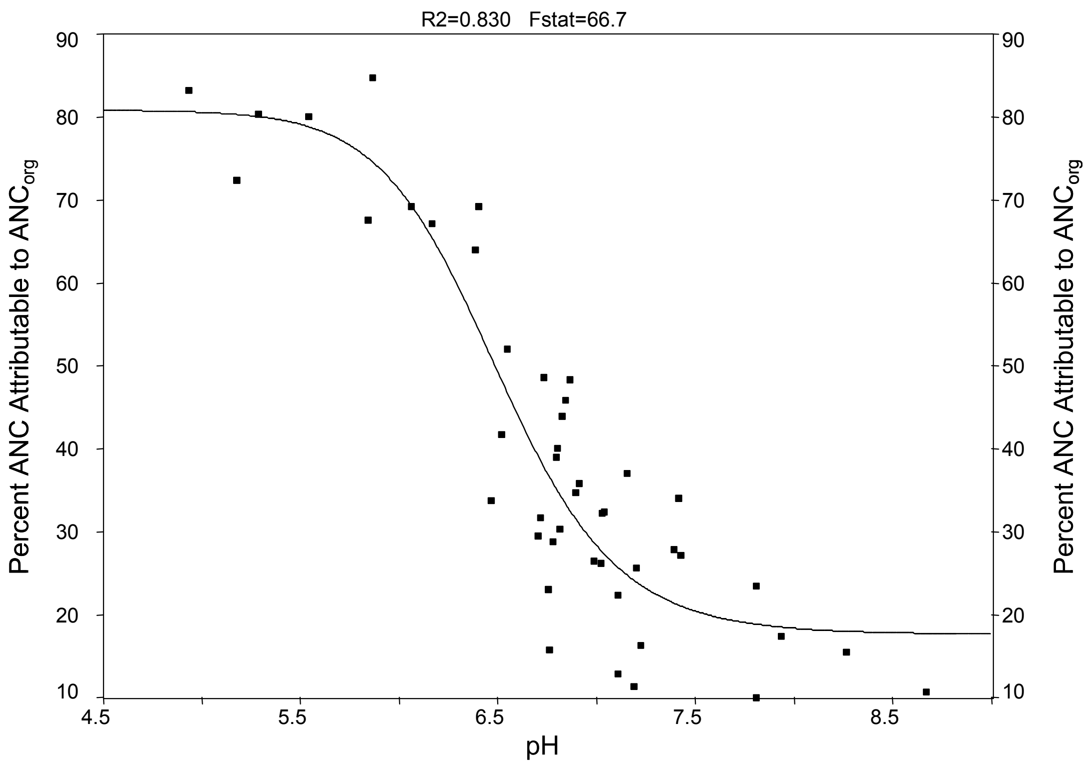


Figure 8.8 Percent organic buffering as a function of pH for RAMP lakes.



8.4 DISCUSSION

8.4.1 Current Status of the RAMP Lakes

The chemical characteristics of the 50 RAMP lakes fit well into those of the 460 regional lakes examined in the NSMWG report on lake sensitivity (WRS 2004). Differences between the two lake populations were due to a bias in the selection process for the RAMP lakes that favored lakes considered to be highly sensitive to acidic deposition. Following this selection criterion, the RAMP lakes were often chosen to be low in ANC and pH. These and related parameters, including conductivity and base cation concentrations, were, therefore, lower in the RAMP lakes than in the regional lake population. Only the dissolved organic carbon was greater in the RAMP lakes. The high levels of DOC in these lakes were related to the large number of fens and bogs within the catchment basins of the RAMP lakes that were often located in the upland regions.

The division of the lakes into sub-regions was found to be more for convenience than reflective of real differences between the sub-regions. More important than the sub-regional differences were the characteristics of the catchment basin for the individual lakes. In particular, lakes having catchment basins in the upland regions (Birch Mountains, Stony Mountains, Muskeg River Uplands) showed distinctly lower pH, conductivity and ANC than lakes in other areas.

There are insufficient monitoring data to detect trends in key chemical parameters that would indicate a process of lake acidification. Comparisons between the first three and last two years of monitoring identified 26 lakes where the pH increased and 6 showing pH decreases. Total alkalinity increased in 21 lakes and decreased in 8 lakes. Most of these increases/decreases were small enough to be considered as simply analytical error, or seasonal variability. A few lakes had significant changes in both parameters and deserve additional attention in future monitoring cycles. These include A26 in the Stony Mountains, L7 north-east of Fort McMurray, and Whitesand Lake in the Caribou Mountains.

8.4.1.1 Critical Load Exceedances as an Indication of Lake Sensitivity

Critical loads were calculated for each lake and year for comparison with the predicted PAI. An exceedance of the critical load by the PAI suggests that a lake has the potential for acidification under the particular PAI modeling scenario. A total of 13 of the 50 RAMP lakes fell into this category and by this criterion are sensitive to acidic deposition (Figure 8.9).

The ability of the Henriksen model to predict lake sensitivity has been discussed at length in the NSMWG report (WRS 2004) and will not be repeated here in detail. Relevant to RAMP are the following assumptions of the model:

1. The assumption that bicarbonate provides the principal source of buffering in each lake; and
2. The assumption that all nitrates contained in modeled PAI are acidifying.

First Assumption

The Henriksen model assumes that buffering is dominated by bicarbonate species rather than organic anions or aluminum. The bicarbonate assumption is implicit in the model as the weathering of base cations alone accounts for alkalinity generation in the catchment. Questions have always been posed by stakeholders as to the possibility of organic buffering replacing the bicarbonate buffering in low ANC-low pH lakes. This would imply that low ANC lakes are less sensitive than indicated by the model.

Since the Henriksen model cannot logically be applied to lakes where bicarbonate buffering is low or absent, a cutoff ANC of 50 μeq/L was recommended in the NSMWG report below which the model should not be applied. Seven of the 13 exceeded RAMP lakes fall into this category.

Further examination of the principle of a cut-off ANC (50 μeq/L) recommended in NSMSG report is warranted based on the analyses of organic buffering in this report. The results of these analyses indicate that at low pH-low ANC, organic buffering is indeed significant relative to bicarbonate buffering (a high percentage of the buffering is organic). However, organic buffering is still small in an absolute sense. Low pH-low ANC lakes remain poorly buffered. In practice this means that, despite the breakdown in some of the logic of the Henriksen model at low pH, the conclusions of the model in regards to lake sensitivity remain true. The 13 lakes having critical load exceedances (including the 7 lakes having an ANC less than 50 μeq/L) are the most sensitive to acidification and should be monitored accordingly.

Second Assumption

Comparison of the critical load for each lake to the PAI assumes that both sources of acidity, nitrogen and sulphate oxides, reach the lake. While it is generally assumed that sulphate is a mobile ion and will reach the lake (Henriksen *et al.* 2002; Henriksen and Braake 1987; Henriksen 1984), nitrates may be retained in the drainage basin by plants and microorganisms (Jeffries 1995; Kamari *et al.* 1992; Dillon and Molot 1990). The critical threshold mapping program conducted in Europe under the UN/ECE Convention on Long-range Transboundary Air Pollution considers a variety of nitrate sinks including denitrification, uptake by vegetation, immobilization in the catchment soils and lake retention. These are all terms in the first order acidity balance (FAB) model applied in the European critical load mapping program (UN/ECE 1996; Posch *et al.* 1997). By assuming that all the nitrates in the PAI are acidifying, both the acidic deposition that is capable of affecting a lake and the number of lakes that are exceeded and at risk to acidification may be overestimated. Further research will be required to determine appropriate nitrogen retention rates for the RAMP lakes.

8.4.2 Use of Acidification Indices to Indicate Effects of Acidification on RAMP Lakes

Two acidification indices have been applied in previous RAMP reports to measure the potential effects of acidification on the RAMP lakes. The first index was the ratio of alkalinity to the sum of the base cations, while the second was the ratio of soleplate to base cations.

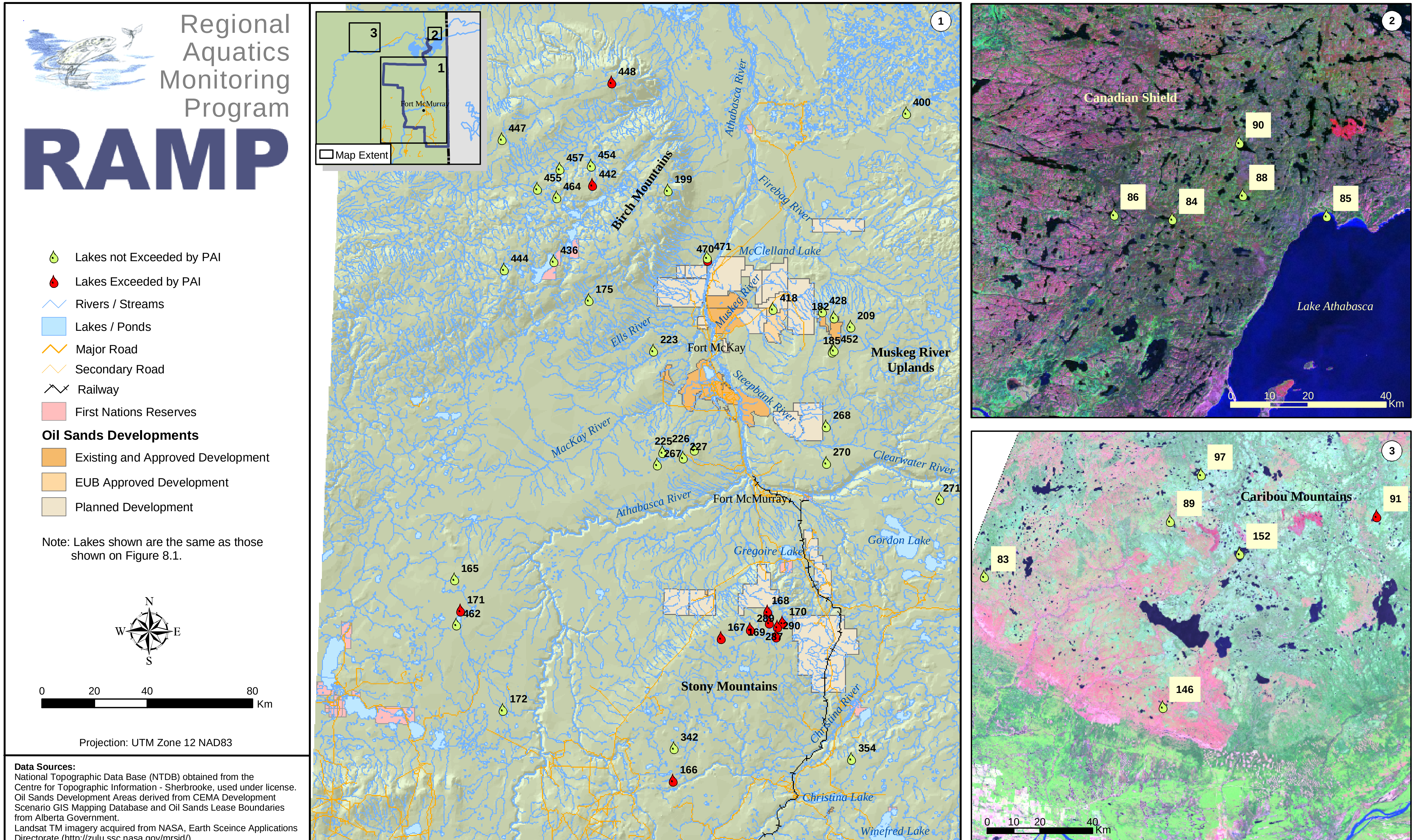
The first ratio assumes that bicarbonate is the dominant buffering system. This ratio did not work well for many of the highly colored, low ANC lakes where bicarbonate buffering is insignificant or non-existent. An unusual number of low values of the ratio were obtained here and in previous RAMP reports. The poor performance of this ratio can be attributed to the presence of organic acids acting in two ways: as strong acids and weak organic buffers.

Strong organic acids act like strong inorganic acids by lowering the ANC and making humid lakes more sensitive to acidification (Brake *et al.* 1987; Driscoll *et al.* 1989; Kortelainen 1993b; Sullivan *et al.* 1989). Strong acids have pKa's well below 4 and remain un-protonated during the Gran titration. The presence of strong organic acids can be accounted for by using the relationship derived between strong organic acidity and the DOC content in each lake (Section 8.3.6.3). The presence and dominance of organic buffers could not be easily incorporated into the index.

In Figure 8.10, the values of Gran alkalinity have been corrected for the presence of strong organic acids by adding the alkalinity decrease attributable to the strong acids in each lake. This was done by multiplying the DOC in each lake by the factor 5.82 μeq/ mg C derived in (Section 8.3.6.3). This increased the slope to 0.935 and the intercept was reduced to -54.6 μeq/L, both much closer to the theoretical values of 1 and zero than in the original regression.

Four lakes still fall significantly below the line. These are listed in Table 8.9 along with key chemical parameters. These lakes are not particularly high in DOC or low in pH although they are very low in Gran alkalinity and as a result have a high proportion of the buffering attributable to organic anions (Section 8.3.6.4). They are all located in the Birch Mountain Uplands.

Figure 8.9 Exceedances of the Critical Loads of Acidity in RAMP Lakes and Ponds.



Mxd: G:\DATA\PROJECTS\RAMP1069\GIS\Fig8-9_AcidExceeded2003.mxd
Last Modified: 2/12/2004 11:14:21 AM

Figure 8.10 Gran alkalinity vs. sum of base cations corrected for strong organic acids.

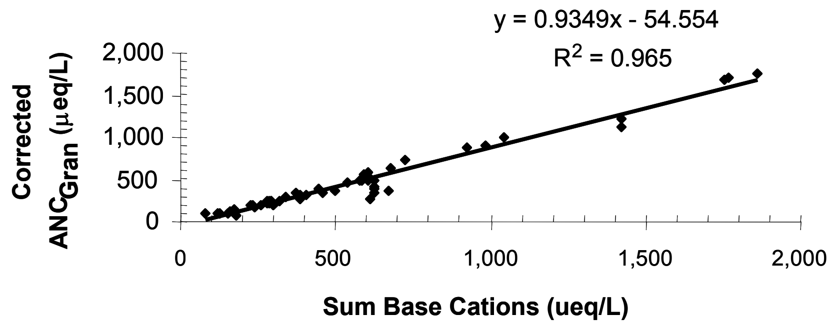


Table 8.9 Chemical characteristics of lakes with a low ratio of Gran alkalinity to base cations.

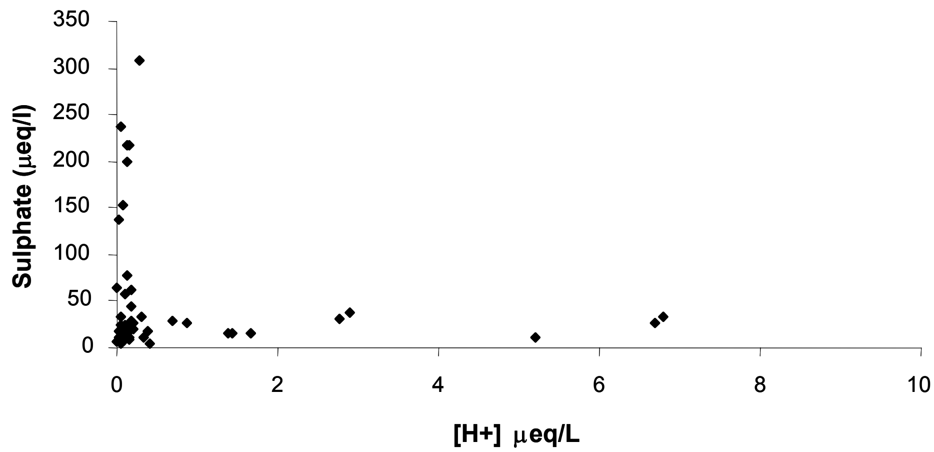
Lake No.	Ratio Alkalinity: SBC[1]	DOC (mg/L)	pH	Gran Alkalinity (μeq/L)	Base Cations (μeq/L)
457 (L49)	0.44	21.0	6.55	146	612
464 (L60)	0.62	18.8	6.89	274	622
454 (L46)	0.54	23.2	6.86	223	672
455 (L47) (E52)	0.81	20.5	6.80	220	623

[1] Gran alkalinity corrected for strong organic acids.

As a result of these analyses, it is evident that the ratio of alkalinity to base cations is of limited applicability to the RAMP lakes.

Like the ratio of alkalinity to base cations, the ratio of sulphate to base cations may also have limited applicability to the RAMP lakes. The index assumes a relationship between sulphate and H^+ in which an increase in sulphate indicates an increase in acidity. In the lower Great Lakes and in Europe, sulphate and H^+ are highly correlated and sulphate is commonly used as a surrogate for acidity (e.g., Henriksen 1980; Dupont and Grimard 1986). Because of the presence of neutral sulphate compounds in wet deposition, the relationship between sulphate and acidity does not apply to Alberta Lakes (AEP 1990; Lau 1982; Legge 1988). In fact, sulphate has been shown to correlate well with calcium rather than the hydrogen ion, probably from the incorporation of calcareous dust in precipitation. Figure 8.11, showing sulphate in each RAMP lake vs. the hydrogen ion concentration, indicates that, as suggested in the literature, the two variables are not well correlated in these lakes.

Figure 8.11 Plot of sulphate vs. hydrogen ion concentration in RAMP lakes.



8.4.3 The Role of Humic Materials in the Acid-Base Status of the RAMP Lakes

Early research on lake acidification involved studies of lakes where bicarbonate provided most of the buffering against acidic deposition and where acidification was often viewed as a large-scale bicarbonate titration (Henriksen 1980; Wright 1984). Although a small number of early studies recognized humic lakes, with their low levels of bicarbonate, as unique ecosystems and potentially sensitive to acidification (e.g., Gorham *et al.* 1984 and Hemond 1980), humic lakes were largely ignored in acidification studies. Serious study on the sensitivity of these lakes to acidification began only the late 1980s and early 1990s. These early studies were conducted largely in Northern Europe, especially in Finland, where these lakes are common.

Based on the European studies, this annual report stresses the role of organic acids in the acid-base dynamics of the RAMP lakes. The acid-base conditions of the RAMP lakes are greatly influenced by the presence of high levels of DOC and the organic acids associated with this organic material. These organic acids act in two principal ways. Strong organic acids have a low pKa and remain dissociated throughout the Gran alkalinity titration. Strong organic acids lower the alkalinity of the lakes in the same way that strong inorganic acids lower alkalinity. Weak organic anions are protonated during the Gran titration and are part of the buffering system along with inorganic bicarbonates. This appears to be the case even for lakes having high base cation and bicarbonate concentrations.

The ability of weak organic acids to buffer against anthropogenic acidification has generated considerable discussion in the lake sensitivity studies conducted by NSMWG (WRS 2004). Weak organic acids were thought by some members of the committee to be capable of considerable buffering capacity in lakes of low pH where inorganic buffering from bicarbonates was at a minimum or non-existent. The analyses conducted in this report attempt to address this issue and determine the importance of organic buffering in these low pH, highly coloured lakes.

8.4.3.1 Measurements of Free Organic Anions

There is no definitive method of measuring organic acidity in surface waters. Two principal approaches have been used: the first using the principle of ion charge balance (anion deficit method) and the second using a dissociation model developed by Oliver *et al.* (1983) and applied to the purified isolates of hydrophobic and hydrophilic acids. Generally, the predictions of the Oliver *et al.* (1983) model and its derivatives are compared to the organic anion concentrations calculated by anion deficit and modifications of the model represent attempts to reconcile the two approaches. The anion deficit method, in a sense, remains a standard against which the Oliver *et al.* model is gauged.

Two terms, relative to organic acid concentrations, require defining. The term *organic acid acidity* refers to the total number of organic acid groups (normally assumed to be carboxyl) in the DOC that is dissociated at the pH of the sample. The *charge density* is the dissociated organic ion concentration per mg DOC. Since the dissociation of the carboxyl groups is a function of acidity, the pH of the charge density must be specified.

The organic acid concentrations in this study range from 98 μeq/L to 655 μeq/L with a median of 256 μeq/L. This median value is high compared to values in the literature, although our DOC concentrations are also higher than most literature values. For comparison, the median organic anion concentration was 92 μeq/L in a study of Finnish Lakes reported by Kortelainen (1992). Our median DOC concentration was 22 mg/L compared with 12 mg/L in the Finnish Lakes. A better indication of the accuracy of our calculations is the charge density. The charge density of the DOC in the RAMP lakes had a median value of 12.1 μeq/mg C. Table 8.9 shows estimates of the charge density in the literature. The literature values range from 2.2 μeq/mg C to 13.4 μeq/mg C with a median of ~ 10 μeq/mg C. The charge densities of the RAMP lakes fit well into this range. The charge density increased with increasing pH over the surveyed lakes, a fact consistent with the expected increase in dissociation of organic acids at the higher pHs.

The exponential equation derived from the anion deficit, the pH and the DOC of the RAMP lakes,

$$A^{-} = 2.788 * DOC \exp(0.208 * pH),$$

is proposed as the most accurate and easiest way of calculating the concentration of free organic anions for lakes in the oil sands region. This equation is based on the relationships between A^- , DOC and pH that were derived by Oliver *et al.* (1983) from his dissociation equations. Using our data for this equation represents a calibration of the model to the RAMP data and condition of North-Eastern Alberta. In a similar exercise, Wilkinson *et al.* (1992) developed a simple regression model for 1,200 shield lakes in Quebec relating anion deficit to both pH and DOC. The authors also suggested that this type of model could be used to predict organic anion concentrations in a regional context. The Wilkinson model, however, failed to maintain the inherent relationships between the three variables suggested in the Oliver et al. model and, although remaining predictive, is therefore less realistic than our model.

In all calculations of anion deficit it is important to determine the carbonate concentrations from DIC, pH and equilibrium relationships. The titration bicarbonate reported by the laboratories greatly overestimates the true bicarbonate concentrations. This error was made in previous RAMP reports.

Table 8.10 Estimates of charge density in the literature (WRS 1999).

Location	Water	DOC mg/L	Method[1]	Charge Density µeq/mg C	Source
Spencer Creek (Ont.)	River	8	O	11.5	Oliver *et al.* (1983)
Missouri River	River	3.8	O	11	Oliver *et al.* (1983)
Ohio River (OH)	River	3.5	O	11.4	Oliver *et al.* (1983)
Yampa River (CO)	River	2	O	11.3	Oliver *et al.* (1983)
Ogeechee R. (GA)	River	7	O	10.4	Oliver *et al.* (1983)
Shawsheen R. (MA)	River	7	O	10.4	Oliver *et al.* (1983)
Como Creek (CO)	River	6.4	O	10.1	Oliver *et al.* (1983)
Deer Creek (CO)	River	0.7	O	11.3	Oliver *et al.* (1983)
Pebbleloggitch (NS)	Lake	18	O	8.3	Oliver *et al.* (1983)
Brainard L.(CO)	Lake	2.8	O	10.7	Oliver *et al.* (1983)
Island L. (NE)	Lake	30	O	13.4	Oliver *et al.* (1983)
Castle Lake (OR)	Lake	145	O	10.6	Oliver *et al.* (1983)
Sphagnum Bog (ME)	Wetland	30	O	9.9	Oliver *et al.* (1983)
Suwanee R. (GA)	Wetland	32	O	11	Oliver *et al.* (1983)
Hawaii Marsh (HI)	Wetland	12	O	10.3	Oliver *et al.* (1983)
Thoreau's Bog (MA)	Wetland	30	O	10.1	Oliver *et al.* (1983)
Alpine Bog (CO)	Wetland	3	O	9.2	Oliver *et al.* (1983)
Biscayne (FL)	Groundwater	13	O	11.4	Oliver *et al.* (1983)
Tupper L (NS)	Lake	11.8	O	7.2	Clair *et al.* (1992)
Tupper L (NS)	Lake	11.8	C	2.2	Clair *et al.* (1992)
Moose Pit Brook (NS)	River	9.3	O	5.6	Clair *et al.* (1992)

Table 8.10 (cont'd).

Location	Water	DOC mg/L	Method [1]	Charge Density µeq/mg C	Source
Moose Pit Brook (NS)	River	9.3	C	3.4	Clair *et al.* (1992)
Mersey River	River	13.9	O	7.1	Clair *et al.* (1992)
Mersey River	River	13.9	C	1.7	Clair *et al.* (1992)
Beaverskin Lake	Lake	2	O	8.6	Clair *et al.* (1992)
Beaverskin Lake	Lake	2	C	1.1	Clair *et al.* (1992)
Skjervatjern Lake (Norway)	Lake	6.85	O	6.6	Clair *et al.* (1992)
Skjervatjern Lake (Norway)	Lake	6.85	C	4.3	Clair *et al.* (1992)
Finnish Lake Survey	Lake	12	AD	7.5	Kortelainen (1992)
Quebec Lakes	Lake	4.7-6.2	OM	6-8.1	Wilkinson *et al.* (1992)
East Bear Brook	River	2.20	EM	7.1-7.7	David *et al.* (1992)
West Bear Brook	River	2.02	EM	7.6-7.7	David *et al.* (1992)
Maine Soils	Soil Leachates	58	AD	3-13	Vance and David (1991)

[1] O = method of Oliver *et al.* (1983); AD = anion deficit; OM = modified method of Oliver *et al.* (1983);
C = method of Clair *et al.* (1992)

8.4.3.2 Strong Acid Nature of Organic Acids

Early studies on humic substances in lakes assumed that organic acids were all weak acids. Dissolved organic carbon is actually a complex mixture of organic acids dissociating across a wide pH range and having a broad pK spectrum (Perdue *et al.* 1984; Brassard *et al.* 1990; Kramer *et al.* 1990; Cantrell *et al.* 1990). Over the pH range of natural waters, these acids are neither all dissociated nor all protonated. A certain fraction acts as strong acids of low pKa. These strong organic acids dissociate completely, decrease ANC and make humic lakes more sensitive to acidification than clear water lakes with similar concentrations of base cations (Brakke *et al.* 1987; Driscoll *et al.* 1989; Kortelainen 1993b; Sullivan *et al.* 1989).

The role of strong organic acids in the acid-base balance of a lake was first recognized by Hemond (1980) who concluded that the acidity of ombrotrophic Thoreau's Bog (pH = 3.8) was determined almost exclusively by strong organic acids. Eshleman and Hemond (1985) fitted data from base titrations on stream water to various chemical titration models. The results were consistent with the presence of strong organic acids of pKa 3.4-3.7. In a study of coloured lakes in the US EPAs Eastern Lakes Survey, Kramer and Davies (1988) found that a DOC greater than 7 mg/L could reduce the pH of a lake having a carbonate alkalinity of 200 mg/L below 5.0. A DOC of only 4 mg/L could reduce the pH below 5.0 in a lake having a carbonate alkalinity of 50 -100 mg/L. Hard waters lakes (alkalinity>2000 ueq/L) were not affected by DOC. The effects of organic acids on surface waters, therefore, depend on the background carbonate alkalinity and the concentrations of organic acid present. Organic acids make humic lakes more sensitive to acidic input from the atmosphere than clear water lakes for lakes with similar concentrations of base cations (Brakke *et al.* 1987).

Much of the evidence for the strong acid properties of organic acids is derived from observed discrepancies between calculated charge balance ANC (ANC_{CB}) and measured Gran alkalinity in coloured waters. In clear water lakes when no organic ions are present, measured Gran alkalinity is equivalent to ANC_{CB}. In humic waters, Gran alkalinity typically underestimates ANC_{CB}. This underestimate corresponds to the ANC remaining at the endpoint pH of the Gran titration and is ascribed largely to the presence of strong, organic acids that remain ionized well below pH 4 (Sullivan *et al.* 1989; Cantrell *et al.* 1990; Munson and Guerini 1990; Kortelainen 1993). As expected, the discrepancy between the calculated and measured ANC was found proportional to the DOC content. Cantrell *et al.* (1990) showed that DOC lowers the ANC by 4.48 μeq per mg of DOC. Hemond (1990) found DOC lowered the Gran alkalinity by a very similar 4.6 μeq per milligram C. Kortelainen (1993b) reported a strong organic acid contribution of 5.3 μeq/mg TOC. Munson and Gherini (1993) reported that DOC contributed 4.5-5 μeq/mg DOC of strong acid to solution in Adirondacks lakes. The largest effects were found at low values of Gran alkalinity (0-50 μeq/L) where strong organic acids depressed pH by up to 1.5 units.

In the RAMP lakes a similar relationship was derived between ANC_{CB}, Gran alkalinity and DOC:

$$ANC_{CB} - ANC_{Gran} = 5.86\ [DOC]$$

Where the $ANC_{CB} - ANC_{Gran}$ is equal to the strong acid concentration, A^{-}_{SA}. This equation can be used to determine the concentration of strong acids in lakes within the Oil Sands region.

The proportionality constant, 5.86, fall well within the literature values. Strong acids in the RAMP lakes ranged from 78.3 μeq/L to 349 μeq/L with a median concentration of 158 μeq/L. The effects of strong organic acids were demonstrated in Section (8.4.2) in which the average ANC was shown to be reduced by greater than 100 μeq/L.

8.4.3.3 Buffering Attributable to Weak Organic Acids

Only a few estimates of the buffering attributable to weak organic acids have been made. These have indicated that the buffering abilities of organic acid anions are limited and are of importance only in lakes of low pH and low ANC where bicarbonate concentrations are low. Even aluminum is a much more effective buffer than organic acid anions. From titrations of the isolated hydrophobic and hydrophilic acids in 10 Finnish lakes, Kortelainen (1993b) calculated the median organic anion fraction titrated during measurements of Gran alkalinity as 15 μeq/L or 1.6 μeq/mg DOC. Waters of high DOC and high pH were titrated over the widest pH range and showed the highest absolute levels of organic alkalinity. However, the proportional contribution of organic alkalinity to total alkalinity was greatest in high DOC - low pH lakes due to the low levels of bicarbonate alkalinity. Only a small fraction of the organic acidity in these waters (16%) contributed to the organic alkalinity.

In a separate study on 40 Finnish Lakes, Roila *et al.* (1994) calculated the organic acid contribution to ANC as the difference between measured Gran alkalinity and the carbonate alkalinity predicted from dissolved inorganic carbon and pH. In waters having a positive ANC, the contribution of organic acid alkalinity averaged 16 and 25 μeq/L in lake and stream waters, respectively, for an overall average of 1.9 μeq/mg DOC.

In a stream acidification study, Hedin *et al.* (1990) found that organic acid anions provided only 2.0 μeq/mg DOC acid neutralizing capacity. Inorganic aluminum release from sediments was the most important mechanism of acid neutralization followed by base cation release and, only then, organic ions. Clair *et al.* (1992) also found that organic anions provided only a small contribution to alkalinity in humic lakes in Nova Scotia and Finland. In Lake Skjervatjern, Finalnd, organic ions provided only 2 μeq/L alkalinity.

In this study, the ANC (ANC_{org}) attributable to weak organic anions was determined from the model of Roila *et al.* (1994) for each lake. The median value of ANC_{org} was 85 μeq/L. The median proportion of the Gran alkalinity represented by ANC_{org} was 33.2 %. The median value of the organic buffering density (ANC_{org}/ mg DOC) is 4.1 μeq/mg C. These values are higher than those reported in the literature; however, the RAMP lakes are generally much greater in DOC content and ANC_{org} is a strong, increasing the function of both DOC and pH. The relationship between ANC_{org}, pH and DOC for the RAMP lakes can be expressed in the following equation:

$$ANC_{org} = 0.149*DOC \exp(0.475* pH).$$

At low pH, ANC_{org} is low but high relative to the total buffering. For example in Lake 168 (A21), having a pH of 4.93 and a DOC of 21.5 mg/L, ANC_{org} was only 4.5 μeq/L (Table 8.8; Section 8.3.6.3). The Gran alkalinity was 5.4 μeq/L. Hence, the proportion of the buffering attributable to ANCorg was high (83.3 %) but the absolute buffering attributable to ANC_{org} was extremely small. At high pH, ANC_{org} is considerably higher, but so are the Gran alkalinity and the importance of bicarbonate buffering. The relative importance of ANC_{org} is much lower. For example in Lake 270, with a pH of 8.26 and a DOC of 28.3, ANC_{org} is high at 253 μeq/L (Table 8.8; Section 8.3.6.3). However, the Gran alkalinity is extremely high at 1592 μeq/L and ANC_{org} represents only 8.8 % of the total ANC. The logistic dose- response curve (Figure 8.8; Section 8.3.6.4), relating the proportion of organic buffering as a function of pH is, perhaps, the most effective way of showing the importance of organic buffering in the RAMP lakes as a function of pH.

In summary, the importance of ANC_{org} is small in an absolute sense in low pH lakes and small in a relative sense in high pH lakes. Organic buffering in low ANC-low pH lakes is not high enough to prevent acidification and these remain the most sensitive regional water bodies.

9.0 SYNTHESIS AND CONCLUSION

This final chapter provides an integrated assessment of all monitoring components and, where possible, assesses whether environmental quality in the study area was linked to oil sands development or other human activities. General comments about the performance of the RAMP program and recommendations for future programs are also provided.

9.1 INTEGRATED ASSESSMENT OF MONITORING COMPONENTS

For the 2003 program, a weight-of-evidence approach was used to assess potential effects of environmental quality on human and aquatic ecosystem health in the RAMP study area. It is important to recognize that the identification of poor environmental quality in a particular area does not necessarily imply that potential effects were caused by oil sands operations or other human activities. Relatively high concentrations of chemicals and/or toxicity may occur in baseline as well as operational areas as a result of high natural concentrations of chemicals, particularly petroleum hydrocarbons, that occur in the RAMP study area.

9.1.1 Methods

Using a weight-of-evidence approach, the magnitude of the response for each endpoint and the degree of concordance among endpoints for a particular station or watershed of interest were evaluated to identify potential effects on human and aquatic receptors related to environmental quality. All endpoints were given equal weight. Endpoints assessed include:

- Hydrology data;
- Water chemistry data;
- Water toxicity data;
- Sediment chemistry data;
- Sediment toxicity data;
- Fish tissue chemistry data; and
- Benthic community data.

Some endpoints, such as water chemistry, which were collected from discrete locations, were used to represent conditions for a specific reaches; whereas, other endpoints, such as fish tissue quality, were used to represent conditions for entire watersheds.

The magnitude of the potential effect for each endpoint for each station or region was scored using the criteria outlined in Table 9.1.

Table 9.1 Criteria for assigning a score for the magnitude of potential for effects for each endpoint.

Component	Score	Potential for Effects	Criteria
Hydrology	○	na	Flows in 2003 were similar to mean historical flows.
Temporal trend for flows	↑	na	Flows in 2003 were higher than mean historical flows.
	↓	na	Flows in 2003 were lower than mean historical flows.
Water Quality			
Chemistry[1]	○	Negligible – Low	None of the analytes exceeded CCME or AENV water quality criteria.
	⦿	Moderate	1-3 analytes exceeded CCME or AENV water quality criteria by up to 5 times.
	●	High	> 4 analytes exceeded the CCME or AENV water quality criteria by up to 5 times, or 1 or more analytes exceed the criteria by greater than 5 times
Toxicity	○	Negligible – Low	No toxicity was observed.
	⦿	Moderate	Growth or reproduction for one test organism was reduced by > 25%.
	●	High	Growth or reproduction for more than one test organism was reduced by > 25%, or survival for one or more test organisms was reduced by > 25%.

Table 9.1 (cont'd).

Component	Score	Potential for Effects	Criteria
Sediment Quality			
Chemistry	○	Negligible – Low	None of the analytes exceeded CCME interim sediment quality guidelines (ISQG) or probable effect levels (PEL).
	⦿	Moderate	1-3 analytes exceeded the CCME ISQG by up to 5 times.
	●	High	>4 analytes exceeded the CCME ISQG by up to 5 times.
			One or more analytes exceeded the ISQG by > 5 times or the PEL by >1 time.
Toxicity	○	Negligible – Low	No toxicity was observed.
	⦿	Moderate	Growth or reproduction for one test organism was reduced by > 25%.
	●	High	Growth or reproduction for more than one test organism was reduced by > 25%, or survival for one or more test organisms was reduced by > 25%.
Benthic Invertebrate Communities Differences between Upstream and Downstream Reaches	○	Negligible – Low	Benthic community endpoints (richness and abundance) differed between upstream and downstream locations by < 2 standard deviations (SDs) for the upstream mean.
	⦿	Moderate	One benthic community endpoint differed between upstream and downstream locations by > 2 SDs but <4 SDs.
	●	High	More than one benthic community endpoint differed between upstream and downstream locations by > 2 SDs, but < 4 SDs, or one benthic community endpoint differed between upstream and downstream locations by > 4 SDs.

Table 9.1 (cont'd).

Component	Score	Potential for Effects	Criteria
Presence of Pollution Tolerant Taxa	○	Negligible – Low	Benthic community is comprised primarily of taxa that are sensitive to pollution.
	◉	Moderate	Benthic community is comprised primarily of taxa that are moderately to highly tolerant of pollution.
	●	High	Benthic community is comprised primarily of taxa that are highly tolerant of pollution.
Fish Tissue Quality			
Protection of Human Health	○	Negligible – Low	Fish tissue concentrations for all analytes were below USEPA and Health Canada criteria for recreational and subsistence fishers and the general consumer.
	◉	High (subsistence)	Fish tissue concentrations for one or more analytes were above USEPA and Health Canada criteria for subsistence fishers, but below criteria for recreational fishers and general consumers.
	●	High (general)	Fish tissue concentrations for one or more analytes were above USEPA and Health Canada criteria for general consumers, and recreational and subsistence fishers.
Protection of Fish Health	○	Negligible – Low	Fish tissue concentrations for all analytes were below literature-based criteria for sublethal and lethal effects on fish.
	◉	Moderate	Fish tissue concentration for one analyte was above literature-based criteria for sublethal effects on fish.
	●	High	Fish tissue concentrations for more than one analyte were above literature-based criteria for effects on fish.

Table 9.1 (cont'd).

Component	Score	Potential for Effects	Criteria
Protection of wildlife	○	Negligible – Low	Fish tissue concentrations for mercury were below CCME criteria for effects on wildlife.
	●	Moderate-High	Fish tissue concentrations for mercury were above criteria for effects on wildlife.
Tainting	○	Negligible – Low	Fish tissue concentrations for tainting compounds were below criteria for palatability of fish (Jardine and Hrudey 1993).
	●	Moderate-High	Fish tissue concentrations for tainting compounds were above criteria for palatability of fish.

[1]Evaluation includes fall water chemistry data only. Total aluminum and iron exceeded criteria at nearly all stations and were excluded from scores for each station.

For the hydrology component, mean flows for 2003 were compared with mean historical flows, to establish whether flows were lower or higher this year. Lower or higher flows influence chemistry and conditions for biota in watersheds of interest.

For the water and sediment quality components, chemistry and toxicity were scored. The water chemistry was rated based on the number and magnitude of exceedances of water quality criteria for each station. Total aluminum and iron were excluded from these analyses because these chemicals exceeded criteria at nearly all stations, and their inclusion would make it impossible to distinguish overall trends across stations. A similar approach was used for the sediment quality component, except that no analytes were excluded from the sediment chemistry assessment. Toxicity was scored based on a 25% sublethal and lethal effect level.

Benthic invertebrate community status was assessed using two criteria based on differences between upstream and downstream stations and the presence (or absence) of pollution tolerant taxa. Upstream and downstream stations were compared using an approach consistent with the federal Environment Effects Monitoring (EEM) Programs, where the richness or abundance of a downstream community is compared to two standard deviations of the mean richness or abundance of an upstream, reference community (Environment Canada 2002). Where possible, downstream and upstream comparisons were made for similar habitat types (i.e., erosional or depositional). However, for some watersheds this was not possible. Differences observed between communities residing in different habitat types were expected and were most likely related to differences in sediment composition and flow.

For the fish tissue quality component, chemical concentrations in fish tissues were compared to criteria for potential effects on human health, fish, and wildlife, and potential tainting.

Acid sensitive lakes were excluded from this assessment because of the inherent complexities of this component that made it difficult to establish effect-based criteria; however, general comments regarding results are provided in Section 9.1.2.4. The aquatic vegetation component was also excluded from the assessment because data limitations (i.e., lack of reference wetlands and differences in methodology between years) prohibited the development of effects-based criteria.

9.1.2 Results

Results for the integrated assessment for each watershed of interest in the RAMP study area, including the Athabasca River mainstem and delta, Athabasca River tributaries, Muskeg River and its tributaries, and regional lakes, are presented separately.

9.1.2.1 Athabasca River Mainstem and Delta

In the 2003 monitoring program, hydrology, water chemistry, sediment chemistry and toxicity, fish tissue chemistry, and benthic invertebrate communities were monitored in the Athabasca Mainstem and/or Delta.

As illustrated in Table 9.2, a majority of stations along the Athabasca River mainstem and delta did not exhibit potential effects related to environmental quality for any of the monitoring components. Where potential effects were observed, there was no concordance among components. In the mainstem, two of the five stations upstream of development were characterized by low sediment quality; three of the four stations in the vicinity of the oil sands operations exhibited high concentrations of chemicals in water; and in two of the five stations downstream of development displayed sediment toxicity. In the delta, no potential effects were observed, with the exception of the presence of pollution tolerant benthic invertebrate communities, which is likely related to the sediment composition and flow found in this depositional habitat.

In general, flows and water quality haven't changed much from previous years. Water chemistry exceeded criteria for phenols and nutrients (nitrogen and phosphorus) at three of fifteen stations, located in the vicinity of the oil sands operations. Concentrations of phenols present at stations located upstream of the Muskeg River were slightly elevated above criteria (up to 1.4-fold) and detection limits. Given the marginal increase in phenols above detection limits, it is not possible to establish whether the slight increase is real and related to development or natural variability or is attributed to analytical error. Total phosphorus concentrations were 20 times higher than criteria upstream of Fort Creek. Given the high total suspended solids and low dissolved phosphorus concentrations observed at this station, most of the phosphorus present at this station were bound to particulate matter and were not readily bioavailable. In addition to these analytes, chloride and conductivity tended to be higher downstream of development.

Sediment chemistry exceeded criteria at two of seventeen stations and sediment toxicity was observed at four of seventeen stations. Sediments from stations located upstream of development, exhibited elevated concentrations of PAHs, including dibenz(ah)anthracene, pyrene, and benzo(a)pyrene, and reduced survival of Hyallela. Given that these stations are located upstream of development, these are not likely development-related effects. Exposure to sediments from ATR-DD-W and ATR-ER, situated downstream of development, also caused reduced growth in Hyallela and survival in chironomids. At ATR-ER, although no criteria exceedances were observed, there were higher concentrations of some metals and PAHs, relative to other stations. At ATR-DD-W, concentrations of chemicals were low; observed toxicity may have been linked with grain size, as sediments from this station were comprised of 100% sand. These sediment quality results suggest that high concentrations of PAHs, likely linked to the presence of exposed bitumen in sediments, are linked to toxicity. However, correlation analyses indicate that toxicity shows a stronger relationship with grain size relative to metals and PAH chemistry.

Benthic invertebrate communities were only examined in the delta. All three delta stations had benthic invertebrate communities comprised of moderate to high pollution tolerant taxa. Despite the presence of these taxa, none of these communities indicated severe habitat degradation. Moreover, the presence of pollution tolerant taxa wasn't directly linked to water and sediment quality (i.e., no criteria exceedances or toxicity were observed at these stations).

Fish tissue chemistry was only monitored within the oil sands region of the mainstem. Fish from the mainstem exhibited high concentrations of mercury that exceeded criteria for human health and wildlife. However, mercury concentrations present in water and sediment in this watershed were below detection limits for all stations. Furthermore, fish tissue concentrations were similar to those observed historically. These findings indicate that mercury concentrations are naturally high in this region and are not related to oil sands developments. Fish inventory surveys also indicated that fish populations have not changed since development of oil sands operations was initiated.

Table 9.2 Weight of evidence assessment of all endpoints for potential effects in the RAMP study area for the Athabasca River Mainstem and Delta, September, 2003.

Watershed Component	Location	Station	Monitoring Status	Hydrology	Water Quality		Sediment Quality		Benthic Invertebrates		Fish Tissue Chemistry			
				Temporal Trend for Average Flows	Chemistry	Toxicity	Chemistry	Toxicity	Upstream vs. Downstream Differences	Presence of Pollution Tolerant Taxa	Human Health Protection	Fish Health Protection	Wildlife Protection	Tainting
Athabasca River Mainstem and Delta														
Upstream of	Upstream of Fort McMurray	ATR-UFM	baseline		○	-	○	○						
Development	Upstream of Donald Creek	ATR-DC-CC	baseline	○	○	-	-	-						
		ATR-DC-W	baseline		○	-	○	○						
		ATR-DC-E	baseline		○	-	●	●						
	Upstream of Steepbank River	ATR-SR-W	baseline		○	-	◉	●						
		ATR-SR-E	baseline		○	-	○	○						
Oil Sands	Steepbank and Muskeg River Areas		operational		-	-	-	-			●	○[1]	●	○
Region	Upstream of Muskeg River	ATR-MR-W	operational		◉	-	○	○						
		ATR-MR-E	operational		◉	-	○	○						
	Upstream of Fort Creek	ATR-FC-W	operational		●	-	○	○						
		ATR-FC-E	operational		○	-	○	○						
Downstream of	Downstream of development	ATR-DD	operational		○	-	-	-						
Development		ATR-DD-E	operational		-	-	○	○						
		ATR-DD-W	operational		-	-	○	●						
	Upstream of Firebag River	ATR-FR	operational		○	-	-	-						
		ATR-FR-E	operational		-	-	○	○						
		ATR-FR-W	operational		-	-	○	○						
	Upstream of Embarras River	ATR-ER	operational		-	-	○	●						
Delta	At Old Fort	ATR-OF	operational		○	-	-	-						
	Big Point Channel	ARD-1/BPC	operational		○	-	○	○	na	◉				
	Goose Island Channel	GIC	operational		-	-	○	○	na	◉				
	Fletcher Channel	FLC	operational		-	-	○	○	na	◉				
	Embarras River	EMR-1	operational		○	-	-	-						

[1]Metals with detection limits higher than criteria were excluded from this score.
- = no data
na = not applicable

In summary, results from this integrated assessment demonstrate that for the Athabasca River mainstem and delta that few potential effects related to environmental quality were observed in this watershed, and those that were observed did not appear to be linked to other effects or oil sands operations. However, the poor water quality observed at some operational and downstream stations, such as those located upstream of the Muskeg River, warrants further consideration in future programs (e.g., consider conducting water toxicity tests for these stations).

9.1.2.2 Athabasca River Tributaries (excluding Muskeg River)

Components including hydrology, water and sediment chemistry and toxicity and benthic invertebrate communities were monitored at eleven tributaries of the Athabasca River in 2003. Four of these tributaries, including the Steepbank River, McLean Creek, Beaver River, MacKay River are located in vicinity of existing oil sands operations or in areas where land disturbance has occurred (i.e., operational stations), north of Fort McMurray. The remaining seven tributaries, including the Clearwater River, Poplar Creek, Ells River, Tar River, Fort Creek, Firebag River, and Calumet River, represent baseline stations that are being monitored prior to development.

A number of stations located along operational tributaries exhibited water chemistry exceedances (Table 9.3). At Beaver River near the Mildred Lake facility, selenium concentrations exceeded the water quality criteria by 12 times; elevated concentrations of sulphate, conductivity, chloride, and dissolved metals were also observed. Concentrations of nitrogen at the mouth and concentrations of phenols at an upstream station of the MacKay River slightly exceeded water quality criteria; the concentrations observed were similar to those observed in previous years. No water quality exceedances were observed at McLean Creek. Similarly, at the mouth of the Steepbank River, where flows were increased this year relative to previous years, no water quality exceedances were observed; however, slightly higher concentrations of phenols, relative to criteria (up to 1.6-fold) and detection limits, were observed at upstream baseline stations. Overall, water quality does not appear to be linked to development, with the possible exception of the MacKay River. No temporal trends were apparent for these stations.

No potential effects were observed in other environmental quality monitoring components at the operational tributaries. However, the assessment of other monitoring components at these operational stations was not comprehensive, limited to sediment chemistry and toxicity at one station in the upper Steepbank River watershed and benthos at the MacKay River. Accordingly, it is difficult to make statements about the presence or absence of potential effects at these stations.

Interestingly, some baseline tributaries exhibited potential effects across multiple monitoring components. At the Ells River phenols and high molecular weight PAH exceedances and toxicity were observed in water and sediment; benthic communities differed between upstream and downstream locations, which is not surprising given that the habitats were dissimilar at these locations. Similar trends were observed at the Tar River; however, chemicals present at higher concentrations were metals and PAHs in sediment and phosphorus in water. At the Clearwater River, sediment toxicity and pollution-tolerant benthos were observed upstream of Fort McMurray. The Christina River, a tributary of the Clearwater River, exhibited water quality exceedances, sediment toxicity, and pollution tolerant taxa. Benthic communities in the Clearwater River watershed also exhibited minor declines in community composition and indices, which were the only temporal changes observed in the entire study area. At the Firebag River and Calumet Rivers, water chemistry exceedances and potential effects in the benthic invertebrate community structure were observed; sediment toxicity was also observed at the Firebag River. No water quality exceedances were observed At Fort Creek and at Poplar Creek. These results indicate that baseline tributaries of the Athabasca River exhibit potential effects for a number of monitoring endpoints, which were most likely linked to naturally elevated concentrations of petroleum hydrocarbons and metals present in this region. Clearly, the capacity to distinguish development-related effects in these systems, once development is initiated, will be limited by the naturally-occurring concentrations of chemicals and natural variability found in this region.

The findings of this integrated assessment of these tributaries demonstrate that environmental quality was lower in a number of baseline tributaries, relative to operational tributaries. The number of tributary stations exhibiting potential effects and/or a concordance of effects was greater than mainstem and delta stations. This observation is not surprising, given the differences and variability in water quality between and within the tributaries compared to the mainstem stations.

Table 9.3 Weight of evidence assessment of all endpoints for potential effects in the RAMP study area for tributaries of the Athabasca River, September, 2003.

Location	Station	Monitoring Status	Hydrology	Water Quality		Sediment Quality		Benthic Invertebrates	
			Temporal Trend for Average Flows	Chemistry	Toxicity	Chemistry	Toxicity	Upstream vs. Downstream Differences	Presence of Pollution Tolerant Taxa
Athabasca River Tributaries (excluding the Muskeg River)									
Clearwater River	watershed	baseline	○						
	CLR-1	baseline		○	-	○	◉		
	CLR-2	baseline		○	-	○	○		
	upstream	baseline							◉
	downstream	baseline						○	●
Christina River (trib. of Clearwater R.)	watershed	baseline	○						
	CHR-1	baseline		○	-	○	◉		
	CHR-2	baseline		●	-	○	●		
	upstream	baseline							◉
	downstream	baseline						○	●
McLean Creek	MCC-1	operational		○	-	-	-		
Poplar Creek	POC-1	baseline		○	-	-	-		
Steepbank River	watershed	?	↑						
	STR-1	operational		○	-	-	-		
	STR-2	baseline		◉	-	-	-		
North Steepbank River	NSR-1	baseline		◉	-	○	○		
Beaver River	BER-1	operational		◉	-	-	-		
MacKay River	watershed	?	↓						
	upstream	baseline							○
	downstream	baseline						○	○
	MAR-1	operational		◉	-	-	-		
	MAR-2	baseline		◉	-	-	-		
Ells River	ELR-1	baseline		◉	●	◉	○		
	upstream	baseline							◉
	downstream	baseline						◉[1]	◉
Tar River	TAR-1	baseline		●	●	◉	●		
	upstream	baseline							○
	downstream	baseline						●[1]	◉
Fort Creek	FOC-1	baseline		○	-	-	-		
Firebag River	watershed		↑						
	FIR-1	baseline		○	-	○	●		
	FIR-2B	baseline		●	-	○	○		
	upstream	baseline							
	downstream	baseline						●[1]	○
Calumet River	CAR-1	baseline		●	○	-	-		
	upstream	baseline							◉
	downstream	baseline						○	◉

- = no data

[1]Upstream and downstream comparisons were made between different habitat types (erosional and depositional).

9.1.2.3 Muskeg River and Tributaries

Components including hydrology, water chemistry, sediment chemistry and toxicity, and benthic invertebrate communities were monitored at 10 stations located along the Muskeg River and its tributaries. The Muskeg River watershed represents a potentially impacted system because several oil sands developments operate in this watershed.

Developments located further upstream along the Muskeg River do not appear to be affecting water quality at the mouth of this river (Table 9.4). Environmental quality was lower in the upper and mid-reaches of the Muskeg River and along its tributaries. Elevated concentrations of phenols in water were observed along upstream sections of the Muskeg, at the mouth of Jackpine Creek, Muskeg Creek, and Stanley Creek. PAHs were elevated in sediments from mid-reach station and Stanley Creek. Sediment toxicity was also observed at the mid-reach station, as well as upstream of Stanley Creek. Not surprisingly, the benthic invertebrate communities collected from depositional zones in Jackpine Creek and the upper and mid reaches of the Muskeg River differed from those collected from an erosional zone at the mouth of the creek.

The only station that exhibited temporal changes in sediment or water quality in 2003 was Stanley Creek, which most likely is linked to discharges released into Stanley Creek by Syncrude as of May 2003. Stanley Creek exhibited the poorest water and sediment quality of all the stations in this watershed. Large increases in sulphate, phenol, alkalinity, conductivity, and other variables were observed at this station in 2003. Extremely high PAH concentrations, comprised primarily of retene, a wood breakdown product, were observed in sediments from this station.

The fish fence inventory conducted this year indicated that large-bodied fish populations are continuing to decline in this watershed. The source of these declines is not necessarily linked to development in this region because a large drop in the fish population was observed in 1995, prior to development in the Muskeg River watershed.

Overall, these findings suggest that water and sediment quality, benthic communities, and fish communities within the Muskeg watershed, especially at Stanley Creek, may be affected by the development in the area. Fortunately, at present, these potential effects appear to be localized, given that no effects were observed for any monitoring components at other downstream stations.

Table 9.4 Weight of evidence assessment of all endpoints for potential effects in the RAMP study area for the Muskeg River and its tributaries, September, 2003.

Location	Station	Monitoring Status	Hydrology	Water Quality		Sediment Quality		Benthic Invertebrates	
			Temporal Trend for Average Flows	Chemistry	Toxicity	Chemistry	Toxicity	Upstream vs. Downstream Differences	Presence of Pollution Tolerant Taxa
Muskeg River and Tributaries									
Muskeg River	watershed		○						
	upper reach	baseline							◉
	lower to mid reach	operational						○	◉
	lower reach	operational							○
Mouth	MUR-1	operational		○	-	○	○		
	MUR-1B	operational		-	-	○	-		
Upstream of Canterra Road	MUR-2	operational		○	-	◉	●		
Upstream of Jackpine Creek	MUR-4	operational		○	-	○	-		
Upstream of Muskeg Creek	MUR-5	baseline		○	-	○	-		
Upstream of Stanley Creek	MUR-D2	baseline		-	-	○	●		
Upstream of Wapasu Creek	MUR-6	baseline		◉	-	○	-		
Jackpine Creek	JAC-1	baseline		◉	-	-	-		
	upstream	baseline							◉
	downstream	baseline						○	◉
Muskeg Creek	MUC-1	baseline		◉	-	-	-		
Stanley Creek	STC-1	operational		●	-	●	-		

- = no data

9.1.2.4 Regional Lakes

Components including hydrology, water and sediment chemistry and benthic invertebrate and/or fish communities were monitored at five regional lakes, Kearl Lake, Shipyard Lake, McClelland Lake, Christina Lake, and Lake Claire. Fish tissue samples from Christina Lake and Lake Claire were provided to RAMP by AENV. Shipyard Lake was the only lake classified as operational; the remaining lakes were categorized as baseline.

Most components evaluated exhibited potential effects related to environmental quality at a majority of the lakes (Table 9.5). However, it is difficult to establish concordance among potential effects because not all components were measured consistently at all lakes. At Kearl Lake only water chemistry and benthic invertebrate communities were examined. At Shipyard and McClelland Lakes, sediment chemistry was assessed, along with water chemistry and invertebrate communities. At Christina Lake and Lake Claire, only fish body burdens were evaluated; however these lakes were not part of the RAMP program.

Shipyard Lake, located in a developed watershed, exhibited low water and sediment quality. Elevated concentrations of phenols in water and high molecular weight PAHs in sediment were observed, possibly due to development in the area. The trend for temporally increasing boron and sulphate concentrations reported in previous years was not observed this year; concentrations were similar to those observed in 1999. Only one of the two baseline lakes where water quality was monitored, Kearl Lake, displayed poor water quality due to the presence of high nitrogen concentrations, relative to criteria.

Benthic invertebrate communities were similar at all three lakes, although, Shipyard Lake exhibited different dominant taxa compared to the other lakes. Overall, communities at all three lakes were comprised of moderately to highly pollution tolerant taxa.

Mercury concentrations in fish tissue from Christina Lake and Lake Claire pose potential risks to human health and wildlife. Because concurrent sediment and water chemistry data are not available for these lakes, it is not clear whether these elevated concentrations in fish were related to mercury in sediment or water. However, given that the range of mercury concentrations observed in these regional lakes falls within the range observed in this region historically, it is likely that these exceedances represent normal background level concentrations. Given the sample sizes involved in these regional lake studies, further investigation of mercury in fish in these lakes is required in order to evaluate these risks comprehensively.

Table 9.5 Weight of evidence assessment of all endpoints for potential effects in the RAMP study area for lakes in the RAMP study area, September, 2003.

Location	Station	Monitoring Status	Water Quality		Sediment Quality		Benthic Invertebrates			Fish Tissue Chemistry			
			Chemistry	Toxicity	Chemistry	Toxicity	Upstream vs. Downstream Differences	Presence of Pollution Tolerant Taxa	Benthos (upstream vs. downstream)	Human Health Protection	Fish Health Protection	Wildlife Protection	Tainting
Lakes													
Kearl Lake	KEL-1	baseline	◉	-	-	-	-	◉		-	-	-	-
Isadore's Lake	ISL-1	operational	-	-	-	-	-	-		-	-	-	-
Shipyard Lake	SHL-1	operational	◉	-	◉	-	-	◉		-	-	-	-
McClelland Lake	MCL-1	baseline	○	-	○	-	-	◉		-	-	-	-
Christina Lake	-	baseline	-	-	-	-	-	-		●	○	●	-
Lake Claire	-	baseline	-	-	-	-	-	-		●	○	●	-

- = no data

For the acid sensitive lakes component, 40 regional lakes and 10 reference lakes were evaluated to assess the long-term effects of acid deposition on sensitive lakes in the region. Results indicated that catchment basins in the upland areas (e.g., Muskeg River uplands, Stony Mountains) showed distinctly lower pH, conductivity, and ANC than other lakes within the RAMP study area. Most of the 13 of 50 lakes that were sensitive to acidification were located in the Stony Mountain area, south of Fort McMurray. Lakes selected for the acid sensitive lakes study exhibited lower pH, acid neutralizing capacity (ANC), conductivity, and base cation concentrations and higher dissolved organic carbon concentrations compared to other lakes in the region. Assessment of temporal data indicated that three lakes in the study area (A26, L7, and Whitesand Lake) exhibited significant changes in pH and alkalinity; only minor changes in lake chemistry were observed in the remaining lakes over the last two to three years.

9.1.2.5 Overview of Environmental Quality in Baseline and Operational Areas

The weight-of-evidence assessment indicates that environmental quality may be causing potential effects on human and aquatic receptors in both the operational and baseline areas. These results suggest that role of natural sources of chemicals must be considered when assessing effects in this region.

In many operational areas, potential effects were often only observed in one component or were negligible. In the Athabasca River mainstem and tributaries (excluding the Muskeg), water quality was the only monitoring component that may be linked to development. Exceptions to this trend were the Muskeg River and its tributaries and Shipyard Lake. In the Muskeg River, effects on sediment and water quality were apparent, especially in Stanley Creek, where there have been significant changes in environmental quality over the past year. Shipyard Lake also exhibited potential environmental effects for more than one endpoint.

Surprisingly, there was a much stronger concordance of potential effects in the some of the baseline areas relative to operational areas. The low environmental quality observed in baseline areas in 2003, such as the Ells River and Tar River, may be attributed to the presence of high naturally-occurring concentrations of petroleum hydrocarbons and metals. In future programs, the consistent measurement of multiple endpoints at all stations is recommended for representative stations in order to effectively evaluate trends for effects.

9.2 PERFORMANCE OF THE RAMP PROGRAM AND RECOMMENDATIONS

The three primary objectives of the RAMP program include:

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

Detailed assessment and discussion regarding the efficacy of the RAMP program in meeting these objectives was presented in the RAMP Five-Year Trend Report (Golder 2003a), and will be assessed further in the soon-to-be-released Peer Review of the Five-Year Trend Report. Therefore, this will not be revisited in this report. However, some general comments and recommendations regarding effectiveness of the RAMP program are presented below.

- In order to effectively measure and evaluate any effects of oil sands developments on aquatic ecosystems in the RAMP study area, more specific information regarding oil sand operations, point and non-point source releases to the environment from these facilities, and characteristics of such releases (e.g., quantity, quality, specific location) is required. Such information could be gathered through an inventory of industry activities and releases to the aquatic environment and the atmosphere.
- Similarly, a comprehensive inventory of predictions of specific EIAs of industry participants in RAMP is necessary to allow effective monitoring and assessment of environmental quality and outcomes associated with these predictions.
- The development and implementation of an EEM-like decision-making framework is recommended to guide the scope and level of monitoring effort for specific watersheds or stations from year to year, and to help distinguish development-related effects from natural background conditions.
- Although RAMP is managed adaptively and modified annually to suit changing development scenarios, industry participants, and environmental concerns, consistent and/or “backward-compatible” methodologies should be followed for each component to allow comparisons to be made across years and across stations.

- Where possible, consistent measurement of multiple endpoints at representative stations is recommended within specific years of sampling to allow more meaningful and comprehensive evaluation of environmental quality and potential effects of development.

- Consider increasing within-station replication of water, sediment and/or other samples in locations where high natural variability is expected or has been previously measured, and to verify findings in areas where data suggests possible effects of development.

- To improve the efficiency and efficacy of future programs, a tailored, watershed-specific approach should be used to test hypotheses and address issues unique to specific watersheds.

- Particularly in watersheds exhibiting high natural concentrations of compounds of concern (e.g., metals and aromatic hydrocarbons), consider future development of site-specific environmental quality criteria, given accepted CCME, AENV or other general criteria for specific variables (e.g., petroleum hydrocarbons) may not be appropriate or sufficiently meaningful to interpret and assess environmental quality in the oil sands area.

10.0 REFERENCES

ATSDR (Agency for Toxic Substances and Disease Registry). 1995. Toxicological profile for polycyclic aromatic hydrocarbons. US Dept. of Health and Human Services, Washington, DC.

AEP (Alberta Environmental Protection). 1994. Ecological Land Survey Site Description Manual. Alberta Environmental Protection. Resource Information Branch, Finance, Land Information and Program Support Services. Edmonton, AB.

AEP. 1997. Draft Alberta Wetlands Policy. Environmental Assessment Division, Environmental Regulatory Service. Edmonton, AB.

AENV (Alberta Environment). 1990a. A Review of Approaches for Setting Acidic Deposition Limits in Alberta. Special Report of Alberta Environment Protection. 63 pp.

AENV. 1990b. Selected methods for the monitoring of benthic invertebrates in Alberta rivers. Environmental Quality Monitoring Branch, Environmental Assessment Division. Alberta Environment. 41 pp.

AENV. 1999a. Regional Sustainable Development Strategy for the Athabasca Oil Sands Area. Alberta Environment Report. Publication No. 1/754. ISBN 0-7785-0680-0.

AENV. 1999b. Surface water quality guidelines for use in Alberta. November 1999. Environmental Assurance Division, Science and Standards Branch, Edmonton, AB.

Anderson, T.C. and B.P. McDonald. 1978. A portable weir for counting migrating fishes in rivers. Fish. Mar. Serv. Tech. Rep. 773: 13 p.

APHA (American Public Health Association). 1989. Standard Methods for the Examination of Waste and Wastewater. 16th Edition. American Public Health Association. Washington, D.C.

Barbour, M.G., J.H. Burk and W.D. Pitts. 1987. Terrestrial Plant Ecology. Second Edition. The Benjamin/Cummings Publishing Company, Inc. Menlo Park, CA.

BC MOELP (British Columbia Ministry of Environment, Lands and Parks). 1998. Manual of Standard Operating Procedures for Hydrometric Surveys in British Columbia. Version 1.0. Resources Inventory Branch for the Aquatic Inventory Task Force, Resources Inventory Committee.

Beamish, R.J. 1973. Determination of age and growth of populations of the white sucker (*Catostomus commersoni*) exhibiting a wide range in size at maturity. J. Fish. Res. Board Can. 30: 607-616.

Beamish, R.J. and A.H. Harvey. 1969. Age determination in white sucker. J. Fish. Res. Board Can. 26: 633-638.

Bode, R.W., M.A. Novak and L.E. Abele. 1996. Quality assurance work plan for biological stream monitoring in New York State. NYS Department of Environmental Conservation, Albany, NY. 89p.

Bohlin, T., T.G. Heggberget and C. Strange. 1990. Electric fishing for sampling and stock assessment. In: I.G. Cowx and P. Lamarque (eds.), Fishing with Electricity, Applications in Freshwater Fisheries Management. Fishing News Books, Oxford, UK. pp. 112-139.

Bond, W.A. and K. Machniak. 1977. Interim report on an Intensive Study of the Fish Fauna of the Muskeg River Watershed of Northeastern Alberta. Prepared by the Department of Fisheries for the Alberta Oil Sands Environmental Research Program. AOSERP Project AF 4.5.1. AOSERP Report 26. 137 pp.

Bond, W.A. and K. Machniak. 1979. An Intensive Study of the Fish Fauna of the Muskeg River Watershed of Northeastern Alberta. Prepared for Alberta Oil Sands Environmental Research Program by Environment Canada, Freshwater Institute. AOSERP Report 76. 180 pp.

Bouloubassi, I. and A. Saliot. 1991. Dissolved, particulate and sedimentary naturally occurring polycyclic aromatic hydrocarbons in a coastal environment. Geochemical significance. Mar. Chem. 42: 127-143.

Brakke, D.F., A. Henriksen and S.A. Norton. 1987. The relative importance of acidity sources for humic lakes in Norway. Nature 329: 432-434

Brassard, P. J.R. Kramer and P.V. Collins. 1990. Binding site analysis using linear programming. Environ. Sci. Technol. Vol. 24:195-201.

Brewer, R., M. Sekela, S. Sylvestre, T. Tuominen and G. Moyle. 1998. Contaminants in bed sediments from 15 reaches of the Fraser River basin. Fraser River Action Plan report 1997-37. Environment Canada, Vancouver, BC.

Brinkhurst, R.O. 1989. Guide to the Freshwater Aquatic Microdrile Oligochaetes of North America. Can. Special Pub. Fish. Aquat. Sci. 84. Ottawa, ON. 259 pp.

Brooks, A.R. and L.A. Kelton. 1967. Aquatic and Semiaquatic Heteroptera of Alberta, Saskatchewan, and Manitoba (Hemiptera). Mem. Ent. Soc. Can. 51 pp.

Burland, G.R. 1994. An Identification Guide to Alberta Aquatic Plants. Prepared for Alberta Environmental Protection. Edmonton, AB.

Butcher, G.A. 2001. Water quality criteria for aluminum. Overview report. British Columbia Ministry of Water, Land and Air Protection, Victoria, BC.

Cantrell, K.J., S.M. Serkiz and E.M. Perdue. 1990. Evaluation of acid neutralizing capacity data for solutions containing natural organic acids. Geochimica et Cosmochimica Acta. 54: 1247-1254.

CCME (Canadian Council of Ministers of the Environment). 1999. Canadian sediment quality guidelines for the protection of aquatic life: Polycyclic aromatic hydrocarbons. CCME, Winnipeg, MB.

CCME. 2001a. Canada-wide Standards for Petroleum Hydrocarbons (PHC) in Soil. CCME, Winnipeg, MB.

CCME. 2001b. Canadian tissue residue guidelines for the protection of wildlife and consumers of aquatic biota. Summary Table. Updated. In: Canadian environmental quality guidelines, 1999, Canadian Council of Ministers of the Environment, Winnipeg.

CCME. 2002. Canadian Environmental Quality Standards (update). CCME, Winnipeg, MB.

CEMA (Cumulative Effects Management Association). 2001. Sustainable Ecosystem Working Group, Terms of Reference and Work Plan, August 2001.

CFIA (Canadian Food Inspection Agency). 2003. Canadian guidelines for chemical contaminants and toxins in fish and fish products. Canadian Food Inspection Agency, Animal Products Directorate, Fish, Seafood and Production, Product Inspection. (www.inspection.gc.ca/english/anima/fispoi/guide/chme.shtml). September 24, 2003.

Clair, T.A., T.L. Pollock, P. Collins and J.R. Kramer. 1992. How brownwaters are influenced by acidification: the HUMEX lake case study. Environ. Int. Vol. 18: 589-596.

Clifford, H.F. 1991. Aquatic Invertebrates of Alberta. University of Alberta Press. Edmonton, AB.

CNRL (Canadian Natural Resources Ltd.). 2002. Horizon Oil Sands Project, Application for Approval. Submitted to: Alberta Energy and Utilities Boards and Alberta Environment. June 2002.

Cummins, K.W. 1962. An evaluation of some techniques for the collection and analysis of benthic samples with special emphasis on lotic waters. American Midland Naturalist. 67: 477-504.

Currie, D.C. 1986. An Annotated List of Keys to the Immature Black Flies of Alberta (Diptera: Simuliidae). Mem. Ent. Soc. Can. 136.

Dillon, P.J. and L.A. Molot. 1990. The role of ammonium and nitrate in the acidification of lakes and forested catchments. Biogeochem. 11: 23-43.

Driscoll, C.T., R.D. Fuller and W.D. Schecher. 1989. The role of organic acids in the acidification of surface waters in the Eastern U.S. Water, Air, Soil Pollut. Vol. 43: 21-40.

Dupont, J. and Y. Grimard. 1986. Systematic study of lake water acidity in Quebec. Water, Air, Soil Pollut. 31: 223-230.

Edmunds, G.F., Jr., S.L. Jensen and L. Berner. 1976. The Mayflies of North and Central America. University of Minnesota Press. Minneapolis. 330 pp.

Eisler, R. 1987b. Mercury hazards to fish, wildlife, and invertebrates: a synoptic review. U.S. Fish and Wildlife Service Biological Report 85(1.10). 90 pp.

Eisler, R. 1987a. Polycyclic aromatic hydrocarbon hazards to fish, wildlife, and invertebrates: a synoptic review. U.S. Fish Wildl. Serv. Biol. Rep. 85(1.11).

Engstrom, D.R. 1987. Influence of vegetation and hydrology on the humus budgets of Labrador Lakes. Can. J. Fish Aquat. Sci. 44: 1306-1314.

Environment Canada. 1992. Aquatic environmental effects monitoring requirements. Annex 1: Aquatic environmental effects monitoring requirements at Pulp and Paper mills and off-site treatment facilities under the pulp and paper effluent regulations of the Fisheries Act, May 20, 1992. Conservation and Protection, Ottawa.

Environment Canada. 1993. Guidelines for Monitoring Benthos in Freshwater Environments. Prepared for Environment Canada, Environmental Protection. Prepared by EVS Consultants. Vancouver, BC.

Environment Canada. 2001. Metal mining guidance document for aquatic Environmental Effects Monitoring. June 2001. Ottawa.

Environment Canada. 2002. Metal mining guidance document for aquatic environmental effects monitoring. June 2002.

Environment Canada. 2003. Annual precipitation data. www.climate.weatheroffice.ec.gc.ca/climateData/monthlydata.html. Published by the Climate and Weather Office.

Epler, J.H. 2001. Identification Manual for the Larval Chironomidae (Diptera) of North and South Carolina. Prepared for North Carolina Department of Environment and Natural Resources.

Erickson, P.K. 1987. An Assessment of the Potential Sensitivity of Alberta Lakes to Acidic Deposition. Special Report: Water Quality Control Branch, Pollution Control Division, Alberta Environment. 137pp. 1987.

Eshleman, K.N and H.F. Hemond. 1985. The role of organic acids in the acid-base status of surface waters at Bickford watershed, Massachusetts. Water Resour. Res. 1985. Vol. 21: 1503-1510.

Forsius, M.F. 1992. Acidification of lakes in Finland: Regional estimates of lake chemistry and critical loads. National Board of Waters and the Environment, Helsinki (Finland) Publications of the Water and Environment Research Institute 10(0): 1-37.

Gauch, H.G. Jr. 1982. Multivariate Analysis in Community Ecology. Cambridge University Press.

Gaufin, A.R. 1973. Use of aquatic invertebrates in the assessment of water quality. Biological Methods for the Assessment of Water Quality. ASTM STP 528, American Society for Testing and Materials, 1973, pp. 96-116.

Glozier, N.E., J.M. Culp and D. Halliwell. 2002. Revised guidance for sample sorting and subsampling protocols for EEM benthic invertebrate community surveys. Prepared by: Environment Canada. August 2002.

Goede, R.W. 1993. Fish health/condition assessment procedures. Parts 1 and 2. Procedures manual and color atlas of autopsy classification categories. Utah Division of Wildlife Resources. Logan, Utah.

Goede, R.W. and B.A Barton. 1990. Organismic indices and an autopsy-based assessment as indicators of health and condition of fish. Am. J. Fish. Soc. Symp. 8: 93-108.

Golder (Golder Associates Ltd.). 1996. Shipyard Lake Environmental Baseline Group. Prepared for Suncor Inc., Oil Sands Group. Fort McMurray, AB. 22 pp. + Appendices.

Golder. 1999a. Oil Sands Regional Aquatic Monitoring Program: field technical procedures. Final report submitted to the RAMP Steering Committee.

Golder. 1999b. Oil Sands Regional Aquatics Monitoring Program (RAMP) 1998. Final report for the RAMP Steering Committee. 183 pp. + Appendices.

Golder. 2001. Oil Sands Regional Aquatics Monitoring Program (RAMP) 2000. Final report for the RAMP Steering Committee.

Golder. 2002a. Oil Sands Regional Aquatics Monitoring Program (RAMP) Program design and rationale – Version 2. A report to the RAMP Steering Committee.

Golder. 2002b. Oil Sands Regional Aquatics Monitoring Program (RAMP) 2001. Volume I: Chemical and biological monitoring. Annual report prepared for the RAMP Steering Committee. Calgary, AB.

Golder. 2003a. Oil Sands Regional Aquatics Monitoring Program (RAMP) five year report. May 2003. March 2003 Draft. Prepared for: the RAMP Steering Committee. Calgary, Alberta.

Golder. 2003b. Oil Sands Regional Aquatics Monitoring Program (RAMP) 2002. Prepared for the RAMP Steering Committee. Calgary, AB.

Gorham, E, S.E. Bayley and D.W. Schindler. 1984. Ecological effects of acid deposition upon peatlands: A neglected field in "acid-rain" research. Can. J. Fish. Aquat. Sci. 41: 1256-1268.

Halsey, L. and D.H. Vitt. 1996. Alberta wetland inventory standards – Version 10.0 in Nesby R. (ed.). Alberta Vegetation Inventory Standards Manual 1997. Alberta Environmental Protection, Resource Data Division.

Hedin, L.O., G.E. Likens, K.M. Postek and C.T. Driscoll. 1990. A field experiment to test whether organic acids buffer acid deposition. Nature. Vol. 345: 798-800.

Hemond, H. 1980. Biogeochemistry of Thoreau's bog, Concord, Massachusetts. Ecological Monographs 50: 507-526.

Henriksen, A. 1980. Acidification of freshwaters - a large scale titration. In: D. Drablos and A. Tollan (eds.), Ecological Impact of acid precipitation. Proc. Int. Conf. Ecol. Impact Acid Precip., Norway 1980. pp. 68-73.

Henriksen, A. and D.F. Brakke. 1988. Sulfate deposition to surface waters: Estimating critical loads for Norway and the eastern United States. Environ. Sci. Technol. 22: 8-14.

Henriksen, A., P.J. Dillon and J. Aherne. 2002. Critical loads of acidity for surface waters in south-central Ontario, Canada: regional application of the steady-state water chemistry (SSWC) model. Can. J. Fish. Aquat. Sci. 59: 1287-1295.

Heyes, A., T.R. Moore, J.W.M. Rudd and J.J. Dugoua. 2000. Methyl mercury in pristine and impounded boreal peatlands, Experimental Lakes Area, Ontario. Can. J. Fish. Aquat. Sci. 57: 2211-2222.

Hoke, R.A., J.P. Geisy and J.R. Adams. 1990. Use of linear orthogonal contrasts in environmental data. Environmental Toxicology and Chemistry, 9: 815-819.

Hubert, W.A. 1996. Passive capture techniques. In: B.R. Murphy and D.W. Willis (eds.), Fisheries Techniques, 2nd ed. American Fisheries Society. Bethesda, Maryland. pp. 157-192.

Hudson, J. H. 1977. Carex in Saskatchewan. Bison Publishing House. Saskatoon, SK.

Jardine, C.G. and S.E. Hrudey. 1988. Threshold detection values of potential fish tainting substances from oil sands wastewaters. Wat. Sci. Tech. 20: 19-25.

Jarvinen, A.W. and G.T. Ankley. 1999. Linkage of effects to tissue residues: development of a comprehensive database for aquatic organisms exposed to inorganic and organic chemicals. Society of Environmental Toxicology and Chemistry (SETAC), Pensacola, FL. 364 pp.

Jeffries, D.S. 1991. Southeastern Canada: An overview of the effect of acidic deposition on aquatic resources. In: (D.F. Charles editor) Acidic Deposition and Aquatic Ecosystems. Springer Verlag, New York. p 273-289.

Jeffries, D.S. 1995. Fresh Water Acidification in Canada Caused by Atmospheric Deposition of Nitrogen Pollutants: A Preliminary Assessment of Existing Information. NWRI contribution No. 95-116.

Johnson, D.L., A.L. Kershaw, A. MacKinnon, J. Pojar, T. Goward and D. Vitt. 1995. Plants of the Western Boreal Forest and Aspen Parkland. Lone Pine Publishing and Canadian Forestry Service. Edmonton, AB.

Jones, M.L., G.J. Mann and P.J. McCart. 1978. Fall fisheries investigations in the Athabasca and Clearwater rivers upstream of Fort McMurray: Volume I. Prepared for the Alberta Oil Sands Environmental Research Program (AOSERP) by Environment Canada, Freshwater Institute, Winnipeg, Manitoba. AOSERP Report 35. 71 p.

Kahl, J.S., S.A. Norton, R.K. MacRae, T.A. Haines and R.B. Davis. 1989. The influence of organic acidity on the acid-base chemistry of surface waters in Maine, USA. Water, Air, and Soil Pollution 46: 221-233.

Kamari, J., D.S. Jeffries, D.O. Hessen, A. Henriksen, M. Forsius and M. Posch. 1992. Nitrogen critical loads and their exceedances for surface waters. In: P. Grennfelt, and E. Thornelof (eds.). Proceedings Workshop on Critical loads for Nitrogen, Lokeberg, Sweden, 161-200.

Kershaw, L., J. Gould, D. Johnson, and J. Lancaster. 2001. Rare Vascular Plants of Alberta. University of Alberta Press, Edmonton, Alberta and Natural Resources Canada, Canadian Forest Service, Northern Forestry Centre, Edmonton Alberta.

Kilgour, B.W. and D.R. Barton. 1999. Associations between stream fish and benthos across environmental gradients in southern Ontario, Canada. Freshwater Biology, 41: 553-566.

Kortelainen, P. 1992. Charge Density of Total Organic Carbon in Finnish Lakes Environmental Pollution 77: 107-113.

Kortelainen, P. 1993. Contribution of organic acids to the acidity of Finnish lakes. Publications of the Water and Environment Research Institute No. 13. 1993. National Board of Waters and the Environment, Finland.

Kortelainen, P. 1999. Acidity and Buffer Capacity. Occurrence of Humic Waters. In: Organic Acids in Aquatic Systems. John Wiley and Sons.

Kortelainen, P. and J. Mannio. 1990. Organic acidity in Finnish lakes. In: P. Kauppi, P. Antilla and K. Kenttamies, (eds.). Acidification in Finland. Springer-Verlag. Berlin. p. 849-863.

Kortelainen, P., J. Mannio, M. Forsius, J. Kamari and M. Verta. 1989. Finnish Lake Survey: The role of organic and anthropogenic acidity Water Air and Soil Pollution 46: 235-249.

Kramer, J.R. and S.S. Davies. 1988. Estimation of non-carbonate protolytes in the Eastern Lakes Survey. Environ. Sci. Technol. Vol. 22: 182-185.

Kramer, J.R., P. Brassard, P. Collins, T.A. Clair and P. Takats. 1990. Variability of organic acids in watersheds. In: E.M. Perdue and E.T. Gjessing (eds.) Organic acids in Aquatic Ecosystems. J. Wiley and Sons Ltd. pp.127-139.

Kristofferson, A.H., D.K. McGowan and W.J. Ward. 1986. Fish weirs for the commercial harvest of sea run Arctic char in the Northwest Territories. Can. Ind. Rep. Fish. Aquat. Sci. 174: iv + 31 p.

Lau, Y. K. 1982. Precipitation chemistry. Air Quality Control Branch, Pollution Control Division, Alberta Environment. Edmonton, Alberta. 75 pp.

LaZerte, B.D. and P.J. Dillon. 1984. Relative importance of anthropogenic versus natural sources of acidity in lakes and streams of central Ontario. Can. J. Fish. Aquat. Sci. 1984. 41: 1664-1677.

Legge, A. H. 1988. The present and potential effects of acidic and acidifying air pollutants on Alberta's Environment. Prepared for the Acid Deposition Research Program by the Kananaskis Centre of Environmental Research, University of Calgary. Calgary Alberta. ADRP-B-16-88. 79pp.

Lockhart, L., P. Wilkinson, R. Hunt and R. Wagemann. 1995. Mercury in lake and marine sediments from Northern Canada. Proceedings of 1995 Canada Mercury Network Workshop. (http://ces.iisc.ernet.in/hpg/envis/prodoc1712.html). Oct. 16, 2004.

MacDonell, D.S. 1991. Enumeration and biological description of migrating fish in the Limestone River, Manitoba, 1990. A report prepared for Manitoba Hydro by North/South Consultants Inc. 86 pp.

MacKay, W.C., G.R. Ash, and H.J. Norris. (eds.). 1990. Fish Ageing Methods for Alberta. RL&L Environmental Services Ltd., in association with Alberta Fish and Wildlife Division and University of Alberta. Edmonton, AB. 113 p.

McCafferty, W.P. and R.P. Randolph. 1988. Canada Mayflies: A faunistic compendium. Proc. Ent. Soc. Ont. 129:47-97.

Merritt, R.W. and K.W. Cummins. 1984. An Introduction to the Aquatic Insects. 2nd Ed. Kendall/Hunt, Dubuque, Iowa. 772 pp.

Merritt, R.W. and K.W. Cummins. 1996. An Introduction to the Aquatic Insects of North America, 3rd ed. Kendall/Hunt Pub. Co., Dubuque, Iowa.

Mill, T.A. 1997. Fish distribution, movement, and gross external pathology information for the Peace, Athabasca, and Slave River Basins. Northern River Basins Study Project Report No. 147. Edmonton, AB, February 1997.

Moss, E.H. 1983. Flora of Alberta. 2nd Edition (Revised by Packer, J.G.). University of Toronto Press. Toronto, ON. 687 pp.

Munkittrick, K.R., M.E. McMaster, G. Van Der Kraak, C. Portt, W.N. Gibbons, A. Farwell, and M. Gray. 2000. Development of methods for effects-driven cumulative effects assessment using fish populations: Moose River Project. Published by the Society of Environmental Toxicology and Chemistry (SETAC). 256 p.

Munson, R. K. and S.A. Guerini. 1993. Influence of organic acids on the pH and acid-neutralizing capacity of Adirondack lakes. Water Resources Research 29: 891-899.

NWWG (National Wetlands Working Group). 1988. Wetlands of Canada. Ecological Land Classification Series No. 24. Sustainable Development Branch. Environment Canada. Ottawa, ON.

Oliver, B.G., E.M. Thurmond and R. Malcolm. 1983. The contribution of humic substances to the acidity of coloured natural waters. Geochim. Cosmochim. Acta. 47: 2031-2035.

Oliver, D.R. and M.E. Roussel. 1983. The Insects and Arachnids of Canada, Part II: The Genera of Larval Midges of Canada (Diptera: Chironomidae). Ag. Can. Publ. 1746. 263 pp.

Paine, M.D. 1998. Volume II: CANMET/MMSL-INTEMIN manual on statistical analysis of environmental data. Prepared by Paine, Ledge and Associates (PLS). North Vancouver, BC. May 6, 1998. 228 p.

Pennak, R.W. 1989. Freshwater Invertebrates of the United States, Protozoa to Mollusca. Third Edition. John Wiley and Sons Inc., New York, N.Y. 628 pp.

Perdue, E.M., J.H. Reuter and M. Ghosal. 1980. The operational nature of acidic functional group analyses and its impact on mathematical descriptions of acid-base equilibria in humic substances. Geochim. Cosmochim. Acta. 44: 1841-1851.

Persaud, D., R. Jaagumagi and A. Hayton. 1993. Guidelines for the protection and management of aquatic sediment quality in Ontario. Ontario Ministry of Environment and Energy.

Posch, M., P.A.M. De Met, J-P. Hettelingh and R.J. Downing. 1999. Calculation and Mapping of Critical Thresholds in Europe: Status Report 1999. RIVM Report, No. 259101009. Coordination Centre for Effects. National Institute of Public Health and the Environment. Bilthoven, the Netherlands.

Ramdahl, M. 1983. Retene – a molecular marker of wood combustion in ambient air. Nature 306: 580-582.

Rasmussen, J.B., L. Godbout and M.F. Schallenberg. 1989. The humic content of lake water and its relationship to watershed and lake morphometry. Limnol. Oceanogr. 34: 1336-1343.

Reynolds, J.B. 1996. Electrofishing. *In*, Murphy, B.R. and D.W. Willis (eds.), Fisheries Techniques, Second Edition. American Fisheries Society. Bethesda, Maryland. pp. 221-253.

Rhim, B. 1995. Critical loads of acidity for forest soils and alpine lakes: steady state mass balance method. Published by the Federal office at Environment, Forests and Landscape. Berne, Switzerland.

Roila, T., P. Kortelainen, M.B. David and I. Makinen. 1994. Effect of organic anions of acid neutralizing capacity in surface waters. Environ. Int. 20: 369-372.

Rooke, J.B. and G.L. Mackie. 1982a. An ecological analysis of lotic environments: I. design and testing. J. Freshwat. Ecol. 1: 421-431.

Rooke, J.B. and G.L. Mackie. 1982b. An ecological analysis of lotic environments: II. comparison to existing indices. J. Freshwat. Ecol. 1: 433-442.

Rosenberg, D.M. and V.H. Resh (eds.). 1993. Freshwater biomonitoring and benthic macroinvertebrates. Chapman and Hall, New York, 488 p.

Saffran, K. A. and D.O. Trew. 1996. Sensitivity of Alberta Lakes to Acidifying Deposition: an Update of Sensitivity Maps with Emphasis on 109 Northern Lakes. Special report prepared by Water Sciences Branch, Water Management Division, Alberta Environmental Protection.

Scott, W.B. and E.J. Crossman. 1973. Freshwater fishes of Canada. Bulletin 184. Fisheries Research Board of Canada. Ottawa. 966 pp.

Scruton, D.A. and D.H. Taylor. 1989. A survey of dilute lakes on the south coast of insular Newfoundland (Canada) in relation to natural and anthropogenic acidification. Canadian Technical Report of Fisheries and Aquatic Sciences 1711: I-V, 1-58.

Shell Canada Ltd. 2002. Application for Approval of the Jackpine Mine – Phase I. Shell Canada Ltd., Calgary, AB.

Sokal, R.R and F. J. Rohlf. 1981. Biometry: The Principles and Practice of Statistics in Biological Research. W.H. Freeman and Co., New York, 2nd edition.

SPSS Inc. 2000. SYSTAT, Version 10. Evanston, IL.

SPSS Inc. 2002. SYSTAT, Version 10.2. Evanston, IL.

Stewart D.B. and L.M. Bernier. 1999. Common parasites, diseases, and injuries of freshwater fishes in the Northwest Territories and Nunavut. Prepared for: Department of Fisheries and Oceans, Central and Arctic Region, Winnipeg, MB. Prepared by: Arctic Biological Consultants, Winnipeg, MB. 41 pp.

Stewart, K.W. and B.P. Stark. 1988. Nymphs of North American Stonefly Genera (Plecoptera), Ent. Soc. America, Lanham, Maryland. 460 pp.

Stumm W. and J.J. Morgan. 1981. Aquatic Chemistry, 2nd edition. Wiley-Interscience. New York.

Sullivan, T.J., C.T. Driscoll, S.A. Gherini, R.K. Munson, R.B. Cook, D.F. Charles and C.P. Yatsko. 1989. Influence of aqueous aluminum and organic acids on measurements of acid neutralizing capacity in surface waters. Nature 338: 408-410.

ter Braak, C.J.F. 1992. CANOCO. A FORTRAN program for Canonical Community Ordination. Microcomputer Power, Ithaca, New York, USA.

Terrell, J.W. and E.P. Bergersen. 2003. Predicting stream bed particle size distributions that limit oligochaete densities [IN] Proceedings of the 9th Annual Whirling Disease Symposium "Managing the Risk", Seattle, WA, Feb 6-7, 2003: Bell Harbor Conference Center, Seattle, WA, Whirling Disease Foundation, p. 29-30.

Teskey, H.J. 1969. Larvae and Pupae of Some Eastern North American Tabanidae (Diptera). Mem. Ent. Soc. Can. 63.

Thorp, J.H. and A.P. Covich (eds). 1991. Ecology and Classification of North American Freshwater Invertebrates. Academic Press, Inc, Toronto. 911 pp.

Underwood, A.J. 1994. On beyond BACI: sampling designs that might reliably detect environmental disturbances. Ecological Applications 4: 3-15.

UNECE. 1996. Manual on Methodologies and Criteria for Mapping Critical Levels/Loads and Geographical Areas where they are Exceeded. United Nations Coordination Centre for Effects. Task Force on Mapping. Federal Environmental Agency, Berlin.

USEPA (United States Environmental Protection Agency). 2000. Guidance for assessing chemical contaminant data for use in fish advisories. Volume 2. Risk assessment and fish consumption limits. Third Edition. EPA 823-B-00-008. November 2000. Office of Water. USEPA. Washington, DC.

USEPA. 2003. Region III risk-based concentration table. (http://www.epa.gov/reg3hwmd/risk/index.htm). April 16, 2003.

USGS (United States Geological Survey). 1982. Measurement and Computation of Streamflow: Volume 1. Measurement of Stage and Discharge. By S.E. Rantz et al. Geological Survey Water Supply Paper 2175. United States Government Printing Office, Washington.

Vujnovic, K. and J. Gould. 2002. Alberta Natural Heritage Information Centre Tracking and Watch Lists – Vascular Plants, Mosses, Liverworts and Hornworts. Alberta Community Development, Parks and Protected Areas Division, Edmonton, AB.

Washington, H.G. 1984. Diversity, biotic, and similarity indices: A review with special relevance to aquatic ecosystems. Water. Res. 18: 653-694.

Water Survey of Canada. 2001. Hydrometric Technician Career Development Program. http://www.smc-msc.ec.gc.ca/wsc/CDP/.

Welsh, P.G., J. Lipton, G.A. Chapman and T.L. Podrabsky. 2000. Relative importance of calcium and magnesium in hardness-based modification of copper toxicity. Env. Tox. Chem. 19 (6): 1624-1631.

Westfall, M.J. Jr. and M.L. May. 1996. Damselflies of North America. Scientific Publishers, Gainesville, Florida. 649 pp.

Wetzel, R.G. 1973. Limnology. Saunders College Publishing. Philadelphia, PA. 767 p.

Wiederholm, T. (ed.). 1986. Chironomidae of the Holarctic Region. Keys and Diagnosis. Part 1. - Larvae. Ent. Scand. Suppl. No. 19. 457 pp.

Wiggins, G.B. 1996. Larvae of the North American Caddisfly Genera (Trichoptera). 2nd ed. University of Toronto Press. Toronto, ON. 457 pp.

Wilkinson, K.J., H.G. Jones, P.G.C. Campbell and M. Lachance. 1992. Estimating organic acid contributions to surface water acidity in Quebec. Water, Air and Soil Pollution 61: 57-74.

Wright, R.F. 1984. Norwegian models for surface water chemistry: An overview. In: J.L. Schnoor, (ed.). Modeling of Total Acid Precipitation Impacts. Acid precipitation Series – Volume 9. Butterworth Publishers. 222 pp.

Wrona, F.J., J.M. Culp and R.W. Davies. 1982. Macroinvertebrate subsampling: a simplified apparatus and approach. Can. J. Fish. Aquat. Sci. 39: 1051-1054.

WRS (Western Resource Solutions). 1999. A review of acidification of humic lakes with recommendations for further studies. Report to Alberta Environment by Western Resource Solutions.

WRS. 2000. Critical loads of acidity to 162 lakes sampled by Alberta-Pacific Forest Industries during 1998. Special Report prepared for Syncrude Canada Ltd., Fort McMurray.

WRS. 2003. Calculation of critical loads of acidity to lakes in the oil sands region. Report to the NO_X-SO_X Management Working Group, Fort McMurray Alberta.

WRS. 2004. Calculations of critical loads of acidity to lakes in the oil sands region. Report by Western Resource Solutions to the NOx-SOx Management Working Group.

Zloty, J. and G. Pritchard. 1997. Larvae and adults of *Ameletus* mayflies (Ephemeroptera: Ameletidae) from Alberta. Can. Ent. 129: 251-289.

11.0 GLOSSARY AND LIST OF ACRONYMS

11.1 GLOSSARY

Abundance	Number of organisms in a defined sampling unit, usually expressed as aerial coverage.
Acute	Acute refers to a stimulus severe enough to rapidly induce an effect; in aquatic toxicity tests, an effect observed in 96 hours or less is typically considered acute. When referring to aquatic toxicology or human health, an acute effect is not always measured in terms of lethality.
Ageing Structures	Parts of the fish which are taken for ageing analyses. These structures contain bands for each year of growth or maturity which can be counted. Some examples of these structures are scales, fin rays, otoliths and opercula. Most ageing structures can be taken with minimal effect on the fish and vary according to fish species.
Alkalinity	A measure of water's capacity to neutralize an acid. It indicates the presence of carbonates, bicarbonates and hydroxides, and less significantly, borates, silicates, phosphates and organic substances. It is expressed as an equivalent of calcium carbonate. The composition of alkalinity is affected by pH, mineral composition, temperature and ionic strength. However, alkalinity is normally interpreted as a function of carbonates, bicarbonates and hydroxides. The sum of these three components is called total alkalinity.

ANCOVA	Analysis of covariance. ANCOVA compares regression lines, testing for differences in either slopes or intercepts (adjusted means).
ANOVA	Analysis of Variance. An ANOVA tests for differences among levels of one or more factors. For example, individual sites are levels of the factor site. Two or more factors can be included in an ANOVA (e.g., site and year).
AOSERP	Alberta Oil Sands Environmental Research Program
Baseline	A surveyed condition which serves as a reference point to which later surveys are compared.
Benthic invertebrates	Invertebrate organisms living on the bottom of lakes, ponds and streams. Examples of benthic invertebrates include the aquatic insects such as caddisfly larvae, which spend at least part of their life on or in bottom sediments. Many benthic invertebrates are major food sources for fish.
Benthos	Organisms that inhabit the bottom substrates (sediments, debris, logs, macrophytes) of aquatic habitats for at least part of their life cycle. The term benthic is used as an adjective, as in benthic invertebrates.
Bioaccumulation	A general term meaning that an organism stores within its body a higher concentration of a substance than is found in the environment. This is not necessarily harmful. For example, freshwater fish must bioaccumulate salt to survive in intertidal waters. Many toxicants, such as arsenic, are not included among the dangerous bioaccumulative substances

	because they can be handled and excreted by aquatic organisms.
Bioavailability	The amount of chemical that enters the general circulation of the body following administration or exposure.
Bioconcentration	A process where there is a net accumulation of a chemical directly from an exposure medium into an organism.
Biological Indicator (Bioindicator)	Any biological parameter used to indicate the response of individuals, populations or ecosystems to environmental stress. For example, growth is a biological indicator.
Biomonitoring	The use of living organisms as indicators of the quality and integrity of aquatic or terrestrial systems in which they reside.
Bitumen	A highly-viscous, tarry, black hydrocarbon material having an API gravity of about 9^{o} (specific gravity about 1.0). It is a complex mixture of organic compounds. Carbon accounts for 80% to 85% of the elemental composition of bitumen, hydrogen – 10% sulphur – 5%, and nitrogen, oxygen and trace elements the remainder.
BOD	Biochemical oxygen demand. The test measures the oxygen utilized during a specified incubation period for the biochemical degradation of organic material and the oxygen used to oxidize inorganic material such as sulfides and ferrous iron. Usually conducted as a 5-day test (i.e., BOD_5).
Bottom Sediments	Substrates that lie at the bottom of a body of water. For example, soft mud, silt, sand, gravel, rock and organic litter, that make up a river bottom.

Catch-Per-Unit	A measure which relates to the catch of fish, with a particular type of gear, per unit of time (number of fish/hour). Results can be given for a particular species or the entire catch. The results can reflect both the density and/or the vulnerability of the gear utilized, of a species in a particular system.
Chronic	Defines a stimulus that lingers or continues for a relatively long period of time, often one-tenth of the life span or more. Chronic should be considered a relative term depending on the life span of the organism. The measurement of a chronic effect can be reduced growth, reduced reproduction, etc., in addition to lethality.
CL	Confidence limits. A set of possible values within which the true value will lie with a specified level of probability.
Colour	True colour of water is the colour of a filtered water sample (and thus with turbidity removed), and results from materials which are dissolved in the water. These materials include natural mineral components such as iron and calcium carbonate, as well as dissolved organic matter such as humic acids, tannin, and lignin. Organic and inorganic compounds from industrial or agricultural uses may also add colour to water. As with turbidity, colour hinders the transmission of light through water, and thus 'regulates' biological processes within the body of water.
Community	A set of taxa coexisting at a specified spatial or temporal scale.

Concentration — Quantifiable amount of a chemical in environmental medium, expressed as mass of a substance per unit volume (e.g., mg/L), or per unit sample mass (e.g., mg/g).

Concentration Units

Concentration Units	Abbreviation	Units
Parts per million	ppm	mg/kg or µg/g or mg/L
Parts per billion	ppb	µg/kg or ng/g or µg/L
Parts per trillion	ppt	ng/kg or pg/g or ng/L
Parts per quadrillion	ppq	pg/kg or fg/g or pg/L

Condition Factor — A measure of the plumpness or fatness of aquatic organisms. For oysters and mussels, values are based on the ratio of the soft tissue dry weight to the volume of the shell cavity. For fish, the condition factor is based on weight-length relationships.

Conductivity — A measure of a water's capacity to conduct an electrical current. It is the reciprocal of resistance. This measurement provides an estimate of the total concentration of dissolved ions in the water.

Contaminant Body Burdens — The total concentration of a contaminant found in either whole-body or individual tissue samples.

Covariate — An independent variable; a measurement taken on each experimental unit that predicts to some degree the final response to the treatment, but which is unrelated to the treatment (e.g., body size [covariate] included in the analysis to compare gonad

	weights of fish collected from reference and exposed areas).
CWQG	Canadian Water Quality Guidelines. Numerical concentrations or narrative statements recommended to support and maintain a designated water use in Canada. The guidelines contain recommendations for chemical, physical, radiological and biological parameters necessary to protect and enhance designated uses of water.
dam^3	Cubic decameter, equal to 1000 m^3
Detection Limit	The lowest concentration at which individual measurement results for a specific analyte are statistically different from a blank (that may be zero) with a specified confidence level of a given method and representative matrix.
Development Area	Any area altered to an unnatural state. This represents all land and water areas included within activities associated with development of the oil sands leases.
Discharge	In a stream or rive, the volume of water that flows past a given point in a unit of time (i.e., m^3/s).
Diversity	The variety, distribution and abundance of different plant and animal communities and species within an area.
DO	Dissolved oxygen, the gaseous oxygen in solution with water. At low concentrations it may become a limiting factor for the maintenance of aquatic life. It is normally measured in milligrams/litre, and is widely used as a criterion of receiving water quality. The level of dissolved oxygen which can exist in water before the saturation point is reached is primarily controlled by temperature, with lower temperatures

	allowing for more oxygen to exist in solution. Photosynthetic activity may cause the dissolved oxygen to exist at a level which is higher than this saturation point, whereas respiration may cause it to exist at a level which is lower than this saturation point. At high saturation, fish may contract gas bubble disease, which produces lesions in blood vessels and other tissues and subsequent physiological dysfunctions.
Drainage Basin	The total area that contributes water to a stream.
EC*p*	A point estimate of the concentration of test material that causes a specified percentage effective toxicity (sublethal or lethal). In most instances, the EC*p* is statistically derived by analysis of an observed biological response (e.g., incidence of nonviable embryos or reduced hatching success) for various test concentrations after a fixed period of exposure. EC25 is used for the rainbow trout sublethal toxicity test.
Ecological Indicator	Any ecological parameter used to indicate the response of individuals, populations or ecosystems to environmental stress.
Ecosystem	An integrated and stable association of living and non-living resources functioning within a defined physical location.
Environmental Impact Assessment	A review of the effects that a proposed development will have on the local and regional environment.
Evenness	A measure of the similarity, in terms of abundance, of different species in a community. When there are similar proportions of all species then evenness is one, but when the abundances are very

	dissimilar (some rare and some common species) then the value increases.
Exposure	The contact reaction between a chemical and a biological system, or organism.
Fauna	A term referring to an association of animals living in a particular place or at a particular time.
Fecundity	The number of eggs or offspring produced by a female.
Fecundity Index	The most common measure of reproductive potential in fishes. It is the number of eggs in the ovary of a female fish. It is most commonly measured in gravid fish. Fecundity increases with the size of the female.
Filter-Feeders	Organisms that feed by straining small organisms or organic particles from the water column.
Forage Fish	Small fish that provide food for larger fish (e.g., longnose sucker, fathead minnow)
Gonad	A male or female organ producing reproductive cells or gametes (i.e., female ovum, male sperm). The male gonad is the testis; the female gonad is the ovary.
Gonad Somatic Index (GSI)	The proportion of reproductive tissue in the body of a fish. It is calculated by expressing gonad weight as a percentage of whole body weight. It is used as an index of the proportion of growth allocated to reproductive tissues in relation to somatic growth.
GPS	Global Positioning System. This system is based on a constellation of satellites which orbit the earth every 24 hours. GPS provides exact position in standard geographic grid (e.g., UTM.)

Habitat	The place where an animal or plant naturally or normally lives and grows, for example, a stream habitat or a forest habitat.
Hardness	Total hardness is defined as the sum of the calcium and magnesium concentrations, both expressed as calcium carbonate, in milligrams per litre.
IC*p*	A point estimate of the concentration of test material that causes a specified percentage impairment in a quantitative biological test which measures a change in rate, such as reproduction, growth, or respiration.
Inorganics	Pertaining to a compound that contains no carbon.
KIRs	Key indicator resources are the environmental attributes or components identified as a result of a social scoping exercise as having legal, scientific, cultural, economic or aesthetic value.
LC_{50}	Median lethal concentration. The concentration of a substance that is estimated to kill half of a group of organisms. The duration of exposure must be specified (e.g., 96-hour LC_{50}).
Lesions	Pathological change in a body tissue.
Lethal	Causing death by direct action.
Littoral Zone	The zone in a lake that is closest to the shore.
Liver Somatic Index (LSI)	Calculated by expressing liver weight as a percent of whole body weight.
m^3/s	Cubic metres per second. The standard measure of water flow in rivers; i.e., the volume of water in cubic metres that passes a given point in one second.

Macro-invertebrates	Those invertebrate (without backbone) animals that are visible to the eye and retained by a sieve with 500 µm mesh openings for freshwater, or 1,000 µm mesh openings for marine surveys (EEM methods).
mean annual flood	The average of the series of annual maximum daily discharges.
Microtox®	A toxicity test that includes an assay of light production by a strain of luminescent bacteria (*Photobacterium phosphoreum*).
MSC	Meteorological Service of Canada
Negative control	Material (e.g., water) that is essentially free of contaminants and of any other characteristics that could adversely affect the test organism. It is used to assess the 'background response' of the test organism to determine the acceptability of the test using predefined criteria.
NO_x	A measure of the oxides of nitrogen comprised of nitric oxide (NO) and nitrogen dioxide (NO_2).
Nutrients	Environmental substances (elements or compounds) such as nitrogen or phosphorus, which are necessary for the growth and development of plants and animals.
Oil Sands	A sand deposit containing a heavy hydrocarbon (bitumen) in the intergranular pore space of sands and fine grained particles. Typical oil sands comprise approximately 10 wt% bitumen, 85% coarse sand (>44 µm) and a fines (>44 µm) fraction, consisting of silts and clays.

Organics	Chemical compounds, naturally occurring or otherwise, which contain carbon, with the exception of carbon dioxide (CO_2) and carbonates (e.g., $CaCO_3$).
PAH	Polycyclic Aromatic Hydrocarbon. A series of petroleum-related chemicals composed of at least two fused benzene rings. Toxicity increases with molecular size and degree of alkylation.
PAI	The Potential Acid Input is a composite measure of acidification determined from the relative quantities of deposition from background and industrial emissions of sulphur, nitrogen and base cations.
Pathological Index	A quantitative summary of pathology where variables examined are assigned numerical values (either 0, 10, 20 or 30) to indicate normal or abnormal condition. In this system, variables that exhibit an increasing degree of pathology are assigned higher values. The PI is calculated by summing the index values for each variable. The PI value increases as the number and severity of abnormalities increases. Based on the Health Assessment Index (HAI) developed by Adams *et al*. (1993).
Pathology	The science which deals with the cause and nature of disease or diseased tissues.
Peat	A material composed almost entirely of organic matter from the partial decomposition of plants growing in wet conditions.
PEL	Probable Effect Level. Concentration of a chemical in sediment above which adverse effects on an aquatic organism are likely.
pH	A measure of the acid or alkaline nature of water or some other medium. Specifically,

	pH is the negative logarithm of the hydronium ion (H_30^+) concentration (or more precisely, activity). Practically, pH 7 represents a neutral condition in which the acid hydrogen ions balance the alkaline hydroxide ions. The pH of the water can have an important influence on the toxicity and mobility of chemicals in pulpmill effluents.
Population	A group of organisms belonging to a particular species or taxon, found within a particular region, territory or sampling unit. A collection of organisms that interbreed and share a bounded segment of space.
ppt	Parts per thousand.
Quality Assurance (QA)	Refers to the externally imposed technical and management practices which ensure the generation of quality and defensible data commensurate with the intended use of the data; a set of operating principles that, if strictly followed, will produce data of known defensible quality.
Quality Control (QC)	Specific aspect of quality assurance which refers to the internal techniques used to measure and assess data quality and the remedial actions to be taken when data quality objectives are not realized.
Reach	A comparatively short length of river, stream channel or shore. The length of the reach is defined by the purpose of the study.
Receptor	The person or organism subjected to exposure to chemicals or physical agents.

Reference Toxicant	A chemical of quantified toxicity to test organisms, used to gauge the fitness, health, and sensitivity of a batch of test organisms.
Relative Abundance	The proportional representation of a species in a sample or a community.
Replicate	Duplicate analyses of an individual sample. Replicate analyses are used for measuring precision in quality control.
Riffle Habit	Shallow rapids where the water flows swiftly over completely or partially submerged materials to produce surface agitation.
Run Habitat	Areas of swiftly flowing water, without surface waves, that approximates uniform flow and in which the slope of water surface is roughly parallel to the overall gradient of the stream reach.
SD	Standard deviation.
SE	Standard error.
Sediments	Solid fragments of inorganic or organic material that fall out of suspension in water, wastewater, or other liquid.
Sentinel Species	A monitoring species selected to be representative of the local receiving environment.
Shannon-Weiner Diversity Index	A calculation used to estimate species diversity using both species richness and relative abundance. A basic count of the number of species present in a community represents species richness. The number of individuals of each species occurring in a community is the species relative abundance.

Spawning Habitat	A particular type of area where a fish species chooses to reproduce. Preferred habitat (substrate, water flow, temperature) varies from species to species.
Species	A group of organisms that actually or potentially interbreed and are reproductively isolated from all other such groups; a taxonomic grouping of genetically and morphologically similar individuals; the category below genus.
Species Richness	The number of different species occupying a given area.
Sport/Game Fish	Large fish that are caught for food or sport (e.g., northern pike, trout).
Stressor	An agent, a condition, or another stimulus that causes stress to an organism.
Sublethal	A concentration or level that would not cause death. An effect that is not directly lethal.
Suspended Sediments	Particles of matter suspended in the water. Measured as the oven dry weight of the solids in mg/L, after filtration through a standard filter paper. Less than 25 mg/L would be considered clean water, while an extremely muddy river might have 200 mg/L of suspended sediments.
Thalweg	The (imaginary) line connecting the lowest points along a streambed or valley. Within rivers, the deep channel area.
Tolerance	The ability of an organism to subsist under a given set of environmental conditions. Organisms with high tolerance to pollution are usually indicators of poor water quality.

Total Dissolved Solids	The total concentration of all dissolved compounds solids found in a water sample. See filterable residue.
Toxic	A substance, dose, or concentration that is harmful to a living organism.
Toxicity	The inherent potential or capacity of a material to cause adverse effects in a living organism.
Transect	A line drawn perpendicular to the flow in a channel along which measurements are taken.
TSS	Total suspended solids (TSS) is a measurement of the oven dry weight of particles of matter suspended in the water which can be filtered through a standard filter paper with pore size of 0.45 micrometres.
Turbidity	Turbidity in water is caused by the presence of matter such as clay, silt, organic matter, plankton, and other microscopic organisms that are held in suspension.
v/v	volume/volume - used to define dilution ratios for two liquids.
VOC	Volatile Organic compounds include aldehydes and all of the hydrocarbons except for ethane and methane. VOCs represent the airborne organic compounds likely to undergo or have a role in the chemical transformation of pollutants in the atmosphere.
Watershed	The entire surface drainage area that contributes water to a lake or river.
Wetlands	Term for a broad group of wet habitats. Wetlands are transitional between terrestrial and aquatic systems, whether the water table is usually at or near the

surface or the land is covered by shallow water. Wetlands include features that are permanently wet, or intermittently water-covered such as swamps, marshes, bogs, muskeg, potholes, swales, glades, slashes and overflow land of river valleys.

11.2 LIST OF ACRONYMS

ADL	Analytical Detection Limit
AENV	Alberta Environment
AEP	Alberta Environmental Protection
AES	Atmospheric Environment Services
ANC	Acid Neutralizing Capacity
ANCOVA	Analysis of Covariance
ANOVA	Analysis of Variance
ARC-Vegreville	Alberta Research Council located in Vegreville
ASL	Acid Sensitive Lake
ASRD	Alberta Sustainable Resource Development
AWI	Alberta Wetland Inventory
AXYS	AXYS Analytical Services Ltd.
Al-Pac	Alberta-Pacific Forest Industries Inc.
Albian	Albian Sands Energy Inc.
BCI	Bray-Curtis Index
BOD	Biological Oxygen Demand
BPC	Big Point Channel
bpd	barrels per day
Benthos	Benthic invertebrate

CA	Correspondence Analysis
CAEAL	Canadian Association for Environmental Analytical Laboratories
CCME	Canadian Council of Ministers of the Environment
CEA	Cumulative Effects Assessment
CEMA	Cumulative Environmental Management Association
CIR	False-colour infrared
CL	Critical load
CNRL	Canadian Natural Resources Limited
CONRAD	Canadian Oil Sands Network for Research and Development
CPUE	Catch-per-unit-effort
CWD	clean water discharge
CWQG	Canadian Water Quality Guidelines
Devon	Devon Canada Corporation
DFO	Fisheries and Oceans Canada
DIC	Dissolved inorganic carbon
DL	Detection limit
DO	Dissolved oxygen
DOC	Dissolved organic carbon
D/S	Downstream
EEM	Environmental Effects Monitoring
EIA	Environmental Impact Assessment

ENGO	Environmental Non-Government Organization
EPEA	Environment Protection & Enhancement Act
EPI	External Pathology Index
EPT	sum of Ephemeroptera, Plecoptera and Trichoptera taxa
ETL	Enviro-Test Laboratories
Exxon	Exxon Mobil Canada Ltd.
FLC	Fletcher Channel
FSA	Focus Study Area
GIC	Goose Island Channel
GPS	Global Positioning System
GSI	Gonad Somatic Index
HAI	Health Assessment Index
Hydroqual	Hydroqual Laboratories
IBI	Index of Biotic Integrity
ISQG	Interim Freshwater Sediment Quality Guidelines
JACOS	Japan Canada Oil Sands Limited
KIR	Key Indicator Resource
KP	Kilometre Posts
LCS	Laboratory Control Sample
LSI	Liver Somatic Index
MDL	Method Detection Limit
MRRT	McMurray Resources (Research and Testing) Ltd.

MS-222	Tricaine methane sulfonate
MSC	Meteorological Service of Canada
MSE	Mean Squared Error
Nexen	Nexen Canada Ltd.
NIWA	Norwegian Institute for Water Research
NSMWG	NO_x and SO_x Management Working Group
NWRI	National Water Research Institute
OPTI	OPTI Canada Inc.
PAD	Peace-Athabasca Delta
PAH	Polycyclic aromatic hydrocarbon
PAI	Potential Acidic Input
PC	Principal Component
PCA	Principal Components Analysis
Petro-Canada	Petro-Canada Oil and Gas
Pl	Pathology Index
QA	Quality Assurance
QA/QC	Quality Assurance/Quality Control
QAP	Quality Assurance Plan
QC	Quality Control
RAMP	Regional Aquatics Monitoring Program
RBC	Risk-based concentration
RMWB	Regional Municipality of Wood Buffalo
RSDS	Regional Sustainable Development Strategy
SBC	ratio of alkalinity to base cations

SD	Standard Deviation
SPSS	Statistical software Systat
STP	Sewage treatment plant
SWE	Snow water equivalent
SWI	Specific Work Instructions
Shell	Shell Canada Limited
Suncor	Suncor Energy Inc., Oil Sands Group
Syncrude	Syncrude Canada Ltd.
TCU	Total colour units
TDN	Total dissolved nitrogen
TDP	Total dissolved phosphorus
TDS	Total dissolved solids
TEEM	Terrestrial Environmental Effects Monitoring Committee
TIE	Toxicity Identification Evaluation
TKN	Total Kjeldahl nitrogen
TOC	Total organic carbon
TN	Total nitrogen
TP	Total phosphorus
TRH	Total recoverable hydrogen
TrueNorth	TrueNorth Energy L.P.
TSS	Total suspended solids
TVH	Total volatile hydrocarbon
U/S	Upstream

U.S. EPA	United States Environmental Protection Agency
UTF	Underground Test Facility
UTM	Universal Transverse Mercator
WAI	Weighted Average Index
WBEA	Wood Buffalo Environmental Association
WSC	Water Survey of Canada
WWG	Water Working Group (CEMA)
Yr	Year